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Late pleistocene exploitation of *Ephedra* in a funerary context in Morocco

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The active compounds found in many plants have been widely used in traditional medicine and ritual activities. However, archaeological evidence for the use of such plants, especially in the Palaeolithic period, is limited due to the poor preservation and fragility of seed, fruit, and other botanical macro-remains. In this study, we investigate the presence and possible uses of *Ephedra* during the Late Pleistocene based on the analysis of exceptionally preserved plant macrofossils recovered from c. 15 ka year-old archaeological deposits at Grotte des Pigeons in northeastern Morocco. This cave has yielded the earliest carbonized plant macrofossils of *Ephedra*, which were found concentrated in a human burial deposit along with other special finds. *Ephedra* is a plant known to produce high amounts of alkaloids, primarily ephedrine and pseudoephedrine, which have been utilized in traditional medicine. Direct radiocarbon dates on both *Ephedra* and the human remains indicate that they were contemporaneous. To understand the uses of *Ephedra* by people at the site, we discuss the different pathways through which plant remains could have arrived. We suggest that the charred cone bracts of *Ephedra* likely represent residues of the processing and consumption of the plant's fleshy cones, which may have been valued for both their nutritional and therapeutic properties. Furthermore, we interpret the presence of *Ephedra* and its deposition in the burial area as evidence that this plant played a significant role during the funerary activities.

Keywords Archaeobotany, North Africa, Palaeolithic, Medicinal plants, Funerary activities

Recent research on the consumption of wild plants by early humans has focused on their nutritional benefits, and less attention has been paid to their therapeutic properties[1–4]. Plants are widely used in traditional medicine and in ritual activities, and archaeological and textual evidence suggests that this practice has a long history[5]. Documents from early complex societies such as Ancient China or Iran refer to the use of pharmacologically active plants in symbolic behaviors and for healing[6,7]. However, seeds, fruit, and other large plant parts used in medicine are rarely found in archaeological sites from earlier periods, such as the Palaeolithic, due to their fragility and poor preservation compared to other plant remains such as pollen, starch or phytoliths[5]. It is often assumed that they were first used after people became more sedentary and started cultivating plants, although some scholars propose an earlier exploitation based on plant macrofossils, biomarkers and ancient DNA of plants recovered from early hominin dental calculus[8–10], as well as on behaviors of modern foragers[11].

Ephedra is an ancient genus of non-flowering shrubs native to arid and semi-arid regions, with a geological record dating back to the Early Cretaceous period (approximately 120–125 million years ago)[12]. *Ephedra* fleshy cones, a part of the plant that protects the seeds and facilitates seed dispersal, contain higher amounts of crude protein and fat than other cultivated plants and are consumed as food by some groups of Tuareg in the Sahara[13]

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and by Mongolians[14]. They can be eaten in a fresh or dried state, and juice or tea may be extracted from the fleshy cones. *Ephedra* is distinctive among plants in producing high amounts of alkaloids, mostly ephedrine and pseudoephedrine, which are concentrated in the green stems, roots, and cones[15]. Some of the active compounds act as a vasoconstrictor and stimulant, among other actions. The extraction of alkaloids is usually achieved through pounding and later infusing the whole plant, the resulting product being consumed as a tea[16]. In Morocco, China and many other countries, *Ephedra* has been used traditionally as a remedy for asthma, nasal congestion or fever, among other ailments[16,17]. In the early 20th century, ephedrine was chemically isolated and used in the western world as a bronchodilator. However, long-term use of ephedrine was related to problems in the central nervous and cardiovascular systems, and it was later replaced by new therapies[18]. Nowadays, it is banned in many countries but research concerning its phytochemistry, pharmacology, and toxicology has recently increased[16,18].

Although plant fossils can naturally form in environments like lakesides, rivers, and other sedimentary contexts[19,20], archaeological evidence of *Ephedra* and other medicinal plants in the Palaeolithic remains elusive. This is largely because the parts of plants most commonly used in medicinal practices, such as seeds, fruits, leaves, or small branches, rarely survive in archaeological sites due to the fragile nature of organic materials[5]. Without special preservation conditions such as charring, waterlogging, or freezing, plant remains often degrade, making it difficult to directly trace their use, especially in relation to medicinal practices[1]. Prior to the present study, the earliest evidence for the use of *Ephedra* has been from desiccated twigs and branches recorded in burials and cemeteries in northwestern China, dated to around 3800 BP[21]. Pollen grains from the Neanderthal burial in Shanidar (Iraq, 50,000 cal BP) were originally interpreted as a ritual offering of *Ephedra* flowers[22] but more recent analysis indicates that they may be a modern contaminant introduced by burrowing microvertebrates[23] or bees[24].

Here we investigate the use of *Ephedra* during the final stages of the Late Pleistocene based on the analyses of charred plant macrofossils recovered from archaeological deposits at Grotte des Pigeons, also known as Taforalt, in northeastern Morocco (Fig. 1). The site is a large cave that was used by modern humans from before 100,000 to at least 12,600 cal BP[25,26]. The cave presents exceptional conditions for the preservation of animal and human bones and charred plant remains. Between 23,000 and 12,600 cal BP the site was occupied by Iberomaurusians, who used it as a living and burial site[27]. The Iberomaurusians were Later Stone Age hunter-gatherers from north-western Africa who used microlithic bladelet industries, and displayed diverse expressions of symbolic and ritual behavior, including tooth evulsion and elaborate and varied funerary customs[28]. Previous research has investigated the use of wild plant resources from occupation deposits situated towards the front of Grotte des Pigeons[2,29]. Here we extend the research to include plant macrofossils and wood charcoal from Iberomaurusian funerary deposits located at the back of the cave (for wood charcoal see Supplementary Fig. 1 SI & 2 SI online; SI Table 1 online).

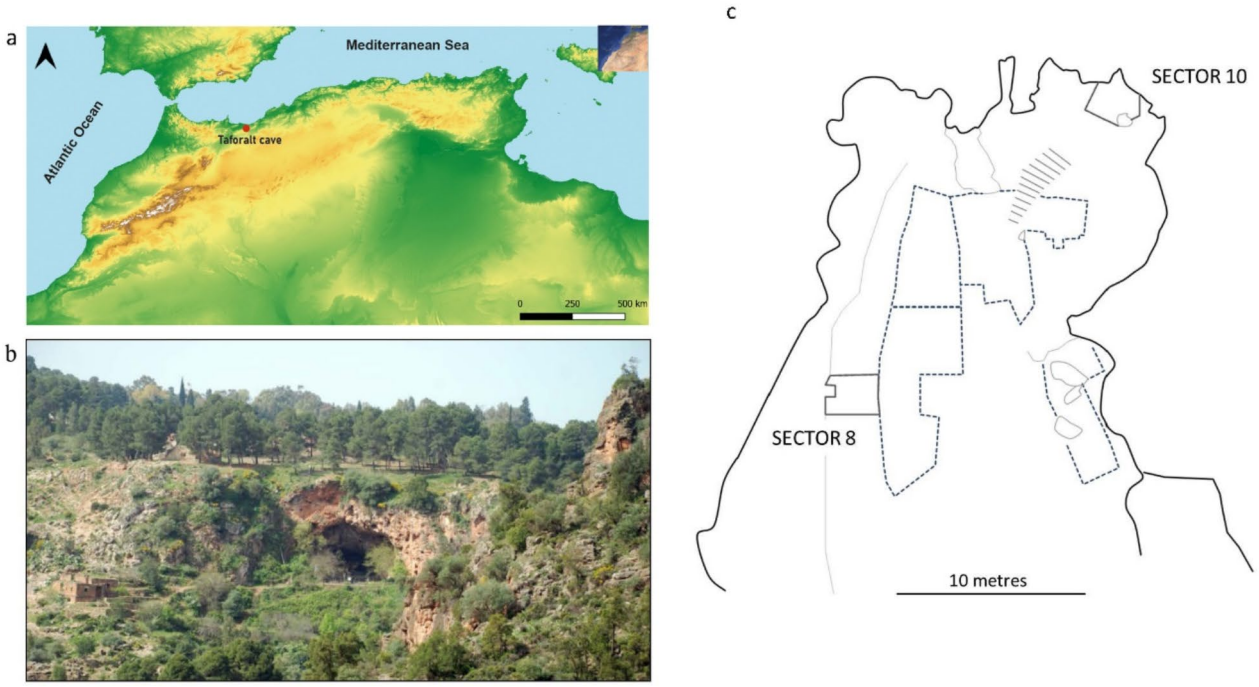


Fig. 1. (**a**), location of Grotte des Pigeons, Taforalt. (**b**), general view of the cave. (**c**), plan view of the site showing location of burial (Sector 10), and midden deposits (Sector 8). The map has been created with free and open source QGIS desktop 3.34.3, https://qgis.org/ (L. Humphrey, J. Morales, I. Ziani).

Sediment context		Within burial pit											Surrounding burial pit													Total
Sample id		12,378	12,264	12,198	12,134	12,084	12,047	12,020	11,984	13,619	13,592	13,544	13,520	13,349	12,954	12,815	11,940	11,896	11,879	11,843	11,832	11,808	11,773	11,771	11,738	
Excavation year		2013	2013	2013	2013	2013	2013	2013	2013	2015	2015	2015	2015	2015	2015	2015	2013	2013	2013	2013	2013	2013	2013	2013	2013	
Volume of sediment (l)		8	7	7	7	7	6	4	5	4	6	5	2	8	7	3	3	6	4	3	1	4	4	7	6	124
Taxa	common name																									
Ephedra sp., pair of bracts	mormon-tea, ma-huang	1	3		1	1	2	2	2	1		2		1	2						2	1		1	1	23
Galium sp., seed	bedstraw											1	1													2
Vicia lens, seed	wild lentil		1				1				1										1					4
Pinus pinaster, seed scale	maritime pine	8	8	7	8	4	4	3	5	8	7	9	3	6	14	10	4	14	8	6	4	5	1	1	3	150
Quercus sp., cupule	acorn	10	15	3	11	4	5	4	10	6	9	12	4	10	29	11	3	19	14	5	3	8	4	1	3	203
Quercus sp., abscision scar	acorn										6			2			1	4		1						14
Rosaceae, fruit	rose hip										1															1
Macrochloa tenacissima, rhizome	alfa			2						1					1				1			1			1	7
Total number of items		19	27	12	20	9	12	9	17	16	24	24	8	19	46	21	8	37	23	12	10	15	5	3	8	404
Seed density per litre of sediment		2.4	2.4	1.7	2.9	1.3	2	2.2	3.4	4	4	4.8	4	2.4	6.6	7	2.7	6.2	5.8	4	10	3.8	1.2	0.4	1.3	3.3

Table 1. Charred plant macrofossils from Sector 10, Grotte des Pigeons.

Results

Excavations between 2005 and 2015 identified several intercutting primary burials, with bodies of adults and infants placed in a seated or reclining position at the back of the cave (Sector 10). These included a seated burial of an adult male, aged 19–20 years and designated Individual 14[30]. The burial of Individual 14 is the most richly endowed of the recently excavated burials and is the earliest stratigraphically.

The grave consisted of an oval pit excavated into the ground with a maximum length of approximately 95 cm (see Supplementary Information online and Fig. 2). The upper part was situated within a grey ashy matrix that comprised the bulk of the excavated sediment in Sector 10 and surrounded most of the burials. This unit contains a high concentration of ash layers, charcoal fragments, rocks, bones fragments, and land snail shells, among other remains. However, intact fireplaces have not been recorded in this unit due to the intense site modification. This pattern of sedimentation is also recorded in other Iberomaurusian and early Holocene sites in North Africa, which are locally known as *rammadiyat*, meaning ashy ground in Arabic. The lower part of the grave cut through a layer of dark brown sediment underlying the grey ashy layer and extended into the underlying compact pinkish-yellow layer.

There were no clearly discernible edges to the grave within the uppermost grey ashy layer, but the edges and the base of the burial pit were clearly discernible below this level. The upper part of the body was disturbed by a subsequent burial, but no burrows or other forms of bioturbation were visible during the excavation process.

The burial incorporates several unusual and potentially highly valued objects[30] (see Supplementary Information online and Supplementary Fig. 3 SI & 4 SI online). Faunal remains from the fill of the grave include bones of great bustard and several mammal species such as Barbary sheep, canids (including fox), and bovines (see Supplementary Fig. 5 SI & 6 SI online). There is evidence that some of these items, such as the bird beaks, modified crania of Barbary sheep, and mandibles of canids were in some way significant to Iberomaurusians, since they appear to have been selected and, along with a marine shell, placed close to the body in the grave[30] (Fig. 2).

Butchery and burning marks on some of the bird and mammal bones indicate that they were processed for consumption. In the case of great bustard, cut-marks are recorded on most of the bones recovered from the grave. For the Barbary sheep, the back of the skull vault has been opened, likely to remove the brain, and the frontal bone is partially preserved along with the bases of the horn cores. This pattern of modification is recurrent and has been observed on many Barbary sheep crania in Sector 10. These represent butchered products, some of which had a secondary function as extraordinary artefacts laid in or close to graves.

In addition, several lithic artefacts were recovered within the fill of the burial pit. An ochre-coated mortar and pestle were deliberately laid in the grave on opposing sides of the body as funerary objects (see Supplementary Fig. 3 SI online). Pounding marks visible on the surface of both utensils attest to extensive use prior to deposition[30]. Additionally, a relatively thin, elongated, pointed straight-backed blade/let was recorded, an object that would have required a high level of skill to create due to its length and fragility.

Plant macrofossils were recovered from the sediments within the burial fill of Individual 14 and from the surrounding deposits in the pit. The sediment is notably ashy and contains large quantities of well-preserved carbonized plant remains, including both seeds and wood charcoals. Among the seeds, 404 charred remains belonging to seven different plant species were identified. The most abundant macrofossils were of acorns

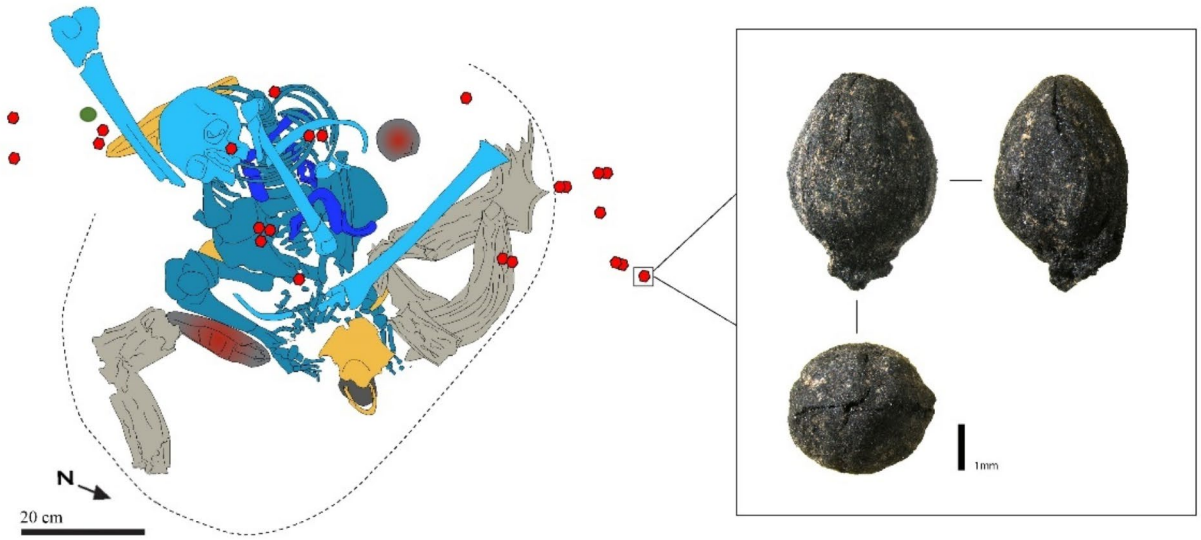


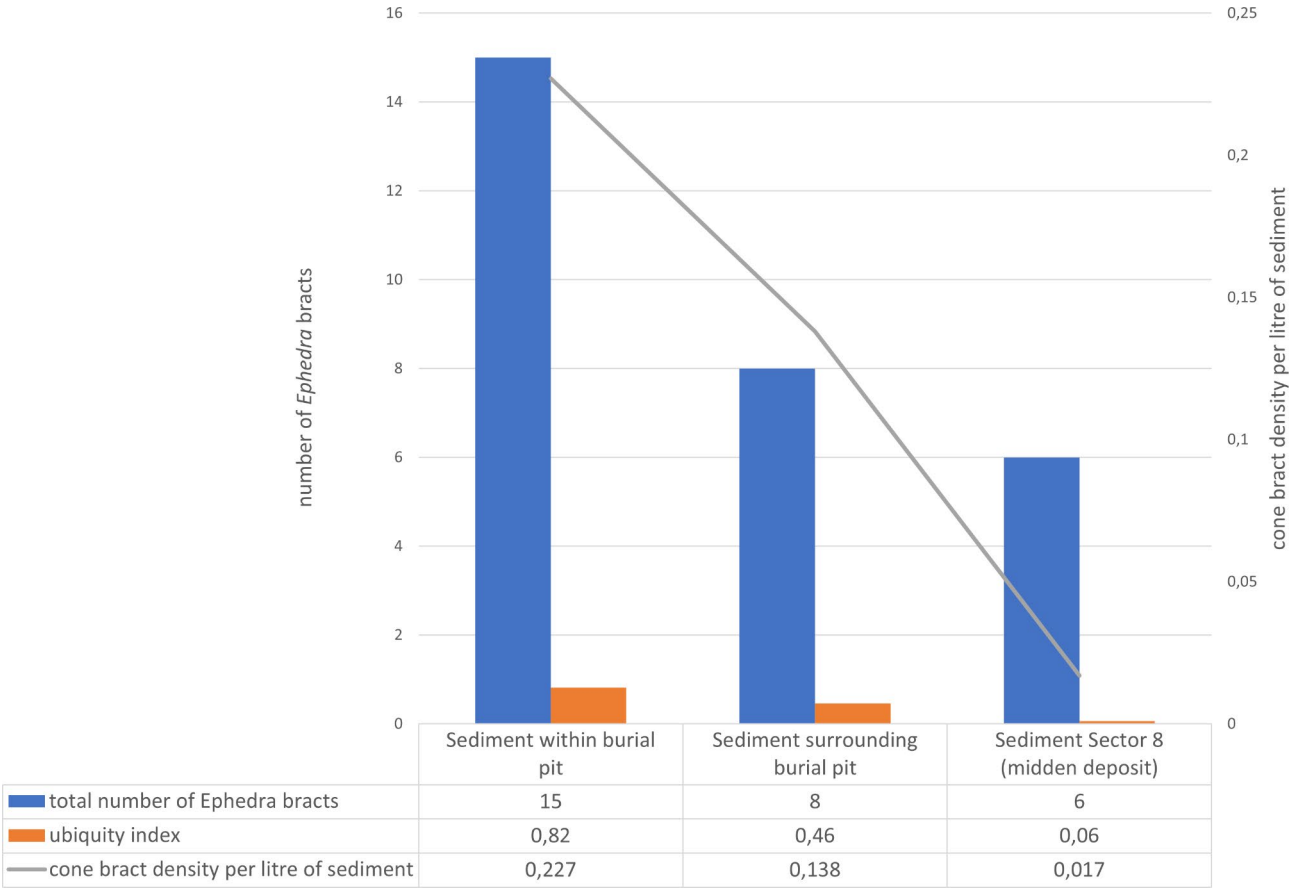
Fig. 2. Drawing showing location of in situ bones of Individual 14 (in blue), Barbary sheep horn core (in grey), stone with ochre (in dark grey and red), animal bones (in yellow), *Ephedra* cone bracts (as red spots), shell (as large green spot), limits of the burial pit (dotted line). Photo on the right side shows an archaeological *Ephedra* pair of cone bracts (author A. Freyne and J. Morales).

(*Quercus* sp.) and Maritime pinecones (*Pinus pinaster*), which were recovered in all the samples and represent 87.3% of the remains. In addition, a few seeds of wild lentil (*Vicia lens*), a rose hip (Rosaceae), a seed of cleaver (*Galium* sp.) and rhizome fragments of Alfa grass (*Macrochloa tenacissima*) were identified. The most notable finds were 23 cone bracts of *Ephedra* sp., concentrated in the burial pit, which form the focus of the present discussion (Table 1) (Fig. 2).

Ephedra is a well-known medicinal plant, as previously mentioned, and to our knowledge, these are the earliest macro-remains of this plant linked to human activity ever recorded. The low number of seeds is due to the fragility of charred fossils and the carbonization process, which preserves only a small fraction of the original plant material. Occasional episodes of carbonization, such as accidents or deliberate destruction, are rarely preserved. This preservation process strongly favors the hardest parts of the plants most frequently used at the site, suggesting that *Ephedra* was regularly utilized despite the limited number of cone bracts found[31].

In addition to seeds and fruits, 1786 wood charcoal fragments from the same samples were analyzed but no charcoal of *Ephedra* was identified (see Supplementary Information online). Wood charcoals are probably residues of plants used as fuel, so this implies that *Ephedra* was not used as firewood. The wood charcoals recorded here represent a conifer-dominated vegetation, with juniper (*Juniperus/Tetraclinis* sp.) and pine (*Pinus* sp.) being the most common taxa. Although assessing the density of plant formations is challenging, these taxa typically give rise to forests characterized by a low density of individuals and an open canopy (See Supplementary Fig. 1 SI & 2 SI online; SI Table 1 online).

Charred cone bracts of *Ephedra* were also identified in an adjacent occupation deposit (Sector 8), from a part of the site that was not used for funerary activities[29]. Sector 8 is characterized by the presence of c. 2 m of dark grey mainly lenticular sediments including ash, charcoal, decomposed organic residues, fire-cracked rocks and significant quantities of land snail shells. Here *Ephedra* was only recorded in a slightly earlier phase of occupation dated between 16,000 and 14,500 cal BP and occurred less frequently, with only six items recovered. No *Ephedra* bracts were recorded in layers of Sector 8 contemporaneous with the burial of Individual 14, despite the high amounts of charred plants documented there[29]. Remains of *Ephedra* in the burial deposits present a density of 0.185 items per litre of sediment and an ubiquity index (number of samples with *Ephedra*/total number of samples) of 0.625; while in Sector 8 the density is 0.086 and the ubiquity index is 0.3.



	Sediment within burial pit	Sediment surrounding burial pit	Sediment Sector 8 (midden deposit)
total number of Ephedra bracts	15	8	6
ubiquity index	0,82	0,46	0,06
cone bract density per litre of sediment	0,227	0,138	0,017

Fig. 3. Graph showing total number of *Ephedra* cone bracts, ubiquity index, and cone bract density per litre of sediment in: (**A**) sediment within the burial pit. (**B**) sediment surrounding the burial pit. (**C**) sediment from the midden deposit at Sector 8. Ubiquity index has been calculated dividing the number of samples in which the presence of *Ephedra* is recorded by the total number of samples analysed.

The density and ubiquity index of *Ephedra* are higher within the burial pit compared to the sediments surrounding the pit (Table 2). In contrast, remains of pinecones and acorns, the most common plants at the site, show lower density values in the burial pit than in the surrounding sediments. The higher concentration of *Ephedra* in the burial pit suggests a possible association between this plant and the funerary activities conducted in this sector of the cave (Fig. 3).

Archaeological remains of *Ephedra* in both the burial area and Sector 8 consist of cone bracts, a woody and ovoid structure surrounded by a fleshy tissue that encloses the seeds. *Ephedra* seeds themselves were not recorded, probably because they are more fragile and would not survive the charring process. Cone bracts were well-preserved, with complete specimens consisting of a pair of bracts still united and fused for almost their entire length (Fig. 4). Comparison with modern specimens of *Ephedra* species currently growing in the region was undertaken for identification purposes. Archaeological cone bracts are similar to *E. altissima* and *E. nebrodensis* but cone morphology does not allow the different species of *Ephedra* to be distinguished accurately[32] and it was only possible to identify the remains to genus level.

Discussion

Routes of entry of *Ephedra* to the burial

Ephedra remains were radiocarbon dated to determine whether they were contemporaneous with human bone from Individual 14 and other items in the burial (Table 3). The dates confirm that at least one of the *Ephedra* remains was contemporaneous with the burial of Individual 14. At present this is the earliest known burial from Grotte des Pigeons but the distribution of disarticulated and unassigned human bone fragments within the grave fill and surrounding sediment indicates the possible presence of earlier disturbed burials at the site. The second date on *Ephedra* is older than Individual 14 and may relate to an earlier burial not yet discovered or other earlier activities at the site. Based on the distribution and chronology of *Ephedra* remains in Sector 10, we suggest a repeated use of *Ephedra* in this burial area over a long period of time.

The presence of carbonized cone bracts of *Ephedra* in the burial deposits raises the question of whether they were introduced into the burial pit as result of activities carried out in this area or were inadvertently incorporated into the sediment brought from other parts of the cave.

The *Ephedra* recovered from the burial could not have been placed in the burial pit as an offering in fresh or dried form, because only charred plant remains survived in the sediment. Preservation of *Ephedra* remains by carbonization indicates that the cone bracts were in contact with fire prior to deposition[34].

We can exclude the possibility that the cone bracts were introduced to the site through the planned use of *Ephedra* as firewood because no wood charcoals of this species have been recorded in the sieved sediments.

It is possible that the plant remains were charred in fires elsewhere in the cave and transported along the sediment to the burial area afterward. However, the lower presence of *Ephedra* remains in contemporaneous layers from Sector 8 indicate that *Ephedra* was not introduced in sediment transported from that part of the cave. The Jaccard Index (JI) statistical test was conducted to compare the similarity in species composition between Sector 8 and Sector 10[35]. The test yielded a JI value of 0.26, indicating that the two sectors have partially distinct species compositions. This low similarity value suggests that the sediment in the burial was likely not transported from other parts of the cave, refuting the hypothesis of sediment relocation. Additionally, the presence of several unique artifacts and animal remains that are only found in the burial area, and not elsewhere in the cave, confirms that at least part of the sediment was deposited in situ.

Another possibility is that the plants were carbonized in activities carried out during the burial of Individual 14 and that after using the fleshy cones and discarding the residues in the fire, some of the charred *Ephedra* was unknowingly incorporated into the burial pit at the time that Individual 14 was interred. Other *Ephedra* remains may have been present in the sediments disturbed during preparation of the burial, reflecting earlier use episodes. The exceptional preservation of the *Ephedra* bracts, other seeds, and wood charcoals suggests they were incorporated into the sediment soon after being charred.

There were no hearths recorded close to the burial, but it is probable that they were dismantled as result of later activities in this part of the cave. Similarly, intact fireplaces have not been recorded in the grey deposits of

	Percentage		Density		Ubiquity	
	Within	Surrounding	Within	Surrounding	Within	Surrounding
Ephedra	8%	3.7%	0.22	0.13	0.8	0.5
Galium	0.5%	0.5%	0.01	0.01	0.1	0.1
Vicia lens	1.6%	0.5%	0.04	0.01	0.3	0.1
Pinus pinaster	37.6%	36.7%	1.07	1.36	1	1
Quercus	50.3%	56.7%	1.43	2.10	1	1
Rosaceae	0.5%	0%	0.01	0	0.1	0
Macrochloa tenacissima	1.6%	1.9%	0.04	0.06	0.2	0.3

Table 2. Percentage, ubiquity index, and seed density per litre of sediment for plant macro-remains recorded within the burial pit and in the sediments surrounding the burial pit. Ubiquity index has been calculated dividing the number of samples in which the presence of *Ephedra* is recorded by the total number of samples analysed.

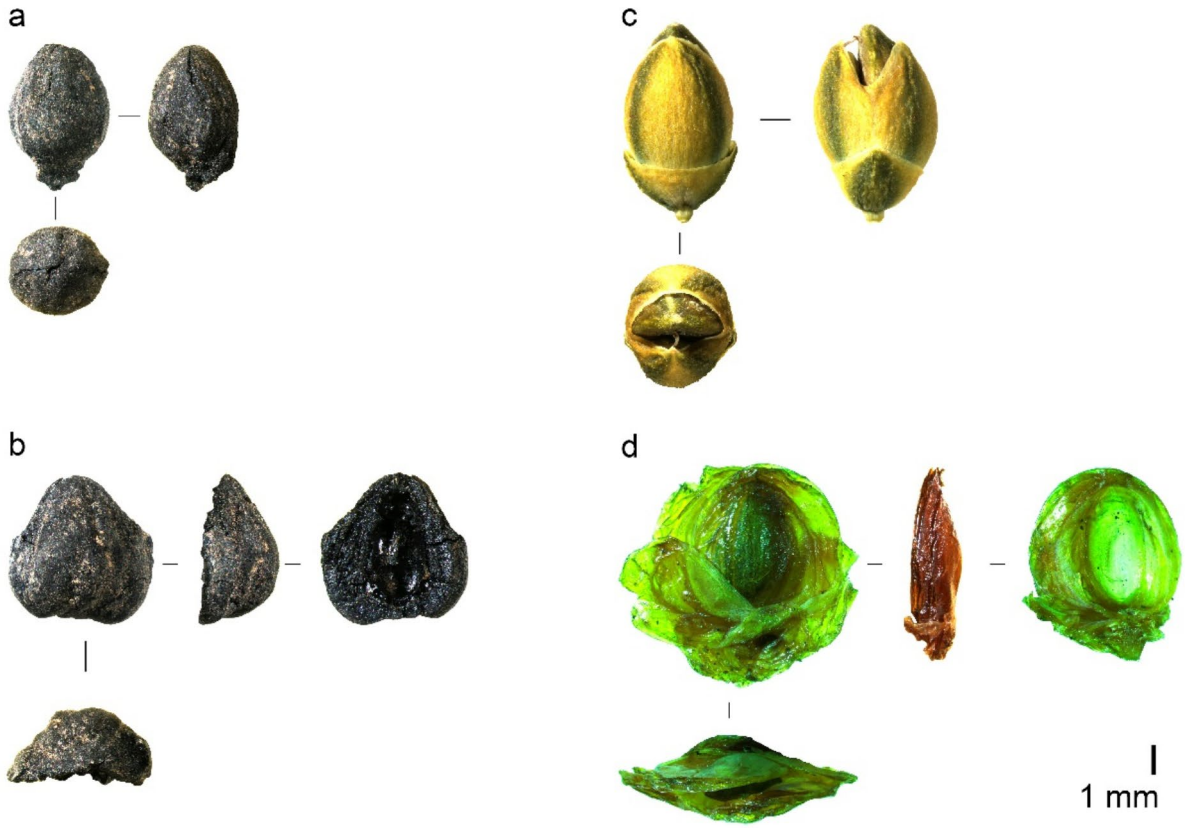


Fig. 4. Frontal, lateral and cross-section views of archaeological and modern *Ephedra* cone bracts. (**a**), archaeological pair of cone bracts still fused (Sector 10). (**b**), archaeological single cone bract including view of the inner face of the bract (Sector 10). (**c**), modern pair of *E. altissima* cone bracts still fused and with seed, collected at Taforalt. (**d**), modern single *E. nebrodensis* cone bract including view of the inner face of the bract (Herbaria Botanical Garden 'Jardin Canario Viera y Clavijo', *Spain) (author J. Morales).*

Sample number	Description	< TAF Ref>	Conventional 14 C age BP (± 1δ)	Calibrated age (cal BP) 95.4% range
OxA-23,781	Ind 14 femur	TAF09 9103	12,410 ± 50	14,895 – 14,231
OxA-23,782	Ind 14 femur (repeat)	TAF09 9103	12,460 ± 55	14,972 – 14,307
OxA-27,284	Canid mandible	TAF10-11398	12,520 ± 55	15,100 – 14,360
OxA-29,263	*Ephedra* cone bract	TAF13 12,047	12,410 ± 50	14,895 – 14,231
OxA-29,264	*Ephedra* cone bract	TAF13 12,264	13,065 ± 55	15,850 – 15,442
OxA-38,079	Bustard sternum	TAF10-11389	12,540 ± 55	15,131 – 14,457

Table 3. Radiocarbon determinations and calibrated ages for items associated with burial of Individual 14. Ranges are calibrated by means of the IntCal20 atmospheric calibration curve[33] and the OxCal online software version 4.4.

Sector 8, despite the ashy content of the sediment and the abundance of charcoal fragments. This absence could be attributed to sedimentation processes and layer formation, which may have prevented the preservation of intact hearths in those layers. We suggest that the high frequency of repeated burials within a very limited area (c. 4 m^2) over a closely related chronological period has hindered the preservation of in situ fireplaces, as well as the formation of clear and distinct stratigraphy.

From this perspective it is notable that bones representing several great bustards were present within the burial of Individual 14, as well as in other burials and in the sediment surrounding them (see Supplementary Information online). Remains from this species were absent elsewhere at the site. The distribution of bustard

skeletal parts within Burial 14 indicates that uneaten parts of the bird were deliberately placed within the burial pit alongside the body and other valued items.

The presence of *Ephedra*, along with that of other plant and animal remains such as acorn, great bustard, and Barbary sheep, can be considered as evidence for the use of special plants and animals within the funerary area, with discarded parts later incorporated into the burial fill. We cannot completely exclude the possibility that *Ephedra* represents residues of activities not linked to the burial and was instead accidentally incorporated into the pit fill, although its scarcity in other areas of the cave suggests that *Ephedra*, along with other plants and animals, was mostly processed and consumed in or close to the part of the cave set aside for funerary activities.

Ephedra processing and uses

Ephedra cones comprise a fleshy, edible part and a woody, non-edible bract. The charred cone bracts of *Ephedra* recorded in the sediments likely represent the residues from the processing and consumption of the fleshy part of the cones. The discarded bracts could have been used as casual fuel following removal of the palatable parts of the cone after processing them. Traditional processing of *Ephedra* involves pounding and infusing branches and cones[16], so it is possible that only the hardest parts such as the bracts were preserved after burning.

Burnt and heat-shattered rocks are commonly found in the same deposits and could be the result of deliberate heating of stones for cooking purposes[36]. Heated stones could also be used to boil *Ephedra* in water-filled vessels made from basketry or animal skin.

Ephedra may have been a 'medicinal food' that was consumed for both its nutritional and therapeutic properties, and it could have been exploited to provide several benefits simultaneously such as to mitigate hunger and maintain health[5]. Evidence of successful recovery from operations, such as tooth evulsion and cranial trephination, performed by Iberomaurusian occupants of Grotte des Pigeons[28,30] suggests that *Ephedra* could have been used for medicinal purposes. *Ephedra* is a vasoconstrictor, and it could have been employed to reduce the amount of blood loss during these surgical procedures and as an aid to recovery. Phenolic compounds of *Ephedra* have antibacterial and antifungal activity that could help in healing[15,16], although it seems unlikely that specific benefits of these compounds would have been fully understood by the Iberomaurusian people, and the deliberate use of *Ephedra* for this purpose cannot be proven with the available evidence.

Nevertheless, the higher prevalence of *Ephedra* within the burial sediments points towards a specific link to activities carried out in this part of the cave. The small number of remains from this taxon in the coeval layers in Sector 8, which mostly represents residues of food processing and consumption, indicate that *Ephedra* was not used as part of day-to-day activities. Regular use of *Ephedra* can cause life-threatening problems in the central nervous and cardiovascular systems[16] so it is likely that it was only consumed on special occasions such as funerary practices or therapeutic uses.

The consumption of special foods and the placement of food debris in highly symbolic contexts, such as burial places, have been interpreted in other archaeological contexts as clear evidence of feasting, and potential sharing of food items with the deceased[37,38]. Here we suggest that at Grotte des Pigeons, people were using or consuming unusual and special foods as part of a c. 15 ka years human burial, and that *Ephedra* had a significant place among them. This interpretation does not exclude other uses, such as therapeutic practices.

Methods

Plant sampling strategy

All the sediment excavated during the 2013 and 2015 excavation seasons was retained as environmental samples and used for flotation and identification of charcoal and charred macro-botanical remains. The environmental samples represent sediment within the undisturbed part of the burial pit of Individual 14 and sediment within the immediate vicinity of the burial. The first set of samples were situated within the boundaries of the burial pit and below the level of the in situ proximal humerus and right knee of Individual 14. The second set of samples were located beyond the boundaries of the burial pit. Another burial placed directly above Individual 14 had been completely removed during previous excavation seasons.

Macro-botanical remains, including seeds and wood charcoals, were collected by floating each sediment sample and then sieving the flot (light fraction) using a column of sieves with a mesh size of 4 mm, 2 mm, 1 mm and 0.5 mm. In total, 24 sediment samples were analyzed, with a total volume of 124 L. Of these, 11 of the sediment samples represented sediment within the undisturbed part of the burial pit (volume 66 L) and 13 samples represented the sediment surrounding the burial (volume 58 L) (Table 1). The coarse stone fraction was removed from the soil samples on site and is excluded from volume measurements.

Observation of Plant Macrofossils (seeds and fruits)

Plant macrofossils, excluding wood charcoals, were examined by JM. The plant fossils were identified using a binocular microscope (8-80x magnification) and by comparison with modern specimens from the seed reference collection of the Department of Historical Sciences, University of Las Palmas de Gran Canaria (Spain); the herbaria at the Botanical Garden 'Jardín Canario Viera y Clavijo', Gran Canaria (Spain) and by consulting specialized literature on plant anatomy. Table 1 presents the estimated number of plant macrofossils in each sample. Botanical nomenclature for plants follows Fennane et al.[39,40] and the updated data of the catalogue of the WFO[41]. Images of all the plant taxa are shown in Fig. 5.

Ephedra macrofossils

We identified a minimum number of 23 pairs of cone bracts in Sector 10. Cone bracts are woody and ovoid structures surrounded by a fleshy tissue that partially enclose the seed. In exceptional cases the pair of bracts were still united and fused for almost their entire length. There are five *Ephedra* species currently growing

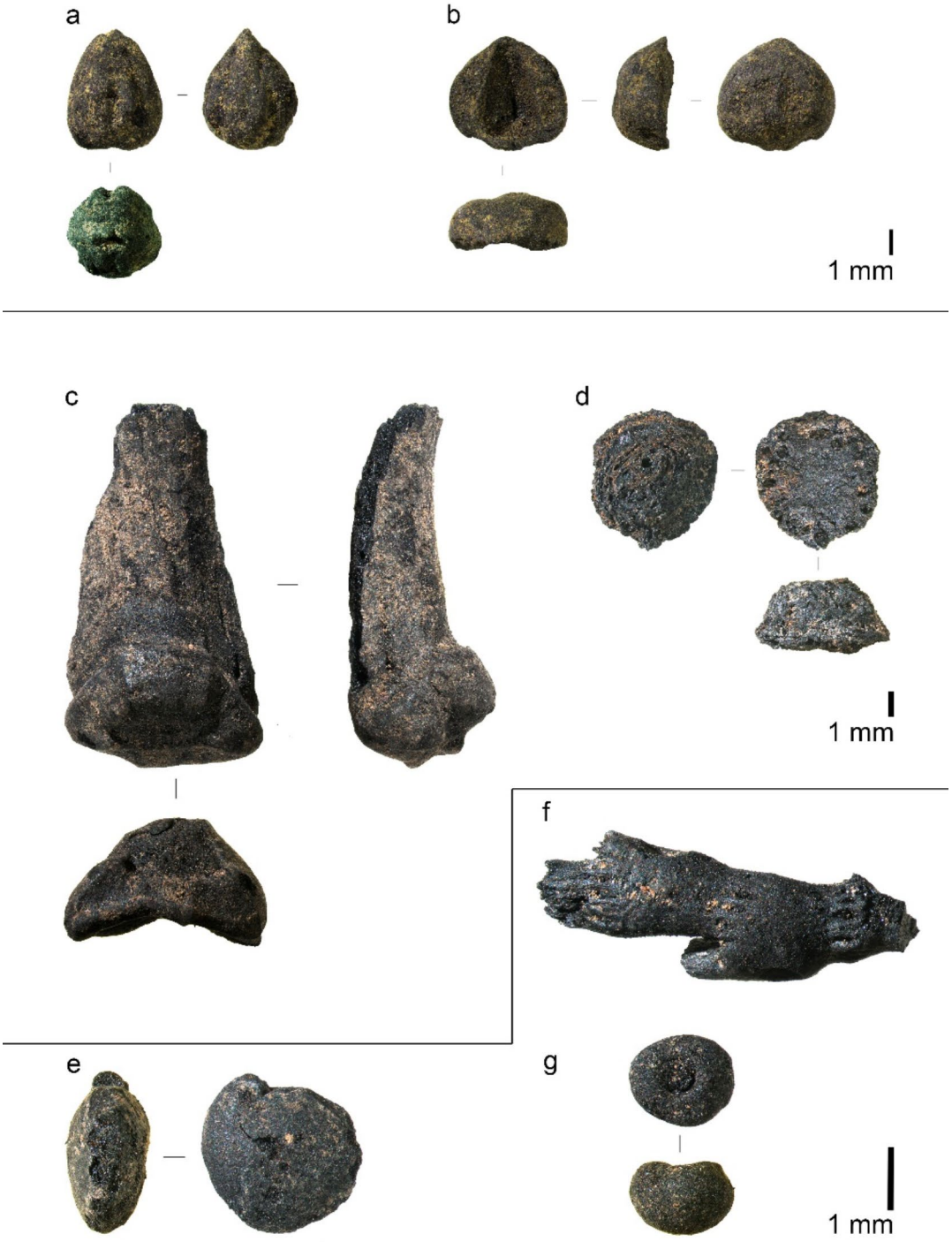


Fig. 5. Plant macrofossils from Sector 10. (**a**), *Ephedra* sp., pair of cone bracts. (**b**), *Ephedra* sp., single cone bract. (**c**), *Pinus pinaster*, seed scale. (**d**), *Quercus* sp., cupule. (**e**), *Vicia lens*, seed. (**f**), *Macrochloa tenacissima*, rhizome fragment. (**g**), *Galium* sp., seed (author J. Morales).

in Morocco: *Ephedra fragilis* Desf., *E. altissima* Desf., *E. nebrodensis* Guss., *E. alata* Decaisne and *E. rollandii* Maire[39]. *E. alata* and *E. rollandii* are restricted to arid regions of Southern Morocco, while *E. fragilis*, *E. altissima* and *E. nebrodensis* are present in Mediterranean type environments[39]. We compared the fossils bracts with modern bracts of all five modern species and they were more similar to the group of *E. fragilis*, *E. altissima* and *E. nebrodensis*, especially to *E. nebrodensis and E. altissima* (Fig. 4). *E. altissima* is an endemic plant of North-

Western Africa that still grows on the hillside surrounding the site, so it is possible that macrofossils at Taforalt belong to this taxon. However, cone bracts from those three species are very similar and distinguishing between them is problematic[32]. In addition, species delimitations in *Ephedra* are sometimes tentative or under debate and attempts to classify them according to gross morphological criteria have resulted in different hypotheses[32]. Consequently, we have identified the archaeological remains from Taforalt to the genus level of *Ephedra*. All the *Ephedra* species growing in Morocco, and broadly in the Old World, contain psychoactive substances in both the stems and cones[42].

The number and density of *Ephedra* cone bracts was higher in the burial pit than in the surrounding sediments (Fig. 3; Table 2). *Ephedra* was present in 9 out of 11 sediments samples from within the burial pit and 6 of the 13 samples located beyond the horizonal boundaries of the burial pit. In total, 15 of the 23 *Ephedra* cone bracts were derived from sediment from within the burial pit (0.227 bracts per litre of sediment) and 8 were from sediment surrounding the burial (0.138 bracts per litre of sediment).

Charred cone bracts of *Ephedra* were previously identified in a LSA midden deposit (Sector 8), located closer to the cave opening and in a part of the site that was not used for burials. However, *Ephedra* occurred less frequently in Sector 8, with only 6 items recorded from a much larger volume of sediment (345 L, representing 0.017 bracts per litre of sediment)[2]. The higher concentration of *Ephedra* in the burial area suggests that this plant was mostly used in this part of the cave, or that residues from hearths used in association with the plants were preferentially deposited in this area. We do not know whether *Ephedra* was also present in other burials because systematic analysis of plant macrofossils was not performed during previous excavations.

Other Plant Macrofossils

Acorns (*Quercus* sp.) are the most common macrofossils, making up 53% of the total plant assemblage. Remains consist of fragments of the cupule, the woody structure made of successive layers of sclerified and suberized bracts that partially enclose the seed[43,44]. Only the central axis to which the seed was attached tends to be preserved, and the fragments lack external layers of bracts, so it has not been possible to identify the remains to species level. Bracts of Holm oak (*Quercus ilex*) were recorded from Sector 8[2]. It is likely that the remains in Sector 10 also belong to this species. A total number of 150 seed scales of *Pinus* were recorded, accounting for 36% of the total plant assemblage. Those are ovoid structures that enclose the seeds and have a prominent and pyramidal apophysis, a diagnostic feature that enabled identification as *Pinus pinaster*[39]. In addition, we recorded 4 seeds belonging to wild lentils (*Vicia lens*), 1 complete fruit of the Rosaceae family, 1 seed of bedstraw (*Galium* sp.), and 7 fragments of rhizomes of Alfa grass (*Macrochloa tenacissima*). Wild lentil and the Rosaceae fruit could have been used for human consumption while *M. tenacissima* may have been utilized as a source of fiber for basketry.

With the exception of the Rosaceae fruit, which was only recorded inside the burial pit, all other species have been identified in both the burial pit and the sediments surrounding it. *Ephedra* shows higher values for percentage, density, and ubiquity inside the burial pit compared to the sediments surrounding the grave. In contrast, the other plant species, with the exception of wild lentils, exhibit higher values for percentage and density in the sediments collected from around the burial pit (Table 2).

In terms of seasonality, *Ephedra* cones, wild lentils, *Galium* and Rosaceae fruit usually ripen in late spring and early summer[39,40]. On the other hand, acorns and pinenuts ripen in autumn[39,40], so it is possible that the burial of Individual 14 took place in summer or in autumn unless stored plants were used.

Data availability

All data generated or analysed during this study are included in this published article (and its supplementary information files).

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Author contributions

All authors contributed equally to this work. J.M., Y.C.M, and I.Z. conducted the observations at the plant macrofossils. J.H.C., E.T., A.F. J.H., R.N.E.B., A.B., and L.T.H. conducted the observations at other archaeological remains. J.M., and L.T.H. wrote the main paper, and Y.C.M., J.H.C., E.T., A.F. J.H., R.N.E.B., A.B. wrote the Supplementary Information. All authors discussed the results and implications and commented on the manuscript at all stages.

Declarations

Competing interests
The authors declare no competing interests.

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