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A TALE OF NEW CROPS IN THE ARID ARABIAN PENINSULA OASIS FROM ANTIQUITY TO THE EARLY ISLAMIC PERIOD

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Abstract

Agriculture in the arid Arabian Peninsula became established during the early Bronze Age and relied, at least in eastern Arabia, on the cultivation of date palm (*Phoenix dactylifera*) and annual crops, namely barley (*Hordeum vulgare* subsp. *vulgare*, *H. vulgare* subsp. *distichon*) and different wheats – in particular, emmer (*Triticum turgidum* subsp. *dicoccon*), durum/rivet wheat (*T. turgidum* subsp. *durum/turgidum*), bread wheat (*T. aestivum* subsp. *aestivum*) – and pulses, such as pea (*Lathyrus oleraceus*) and lentil (*Vicia lens*). The association of these crops with irrigation systems indicates the presence of resilient oasian agrosystems allowing the production of multiple crops over a reduced surface area thanks to water use optimization. It is also a hub connecting local agrarian producers with merchants and travellers through exchange, particularly dynamic during historical times, which can be highlighted through archaeobotanical data. At the crossroads of the Mediterranean, African and Indian Ocean

spheres, the Arabian Peninsula is a relevant observatory of the diffusion processes of new Mediterranean, tropical and subtropical crops. Recent archaeobotanical finds from antique and early medieval Islamic sites show that ancient oases were ecological and economic niches hosting new plants, such as rice (*Oryza sativa*), sorghum (*Sorghum bicolor* subsp. *bicolor*), pepper (*Piper nigrum*) and cotton (*Gossypium arboreum/herbaceum*), some of which were probably acclimatized and cultivated locally. Their introduction should have modified the spatial, temporal and labour organizations of pre-existent agricultural systems, implying the transfer and development of new know-how. Therefore, by following an interdisciplinary approach using archaeobotany, archaeology, history and isotope geochemistry, this contribution aims to describe some of these new plants and their chronology and discuss their potential introduction into local agricultural systems.

Author contributions

All authors contributed to the study conception and design. Data collection and analysis were performed by Vladimir Dabrowski, Charlène Bouchaud, Linda Herveux, Elora Chambraud, Xavier Desormeau, Saskia E. Ryan, Margareta Tengberg. The first draft of the manuscript was written by Vladimir Dabrowski and Charlène Bouchaud and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

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Introduction

The vast majority of the Arabian Peninsula is characterized by an extreme aridity which began 6000 years ago, including minor climatic oscillations (drought episodes, alluvial and lacustrine

deposits), limiting rainfed agriculture (Woor et al. 2022, Parker and Goudie 2008). The first irrigation devices and permanent habitat characteristics of oasis settlements emerged during the early Bronze Age, around 5000 years ago, in eastern and north-western Arabia (Charloux et al. 2021b, Luciani 2021, Tengberg 2012, Cleuziou 2004). At the same time, evidence appears for the presence of various crops in botanical assemblages - cereals, pulses, date palm (*Phoenix dactylifera*), the latter of which did not appear before the end of the 2nd millennium BCE in north-western Arabia (Rohmer et al. 2022 Luciani 2021, Diniès et al. 2016, Tengberg 2012). The oasis is perfectly adapted to arid environments, with agricultural production being concentrated in an intensively cultivated space by using locally available edaphic and water resources (Battesti 2005). At the crossroads of the Mediterranean, African and Indian Ocean spheres, the ancient oases of the Arabian Peninsula are relevant observatories of new crop diffusion in the past. In the framework of this paper, we assume that oases were ecological and economic niches able to integrate new plant products, mostly coming from tropical and subtropical regions into existing agricultural systems. One isolated sesame seed (*Sesamum indicum*) in a 3rd millennium BCE context may indicate the early arrival of a new tropical crop in the Persian Gulf (Zech-Matterne et al. 2015, Bellini et al. 2011, Tengberg and Lombard 2001), although this phenomenon remains limited until the 1st millennium BCE. Based on the botanical results from several archaeological sites linked with important ancient trade routes, this study aims to renew our knowledge of these “new crops” appearing during antiquity and the early Islamic period (mid. 1st millennium BCE-1st millennium CE) with a focus on cotton (*Gossypium arboreum/herbaceum*), rice (*Oryza sativa*) and sorghum (*Sorghum bicolor* subsp. *bicolor*), for which we discuss their chronology, their local or foreign origins and the economic, ecological and technical agents of their diffusion. Except for Yemen (reference to Varisco’s paper in the same volume), and because of the relative absence of known written sources, the role of the Arabian Peninsula in the so-called *Medieval Agrarian Revolution* (or *Islamic Green Revolution*) is only briefly explored. This theory, mainly based on written evidence, assumes that the first centuries of Islam (7th-11th c. CE) were a period of diffusion and adaptation of new tropical and subtropical plants into pre-existent agricultural systems accompanied with new agrarian techniques et know-hows (irrigation, grafting, soils fertilizing...). In this context, the Persian Gulf would have represented a favoured trading route connecting the Indian subcontinent to the Near East (Watson 1974, 1981, 2008 [1983], see Squatriti 2014 for historiographical analysis). These new archaeobotanical elements, and in particular the ones dated to the transition between late antiquity and the first centuries of Islam, are therefore of particular importance when discussing the materiality of Watson’s theory.

Geographical and Historical settings

The Arabian Peninsula is mostly covered by desertic areas with mean annual rainfall levels below 100 mm per year, except in the high-altitude mountainous areas, placing the area in arid and hyper-arid bioclimatic conditions (Fig. 1). Rainfall is more varied in some of the eastern regions (notably in mountainous areas), reaching an annual average of about 200 mm. Greater rainfall of up to 400 mm per annum is observed in south-eastern Oman, Yemen and south-west Saudi Arabia, with the influence of the tropical monsoon and the presence of mountain ranges (Almazroui et al. 2012; Jennings et al. 2015, Sanlaville 2000). Since climatic conditions strongly influence the agricultural system and the nature of crops cultivated, this paper is limited to the study of the hyper-arid and arid Arabian Peninsula, excluding south-western Arabia, which is the focus of another synthesis (reference to Varisco’s paper in the same

volume). Among this vast area, north-western and eastern Arabia regions have provided most of the archaeobotanical data and are therefore described in detail below.

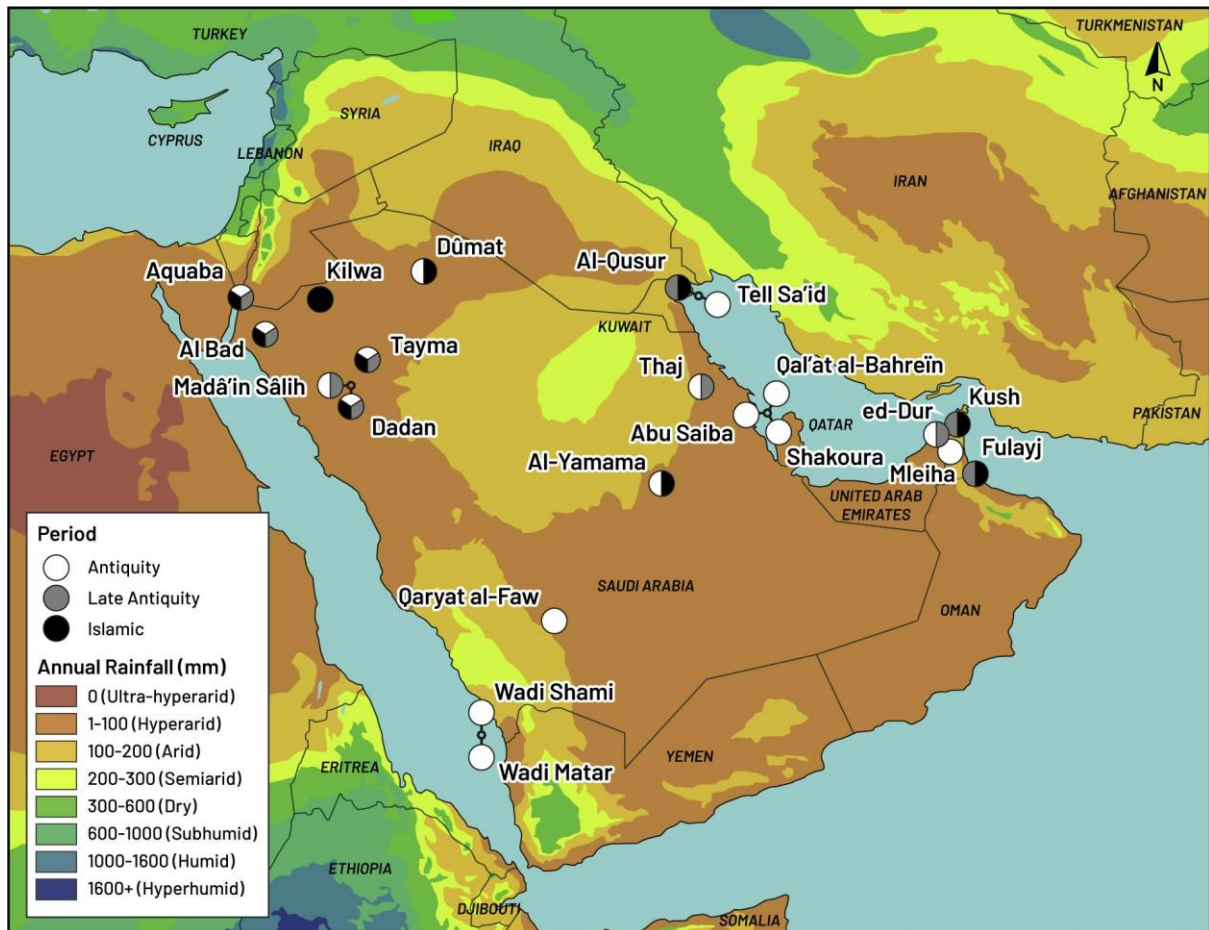


Fig 1. Present day rainfall levels in the Arabian Peninsula (derived from WorldClim data and adapted from Jennings et al. 2015) and the archaeological sites mentioned in this paper. Drawing: X. Desormeau

The political situation in the study area during antiquity is not homogeneous, resulting from population, settlement and trade dynamics emerging in the second half of the 1st millennium BCE. At that time, north-western Arabia was marked by the rise of a kingdom ruled by a tribe known as the Liḥyān tribe, which dominated the main oases in the region, including Dadān (modern Al-‘Ulā), probably Ḥegrā (modern-day al-Hijr), also known as Madā'in Šāliḥ, and Taymā', about 350 km to the north-east. The chronology of this kingdom is still debated, with hypotheses ranging from the late 6th–late 3rd c. BCE to the 4th–2nd c. BCE (Rohmer 2021; Durand and Bauzou 2022). The Nabataeans extended their control over the region by the mid-1st c. BCE (Charloux et al. 2021a; Nehmé 2021). The main Nabataean settlement in the region was probably Ḥegrā (Nehmé et al. 2006; Durand and Gerber 2014; Rohmer and Charloux 2015). Literary, archaeological and epigraphic evidence point to their involvement in Trans-Arabian trade between southern Arabia (*Arabia Felix*) and the Mediterranean world, via their capital city Petra, in present-day Jordan (Nehmé 2021). The Nabataean kingdom remained independent until 106 CE when it was annexed by the Roman Emperor Trajan. However, this event did not put an end to the activities and material production of the Nabataeans, which remained discernible until around the mid-3rd c. CE, indicating the existence of a still prosperous economy (Fiema 2003; Charloux et al. 2018).

Eastern Arabia is marked from the 3rd c. BCE, after the arrival of Alexander the Great in the region, by the influence of the Seleucid then the Parthian Empire in the Persian Gulf. Both included in their influence zones the islands of Ikaros and Tylos (respectively Failaka in Kuwait and Bahrain), possibly resulting in the installation of new populations, such as military garrisons or Greek-speaking immigrants (Kosmin 2013, Gatier et al. 2002, Salles 1996, Potts 1990). On the continent, several population movements, some of them still difficult to understand, involved the likely arrival of new people from Lower Mesopotamia and their islands, like in Thāj, or the sedentarization of nomadic groups leading to the formations of new establishments at Mleiha (Rohmer et al. 2018, Mouton & Schiettecatte 2014: 47-64, Potts 1990). Numerous archaeological artefacts testify to the role of the Persian Gulf connecting remote areas such as the Mediterranean Sea to the western Indian Ocean via Mesopotamia and Iran (for a synthesis, see Mouton and Schiettecatte 2014). From the 1st c. CE onwards, this trade, involving the importation of Indian products through the Persian Gulf and the Euphrates Valley to the Roman Empire, was dominated by Palmyrenian merchant networks, according to archaeological and epigraphic evidence (Andrade 2015, Seland 2015).

Late antiquity (mid-4th–7th c. CE) points to an important upheaval regarding contacts and cultural exchanges with the Mediterranean world, including the emergence of Christian and Jewish communities, in parallel with the long-lasting decline of the caravan trade (Robin 2014) and the abandonment or decline of several Arabian towns, such as Ḥegrā, Dūmat al-Jandal and al-Yamāma. In eastern Arabia, the incursions of the Sasanian Empire to control the trade networks of the Persian Gulf (Daryaee 2003) seem to have brought decline to some settlements, such as Thāj, Qal’at al-Bahreīn, Mleiha, and an overall downturn in economic activity (Kennet 2007). The involvement of the Sasanians in the Oman Peninsula, evidenced by increasing agricultural activity and improving water management technologies (Wilkinson 1977), remains unclear and controversial (Munt 2017); however, it is clear that this period also saw the installation of Sasanian military garrisons, as demonstrated by archaeological evidence (Priestman 2019, Simpson 2019). Certainly, Christian monastic communities settled in the region from the end of antiquity, in connection with the development of co-religionists merchant networks (Seland 2013).

The Islamic period begins with a century of large and fast Arab–Muslim conquests. The first jihād (622–632 CE) led to the emergence of a Muslim state that united Mecca, Medina and all the tribes of central and western Arabia, soon joined by the rest of the Arabian Peninsula under the reign of the first caliph Abū Bakr (632–634 CE). In the following years, the victorious Arabs settled in mass in the newly conquered territories to the north (present-day Jordan, Syria, Iraq) and the west (present-day Egypt). The Umayyads took over the Islamic Empire in 661 CE and established their capital in Damascus, while continuing to expand their territories, followed by the Abbasids from mid. 8th to mid. 11th c. CE (Martinez-Gros 2010). Both these dynasties successively took advantage of the Persian Gulf and Indian Ocean trading networks. From the 8th c. CE, the Abbasids contributed to stimulating trade exchanges within the Persian Gulf (importing Asian and African products to the Near East) by establishing their capital Baghdad in Iraq and developing harbour cities, such as Basra (Iraq), Siraf (Iran) and Sohar (Oman) (Beaujard 2012: 61, Ducellier et al. 2012: 164-6, Whitcomb 2009, Kervran 2004, Rougeulle 1996). In south-east Arabia, Omani Ibadi states emerged twice as strong against the central powers after independence rebellions, especially during the 9th c. CE (al-Rawas 2000: 134-137). From the 10th c. onwards, political, and social troubles led to the decrease of trade exchanges in the Persian Gulf, to the benefit of the Red Sea (Beaujard 2012: 71, Bianquis et al. 2012).

State of the art

Recent archaeobotanical research in the Arabian Peninsula has enhanced our understanding of agricultural systems and plant diffusion during the Late Holocene. This paper presents a review of the archaeobotanical datasets (published and unpublished; ongoing studies are mentioned in the map of Fig. 1 and Supplementary Material 1 but not discussed in the text) between the second half of the 1st millennium BCE, characterized by the emergence of new political entities and increasing long-distance trade exchanges, and the 11th c. CE, corresponding to the end of the early Islamic period. Only plant macroremains (i.e. seeds and fruits, wood and charcoal) are included. Seeds and fruits are mostly preserved by charring, more rarely desiccated in specific contexts (e.g. carved tombs) or as imprints in mudbricks. The map (Fig. 1) presents the geographical distribution of the studied archaeological sites during antiquity (5th c. BCE–4th c. CE), late antiquity (4th c.–mid-7th c. CE) and the Islamic period (mid-7th–11th c. CE). Tab.1 provides references and a brief description of each site, Tab. 2 gives the list of crops (see also Supplementary Material 2 for details on new crops).

Until the 2010s, archaeobotanical analysis dealing with antiquity (5th c. BCE–4th c. CE) in the Arabian Peninsula were particularly limited both in terms of the number of sites (Qala’at al-Bahreïn, Mleiha, Tell Sa’id, Shakoura) and the quantity of available material (Bouchaud et al. 2016). Since 2010, two major sites in the Arabian Peninsula, namely Ḥegrā (north-western Saudi Arabia) and Mleiha (UAE), have yielded a large amount of botanical data highlighting the diffusion of new crops through long-distance trade networks or by their acclimatization into oasian agrosystems. Several other sites occupied during this period, namely Taymā’, Dadān, Dūmat al-Jandal, al-Yamāma, Wadi Matar and Wadi Shami (Farasan island), Qaryat al-Faw, Abu Saiba and Thāj have provided more limited or unpublished information, some of which are currently works in progress.

Only a few sites document late antiquity (4th c.–early 7th c. CE) and most of these datasets are unpublished. Three such sites, Ḥegrā, Taymā’ and Thāj, offer the possibility to study the evolution of agricultural economies throughout this period and classical antiquity, while three others, all located in eastern Arabia, Al-Qusur, Kush and Fulayj, enable us to document the transition between late antiquity and the early Islamic period. Taymā’ is the only site to potentially provide data for the entirety of the 1st millennium CE, although this study is still ongoing.

Archaeobotanical data for the early Islamic period (early 7th c.–11th c. CE) relies on eight sites distributed throughout the peninsula; however, these studies are all ongoing. Only four have yielded partial unpublished (al-Yamāma, Kush, Kilwa) and published (Fulayj) results.

This state-of-the-art data stresses the current dynamism in Arabian archaeobotany to provide new knowledge while also underlining several methodological issues. First, the total number of sites to build a solid synthesis in the study area is very low, covering 1400 km east-west and 2000 km north-south. Secondly, while north-western Arabia and eastern Arabia are quite well represented, central Arabia has been far less investigated. Finally, the majority of data is concentrated on only a few sites, sometimes in particular contexts (e.g. burned buildings) not fully time-representative, with targeted results which make it difficult to draw general trends.

TAXONS	Antiquity (4 th c. BCE-3 rd c. CE)									Late Antiquity (4 th c.-mid. 7 th c. CE)					Early Islamic period (mid. 7 th -11 th c. CE)				
	MS	Tell 4215	DAJ	AI	YAM	FOR	ML	QB	alFaw	MS	DAJ	AI	FJ	KU	YAM	KW	AI	FJ	KU
	4 th c.BC E-3 rd c.	4 th -1 st c. BCE	Late 1 st c. BCE-early 2 nd c.	Late 1 st c. BCE-early 4 th c.	5 th -3 rd c. BCE	3 rd -mid. 2 nd c. BCE	3 rd c. BCE-3 rd c.	3 rd c. BCE-3 rd c.	3 rd c. BCE-3 rd c.	3 rd -5 th c.	5 th -mid. 7 th c.	4 th -mid. 7 th c.	5 th -mid. 7 th c.	5 th -mid. 7 th c.	9 th -11 th c.	Mid. 7 th -10 th c.	Mid. 7 th -10 th c.	Mid. 7 th -8 th c.	Mid. 7 th -11 th c.
Cereals																			
<i>Hordeum vulgare</i>	Barley	s		s	s	s	s	s	s	s		s	s	s		s	s	s	s
<i>Hordeum nudum</i>	Free-threshing barley					s													
<i>Oryza sativa</i>	Asian rice							s											
<i>Sorghum bicolor ssp. bicolor</i>	Sorghum																	s	s
<i>Triticum tetraploid / hexaploid</i>	Free-threshing wheat	s		s		s	s	s		s				s		s			s
Big Panicoidae	Millet													s				s	s
<i>Secale sp.*</i>	Rye			s															
<i>Setaria sp.</i>	Millet											s							
<i>Triticum turgidum ssp. diccocon</i>	Emmer	s																	
<i>Triticum sp.</i>	Wheat				s	s				s									
Cultivated pulses																			
<i>cf. Cajanus cajan</i>	Pigeon pea							s											
<i>Cicer arietinum</i>	Chickpea	s				s						s							
<i>Lathyrus cicera/sativus</i>	Grass pea	s			s			s		s				s					
<i>Lathyrus oleraceus</i>	Pea	s						s	s	s									
<i>Vicia lens</i>	Lentil	s			s	s				s		s		s		s			s
<i>Vicia cf. faba</i>	Fava bean	s																	
<i>Vicia cf. sativa</i>	Common vetch	s			s														
<i>Vigna mungo</i>	Urd bean							s											
<i>Vigna radiata</i>	Mung bean							s											
<i>Vigna unguiculata</i>	Cowpea							s											
Potential cultivated fruit trees and vines																			
<i>Citrullus lanatus</i>	Watermelon									s									

TAXONS		Antiquity (4 th c. BCE-3 rd c. CE)								Late Antiquity (4 th c.-mid. 7 th c. CE)					Early Islamic period (mid. 7 th -11 th c. CE)					
		MS	Tell 4215	DAJ	AI	YAM	FOR	ML	QB	alFaw	MS	DAJ	AI	FJ	KU	YAM	KW	AI	FJ	KU
		4 th c.BC E-3 rd c.	4 th -1 st c. BCE	Late 1 st c. BCE- early 2 nd c.	Late 1 st c. BCE- early 4 th c.	5 th -3 rd c. BCE	3 rd - mid. 2 nd c. BCE	3 rd c. BCE- 3 rd c.	3 rd c. BCE- 3 rd c.	3 rd c. BCE-3 rd c.	3 rd -5 th c.	5 th - mid. 7 th c.	4 th - mid. 7 th c.	5 th - mid. 7 th c.	5 th - mid. 7 th c.	9 th -11 th c.	Mid. 7 th -10 th c.	Mid. 7 th -10 th c.	Mid. 7 th -8 th c.	Mid. 7 th -11 th c.
<i>Ficus</i> sp.	Fig	s, c		s	s						s		s				s	s		
<i>Juglans nigra</i>	Walnut	s																		
<i>Olea europaea</i>	Olive	s, c		s	s				s	s, c	c	s				s, c				
<i>Phoenix dactylifera</i>	Date	s, c	s, c	s, c	s	s	s, c	s, c	s, c	s	s, c	c	s	s	s, c	s, c	s	s	s, c	s, c
<i>Pistacia vera</i>	Pistachio																s			
<i>Punica granatum</i>	Pomegranate	s, c		s					s	s	s, c			s			s			s
Prunoidae										c							c			
<i>Prunus arabica</i> **	Arabian almond	s							s											
<i>Prunus persica</i>	Peach	s															s			
<i>Prunus domestica</i>	Plum																s			
<i>Prunus dulcis</i>	Almond																s			
<i>Vitis vinifera</i>	Grape	s, c		c	s			s	s	s	s	s, c	s		s		s	s		
<i>Ziziphus</i> sp.**	Jujube	s, c						s, c		s	s, c	c	s						s, c	s
Textile / Oleaginous plants																				
<i>Gossypium arboretum/herbaceum</i>	Cotton	s								s			s		s			s		s
<i>Sesamum indicum</i>	Sesame									s		s								
Vegetables, herbs and spices																				
<i>Allium</i> cf. <i>sativum</i>	Garlic									s										
<i>Beta</i> sp.	Beet	s									s									
<i>Brassica</i> cf. <i>nigra</i>	Black mustard									s										
<i>Coriandrum sativum</i>	Coriander	s																		s
<i>Piper nigrum</i>	Pepper									s										s

Table 1: List of crops attested in the arid Arabian Peninsula from antiquity to the early Islamic period. When there is no indication for dates, it is implied to be “CE”. Taxa in red correspond to first evidence in the arid Arabian Peninsula. S= seed/fruit; c= wood charcoal. * These identifications need to be considered with caution as they are not determined to the species level and therefore, may come from wild plants growing in the region; ** These plants may correspond to fruits gathered from wild individuals

Antiquity and late antiquity: long-distance trade and acclimatization of Watson's crops

Botanical finds from archaeological sites dated to antiquity and late antiquity (5th c. BCE–6th c. CE) highlight the presence of 19 new plants, attested for the first time during the end of the 1st millennium BCE and the first half of our Common Era (Tab. 2, Fig. 2 and 3 ; Supplementary Material 2), including tropical (South Asia or Africa) crops - rice, cotton, pepper (*Piper nigrum*), pigeonpea (cf. *Cajanus cajan*), urd bean (*Vigna mungo*), mung bean (*Vigna radiata*), cowpea (*Vigna unguiculata*), watermelon (*Citrullus lanatus*) - and non-tropical (Mediterranean, Near Eastern, West/East Asia, etc.) crops - garlic (*Allium* cf. *sativum*), black mustard (*Brassica* cf. *nigra*), chickpea (*Cicer arietinum*), naked barley (*Hordeum nudum*), grasspea (*Lathyrus cicera/sativus*), black walnut (*Juglans nigra*), Arabic almond (*Prunus arabica*), peach (*Prunus persica*), rye (*Secale* sp.), fava bean (*Vicia* cf. *faba*), bitter vetch (*Vicia* cf. *sativa*). We cannot exclude that some of these were already present (for instance chickpea, which has been cultivated since the Neolithic period in the southern Near East, Zohary et al. 2012, p. 87-89). We decided to include the Arabic almond in the list because, although the tree is native to the Arabian Peninsula, it is also nowadays cultivated in gardens as windbreakers and for the preparation of beverages and cosmetic products (Jongbloed et al. 2003: 482). The site of Mleiha has one of the most impressive datasets showing the arrival of several new plants, notably of tropical origin. In parallel, a detailed examination of cotton archaeological and written records qualifies Andrew Watson's theory by showing an early introduction of this plant in north-west Arabia, several centuries before the *Islamic Green Revolution*.

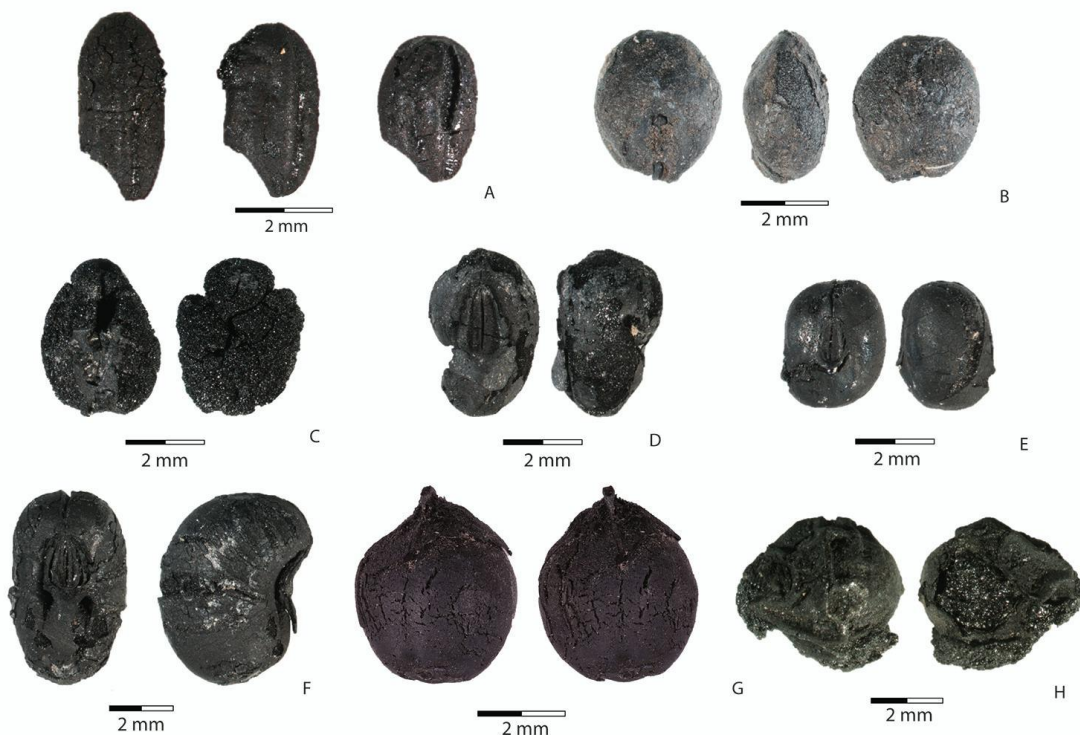


Fig. 2: New tropical crops attested for the first time in the Arabian Peninsula. A = Three caryopses of Asian rice (*Oryza sativa*) in lateral view, Mleiha (Sharjah, UAE); B = One caryopsis of sorghum (*Sorghum bicolor* subsp. *bicolor*) in dorsal, lateral and ventral views

(from left to right), Fulayj (Oman); C = One seed of pigeonpea (cf. *Cajanus cajan*) in frontal and lateral views, Mleiha (Sharjah, UAE); D = One seed of urd bean (*Vigna mungo*) in frontal and lateral views, Mleiha (Sharjah, UAE); E = One seed of mung bean (*Vigna radiata*) in frontal and lateral views, Mleiha (Sharjah, UAE); F = One seed of cowpea (*Vigna unguiculata*) in frontal and lateral views, Mleiha (Sharjah, UAE); G = One seed of cotton (*Gossypium arboreum/herbaceum*), Madā'in Šālīḥ (Saudi Arabia), H = One black peppercorn (*Piper nigrum*), Mleiha (Sharjah, UAE).

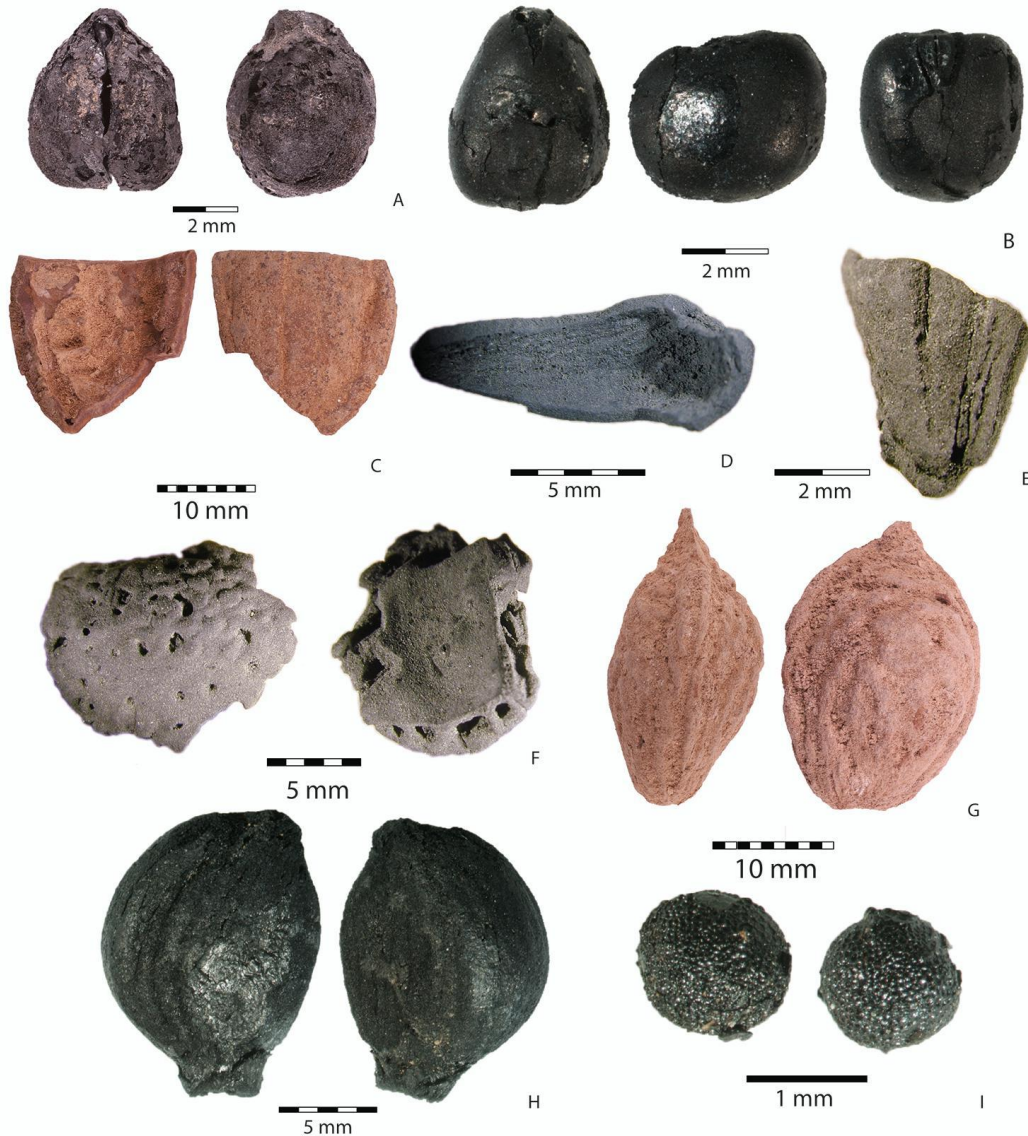


Fig. 3: New non-tropical crops attested for the first time in the Arabian Peninsula. A = One seed of chickpea (*Cicer arietinum*) in frontal and lateral views (from left to right), Madā'in Šālīḥ (Saudi Arabia); B = One seed of grasspea (*Lathyrus sativus*) in frontal, lateral and basal views, Mleiha (Sharjah, UAE); C = One endocarp fragment of walnut (*Juglans regia*) in inside and outside views, Madā'in Šālīḥ (Saudi Arabia); D = One endocarp fragment of pistachio (*Pistacia vera*) in internal view, Kilwa (Saudi Arabia); E = One endocarp fragment of plum (*Prunus domestica*) in outside view, Kilwa (Saudi Arabia); F = Two endocarp fragments of almond (*Prunus amygdalus*) in outside and inside views, Kilwa (Saudi Arabia); G = One kernel of peach (*Prunus persica*) in frontal and lateral views, Madā'in Šālīḥ (Saudi Arabia); H = One bulbil of garlic (*Allium* cf. *sativum*) in both lateral views, Mleiha (Sharjah, UAE); I = Two seeds of black mustard (*Brassica* cf. *nigra*), Mleiha (Sharjah, UAE).

a. At the hub of long-distance Indian Ocean trade networks: The burned down building of Mleiha

Mleiha is located on the western foothills of the Al-Hajar mountains in the Sharjah Emirate (UAE). Evidence suggests that date palm gardens could have been maintained nearby, thanks to loamy soils and groundwater tables outcropping at the surface (Dalongeville 1999). Excavations led in 2010–2011 on Mleiha's burned down building (sector H), dated to the first half of the 3rd c. CE, provided a large amount of exceptionally well-preserved organic material, such as seeds, fruits, wooden beams, combs and containers, textiles, basketry, amorphous remains (Mouton et al. 2012). The subsequent archaeobotanical study revealed evidence of various crops: cereals (hulled barley, *Hordeum vulgare* and free-threshing wheat, *Triticum aestivum/durum/turgidum*), pulses (lentil, *Vicia lens* and grasspea, *Lathyrus sativus*), fruits (date, grape, *Vitis vinifera* subsp. *vinifera*, pomegranate, *Punica granatum*, and Arabic almond), as well as vegetables (garlic) and condiments (sesame and black mustard) (Dabrowski 2019, Mouton et al. 2012). There is evidence for the presence of most of these crops during earlier periods (hulled barley, free-threshing wheat, date, grape, pomegranate, sesame) in the Arabian Peninsula, while others are noted in the region for the first time, namely Arabic almond, garlic, and black mustard. In addition, new tropical crops are also attested, likely of Indian origin, including black pepper, Asian rice and cotton (Dabrowski 2019).

The presence of these new crops in the building raises questions about their provenance: do they correspond to imported products obtained through long-distance trade or were they cultivated locally? While the local origin (either wild or cultivated, see *supra*) of the Arabic almond leaves little doubt, that of garlic and black mustard is open to question. By contrast, several criteria strongly suggest that the three tropical crops come from long-distance trade. For ecological reasons, black pepper originating from the western Ghats in the Kerala State (south-western part of the Indian subcontinent) cannot grow in an environment with an atmospheric humidity of less than 65% (De Ward and Anunciado 1999; Purseglove 1981: 19-21), so we can assert with certainty that the peppercorns were imported from south-west India (Dabrowski 2022). Asian rice grains, discovered mostly in the kitchen and courtyard, were probably in the process of being dehulled/milled for consumption. The presence of Indian millets (*Paspalum scrobiculatum* and *Panicum* cf. *sumatrense*), found as weeds among the rice grains, seem to indicate that the latter were indeed brought to the site via the long-distance trade networks of the western Indian Ocean (Dabrowski et al. 2021). Strontium isotope analyses carried out on the cotton seeds, balls and textile fragments unearthed from several rooms revealed that these most likely came from elsewhere (Ryan et al. 2021) (see *infra*). In summary, the fire that destroyed the building in sector H (Mleiha) in the 3rd c. CE yielded a wide diversity of botanical material and provided substantial information about crop diversity in antiquity, despite the context reflecting only a very limited time span. However, although new tropical crops are evidenced for the first time in this region, they only seem to represent imported products.

b. Cotton in the Arabian Peninsula

The Arabian Peninsula is outside the natural range of cotton distribution. Cotton finds in this region correspond to only two Old World species, either *G. arboreum*, originating from the Indian subcontinent, or *G. herbaceum*, domesticated somewhere in Africa (see review in Bouchaud et al. 2018). Early traces of cotton fibres found at Tel Tsaf, Israel (ca. 5200-4700 BCE) (Liu et al. 2022) and at Dhuweila, eastern Jordan (4450-3000 BCE) (Betts et al., 1994)

suggest possible very ancient cotton trade in the Levant. The oldest reliable mention of cotton in Arabia is in a description from the Greek botanist and philosopher Theophrastus (371–288 BCE), who stated that the island of Bahrain (known as *Tylos* in ancient Greek sources) produced the ‘wool-bearing’ tree, identified as the cotton tree. Cotton textiles have been found on the main archaeological site of this island, Qal’at al-Bahreïn, associated with earlier archaeological contexts; however, they have never been directly dated. Several cotton seeds found at the same site in archaeological layers relatively dated to the Achaemenid period (6th–4th c. BCE) have been the focus of several publications (Bouchaud et al. 2011; Tengberg and Lombard 2001). We recently had the opportunity to perform direct radiocarbon dating on one of the seeds, but the result indicated a much later date, 1221–1276 cal. CE (Fig. 4). This unexpected result shows the extreme importance of direct radiocarbon dating, especially when documenting the first evidence of a crop in a region.

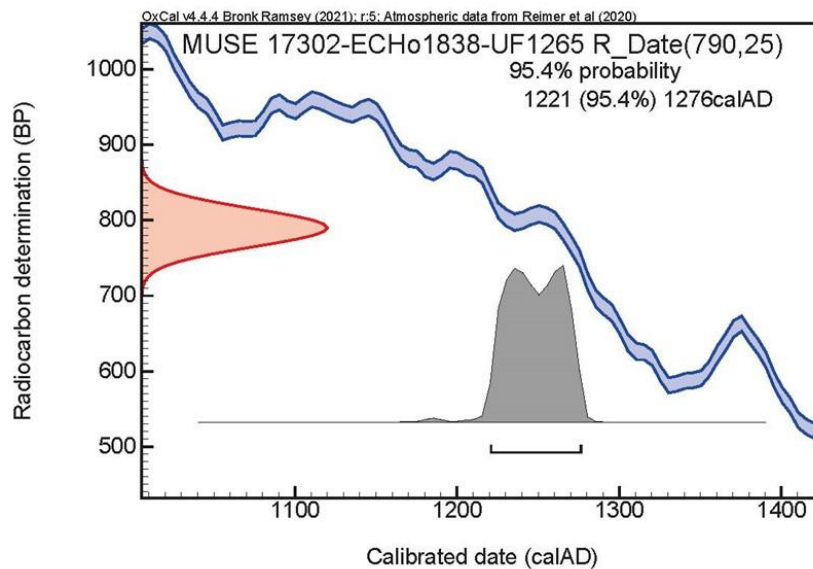


Fig. 4: Calibrated radiocarbon dating of the cotton seed from Qal’at al-Bahreïn (OxCal v.4.4 (Bronk Ramsey 2009); r:5 IntCal20 atmospheric data from Reimer et al. 2020. Lab ID: Muse 17302-ECHo1838 / Archaeological number: UF 1265 / 14C age: 790 ±25

The first directly dated archaeological evidence of cotton in Arabia comes from Madā’ in Ṣāliḥ, ancient Ḥegrā (under excavation since 2008, see list of directors in Tab. 1). The town, which is mainly known for its monumental Nabataean tombs, is located on a key trading route and was occupied from the 5th/4th c. BCE to the 5th/6th c. CE. The climate is arid, but the presence of a high-water table makes the region suitable for human occupation and agricultural activities (Nehmé et al. 2006). The archaeobotanical study on plant material found in the residential area shows the existence of an oasian agrosystem based on date palm cultivation from the mid-1st millennium. BCE onwards (see Bouchaud 2015, Bouchaud et al. 2012, work in progress). In addition to date palm, cereals and pulses, some fruits, namely pomegranate, olive (*Olea europaea*) and fig (*Ficus* sp.), were also present from the beginning of the occupation. Direct radiocarbon dating on cotton textiles and seeds show its presence from the end of the 1st c. BCE/1st c. CE onwards. In addition, hundreds of charred cotton seeds were uncovered in the residential town complex, mostly for the later periods (3rd–end 4th/early 5th cal. c. CE) (Bouchaud et al. 2018; Charloux et al. 2018). The recent find of cotton seeds at the neighbouring site of Dadān for the following period (mid-5th–mid 6th cal. c. CE) supports the large presence of cotton in the wider Al-‘Ulā Valley during late antiquity (Ryan et al. submitted).

The high frequency of cotton seeds at Ḥegrā highlights the plant's common use throughout the living quarters, although the large number most likely results from practices rather than real economic importance – charred cotton seeds are generally the waste products of fibre processing, discarded directly after ginning into domestic fireplaces. We also consider that they could have been used for different purposes because of their rich oil content as is the case today, such as fodder for ruminants, lighting oil, unguent, or fuel. Although there is no clear evidence of such use in the past (Bouchaud et al. 2018, 2019). In addition, several Nabataean tombs contained cotton textiles, used as shrouds. Based on the high proportion of cotton seeds, their location in all parts of Ḥegrā's residential area and their wide chronological distribution, our hypothesis is that cotton was cultivated locally in the oasis during antiquity. In parallel, we do not exclude that some of these items, especially the textiles, could have been imported.

The issue of allochthonous vs local introduction of crops has been assessed through the tracing capabilities of strontium isotopes ($^{87}\text{Sr}/^{86}\text{Sr}$). Strontium (Sr) is a particularly useful geochemical tracer as the strontium isotope values of soil, soil water and rainwater are recorded in plant tissues. The plant reflects the geological region in which it grew, which in turn is dependent on the composition and age of the bedrock, and can therefore be locally characterized by specific strontium isotope values (Bentley 2006; Graustein 1989). The radiogenic strontium analysis of ancient crops (Bogaard et al. 2014; Henriksen et al. 2017) and textiles (e.g. Wozniak and Belka 2022; Frei 2014, 2015; Holstein et al. 2016) has proven to be a successful tool for determining provenance by cross-checking results with archaeological and historical sources. Strontium analysis at Mleiha (Ryan et al. 2021) and Ḥegrā (Ryan et al., submitted) have been conducted in parallel, comparing the strontium values of the archaeological cotton finds, modern local plants and archaeological crop remains that are thought to have been cultivated locally. The isotope results support the archaeological and textual evidence summarized above, showing that the cotton at Mleiha did not originate from the Oman Peninsula but were more likely sourced from further afield, with the north-western coast of India being an isotopically compatible provenance. Because of the scarcity and the location of the finds, we can only assume that the textile fragments found were originally used as transportation and storage bags, while the raw cotton (cotton bolls) had been used as packaging material (Ryan et al. 2021). A follow-up study is currently being conducted on the cotton seeds and textiles found at Ḥegrā and Dadān (Ryan et al., submitted).

In addition to these discoveries, the rare but regular finds of cotton seeds at the Red Sea port of Aila (modern Aqaba, Jordan), from the Late Roman to the Abbasid periods (2nd–10th c. CE) underline a regional spread of cotton in north-western Arabia during the 1st millennium CE (Ramsay and Parker 2016). This phenomenon is also observed further north (around the Dead Sea, at Palmyra, Dura-Europos, etc.) and further west (notably in the western Egyptian and Libyan oases, Nubia and central Sudan), where cotton finds have been interpreted as both imported items and local crops (synthesis in Bouchaud et al. 2018), testifying to a global trend of cotton trading and acclimatization during antiquity.

As previously mentioned, 19 new plants have been recovered in the Arabian Peninsula during antiquity, suggesting that some were cultivated in the oasis while others were of foreign origin. For most of these plants we lack meaningful archaeobotanical elements to determine their status; however, some were most definitely imported, due to their ecological requirements (black pepper) or botanical evidence (Asian rice with Indian weeds) from the site of Mleiha. Strontium isotopic analyses on the cotton finds from Mleiha have demonstrated that it was probably brought from the western part of the Indian subcontinent. By contrast, the abundance

and ubiquity of cotton remains from Hegrā suggests that it was cultivated locally. Further strontium isotopic analyses will allow us to test this hypothesis.

Between the Sasanian period and the first centuries of Islam: what constitutes the *Islamic Green Revolution* in the desertic Arabian Peninsula?

The transition between late antiquity and the first centuries of Islam is scarcely documented, despite its critical importance for understanding the medieval agrarian revolution. Fortunately, three archaeological sites, the Sasanian and early Islamic fort of Fulayj (Batinah, Sultanate of Oman), the coastal settlement of Kush (Ra's al-Khaimah, UAE.) and the monastery site of Kilwa (Saudi Arabia) provide the first possibility to characterize the materiality of this important transition. The archaeobotanical survey reveal the appearance of a few new plants. Among them, in addition to pistachio (*Pistacia vera*), plum (*Prunus domestica*) and almond (*Prunus amygdalus*) at Kilwa, sorghum was found (Tab. 2, Fig. 2 and 3; Supplementary Material 2) – the only new tropical crop, most likely acclimatized and attested in both Fulayj and Kush, which is the focus of the following section.

The site of Fulayj is situated on the Batinah Plain, in the eastern foothills of the Omani Mountains. The site corresponds to a Sasanian military fort built in the 5th c. This military function gave over to domestic occupation during the early Islamic period until the 8th c. CE. Sediment samples from both these phases were collected in 2015/2016 (Priestman 2019, Al-Jahwari et al. 2018). Most of the plant remains corresponded to wild plants, with a small number of crops, such as dates and hulled barley, already evidenced during earlier periods. Despite the limited remains, though a large quantity of sediment was sieved, analysis revealed the presence in early Islamic levels of sorghum, attested for the first time in arid Arabia. One whole and one fragmented carbonized caryopsis, as well as two earthen imprints, were found. The grain fragment was directly radiocarbon dated to the end of the 8th c.–10th c. CE, with archaeological data pointing to the end of the 8th c. CE, at the latest (Dabrowski et al. 2021). Sorghum has been domesticated in the savannahs of eastern Africa since the 4th millennium BCE and was introduced into the Indian subcontinent around the 2nd millennium BCE (Barron et al. 2020, Fuller and Stevens 2018, Winchell et al. 2017). We cannot exclude that sorghum was imported by long-distance trade connecting the Indian subcontinent to Arabia, due to the Indian potteries found on the site; however, we are willing to consider that the presence of earthen imprints of this crop suggest it may have been cultivated locally. Indeed, this evidence could correspond to the use of a by-product (such as chaff) as a temper for making mudbricks, with grains being accidentally incorporated during the process (Dabrowski et al. 2021). As the use of by-products is usually considered as evidence of local growing, the grains may testify to the introduction of this new crop during the early Islamic period.

The coastal site of Kush is situated on the Shimal Plain in the northern Oman Peninsula. It borders two lagoons which were gradually filled in during the site's occupation. The site

occupied from the 5th to the 13th c. CE, divided into seven periods of occupation under the form of military installations, including the construction of a hypothetical tower, during the Sasanian period (5th–mid. 7th c. CE) and then domestic structures until the 13th c. (Kennet 2009, 1997). Several crops predominate over the periods' assemblages, such as hulled barley, free-threshing wheat, dates, grapevine and pomegranate, all typical crops from the Bronze and Iron Ages in the region (Bouchaud et al. 2016, Tengberg and Lombard 2001). Three tropical crops are attested. Cotton seeds and black peppercorn appear sporadically during the Sasanian (5th–mid. 7th c. CE) and Islamic period (9th–11th c. CE). Sorghum grains are absent in the Sasanian archaeological horizon, but are then attested from the beginning of the early Islamic period (mid. 7th c. CE) until the 12th c. CE. Its persistence through time may show the progressive introduction of sorghum into the pre-existent agricultural systems, possibly through experimentation by local farmers in the plain near the site before being cultivated at a small scale among the agrarian productions (Dabrowski et al., unpublished, Dabrowski 2019).

Archaeobotanical data dated to the beginning of Islam in eastern Arabia show that sorghum was potentially a new crop at this time. In the 1980s, sorghum was tentatively identified on the early Bronze Age site of Hili 8 (Abu Dhabi's Emirate, UAE., Cleuziou and Costantini 1980), although this identification has since been questioned (Bouchaud et al. 2016, Tengberg 2012, Charbonnier 2008). The only existing textual testimonies (al Ishtakri 79, Ibn Hawqal I, 53, according to Watson 1983: 153) show that sorghum was probably cultivated from the 10th c. CE onwards in eastern Arabia (Watson 1983: 12), while botanical material suggests an introduction from as early as the mid. 7th–8th c. CE. However, we also have to bear in mind that sorghum may have been introduced earlier and its absence in the botanical record of previous periods may be due to the lack of archaeobotanical studies. Several archaeobotanical mentions of sorghum, some dubious, indicate that the crop was cultivated in Yemen during previous periods. Sorghum grains and spikelets are reported on the site of Sabir (9th c. BCE), though these may actually correspond to wild individuals rather than domesticates (De Moulins et al. 2003). Besides, sorghum grains and starch granules have been potentially identified at the harbour site of Khor Rohri/Sumhuram (2nd c. BCE–5th c. CE), although their preservation did not allow secure identifications to be obtained. The presence of sorghum grains at al-Adhla (1st–5th c. CE) could represent the earliest and most secure identification of the crop in southern Arabia (Lewis 2005).

The agents behind the introduction of sorghum in eastern Arabia during the early Islamic period, if not earlier, currently remain unclear. The crop is drought-resistant and able to face water stress episodes thanks to several physical features (deep root systems) and physiological mechanisms (closing of leaves stomata) (Chanterreau et al. 2013: 46-54); therefore, it is well adapted to arid environments, suggesting that its introduction might be linked to several severe drought episodes identified between 500 and 1000 CE (Fleitmann et al. 2009) when local populations aimed to diversify their production with drought-adapted crops. Moreover, sorghum has other agronomic advantages as a covering (e.g. for avoiding soil compaction and weed development) and low-demanding manure plant (taking advantage of manure used for previous crops) (Chanterreau et al. 2013: 161-165), encouraging its introduction into the pre-existent oasian agrosystems. Its spread may also have resulted from the arrival of new populations (Van der Veen 2010) linked to the coming of Islam in the region and/or increasing trade activities in the western Indian Ocean (Withcomb 2009, Kervran 2004, Rougeulle 1996).

In summary, archaeobotanical analyses from the Arabian Peninsula remains scarce, while any that have been conducted focus purely in eastern Arabia. Based on the first

archaeobotanical discoveries at the sites of Fulayj (earthen imprints) and Kush (occurrence throughout the whole chronological sequence), we can say that the first centuries of Islam may constitute a period of agrarian diversification, supporting Watson's theory with at least one tropical cereal, namely sorghum. An introduction that may have been motivated by the plants' agroecological advantages and favoured by increasing long-distance trade exchanges.

Conclusions and perspectives

To conclude, evidence from the few sites studied so far in the desertic Arabian Peninsula partially documents the diffusion of new crops from antiquity to the early Islamic period. The sites are unequally distributed throughout this wide geographic area and in terms of their chronological periods, with most being situated in eastern Arabia for the early Islamic period. Although archaeobotanical studies in the Arabian Peninsula are increasing for this time period, most are currently still in progress or unpublished. During the last decade, however, new archaeobotanical works on some crucial sites, dated to antiquity/late antiquity and the first centuries of the Islamic period, have provided substantial information on the circulation of plant products by long-distance trade and the adaptation events of new crops within an oasian agricultural system.

For antiquity, the discovery of the exceptionally well-preserved archaeobotanical material of Mleiha in south-east Arabia evidenced the presence of several foreign taxa in the Arabian Peninsula, some for the first time – pepper and Asian rice, for example, are both considered as being imported via the long-distance trade networks of the western Indian Ocean. The concomitant spread of cotton in eastern and north-western Arabia can be seen as a proxy for the intensification of trade dynamics during this period and evidence for the interaction between the Arabian Peninsula and external settlements. We have shown that a multiproxy analysis of data, including archaeobotany, textile and texts, direct radiocarbon dating, and strontium analysis is an effective approach to trace diffusion paths. At Mleiha, the cotton came from elsewhere, most probably the north-western Indian subcontinent (Ryan et al. 2021). By contrast, the site of Hegrā in north-western Arabia have yielded significant amounts of evidence for the local cultivation of cotton (Bouchaud et al. 2018; Ryan et al. submitted).

The only two sites in eastern Arabia documenting the crucial transition between the end of antiquity and the beginning of Islam (Fulayj and Kush) suggest that sorghum was acclimatized in eastern Arabia during the first centuries of Islam, at least two centuries earlier than indicated by Watson (1983). The beginning of Islam, therefore, may correspond to a period of crop diversification using a tropical cereal particularly adapted to drought and low-manured soils, supporting climatic fluctuations or the settlement of new populations.

Studies still in progress or being published will provide a solid body of data, permitting us to characterize more accurately the phenomena of new crop emergence during the 1st millennium CE throughout the desertic Arabian Peninsula and the role of this central region at the intersection of several geographical areas (Mediterranean, African, Persian, Indian) in East-West plant diffusion. Further research will need to consider the potential of geometric morphometrics to characterize the taxonomic diversity of diffusion paths (e.g. cotton). It would also be advantageous to take into consideration later (medieval and modern) Islamic studies, to better reconstruct the longer agricultural history regarding long-distance exchanges between the Middle East and the western Indian ocean in the Arabian Peninsula.

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