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ABSTRACT

Livestock dung is a valuable material in many rural communities worldwide. In our research area, the site of Althiburos and its surroundings, now el Médéïna, in northwestern Tunisia, dung is the main source of fuel for domestic purposes, primarily the processing and cooking of foods. Ovicaprine dung is daily used in traditional mud *tannur* type ovens, namely *tabouna*. The archaeological record shows that mud constructed cooking installations were common during the first millennium BC. Previous studies of phytoliths and dung spherulites at Numidian Althiburos suggested the use of vegetal and fecal matter for fuel purposes. We present here the results of the continuation study based on the comparison between archaeological results (a selection of cooking installations, six hearths and two mud ovens) and those obtained from the ethnographic study of dung fuel materials from the site area. The present study builds up on ethnographic observations and informal interviews (dung collection, management, storage, waste disposal and cooking and baking activities), temperature measurements within the burning fuel, as well as modern material sampling (fresh dung, burned pellets, dung ashes and fuel trash paths) which was followed by integrated studies of phytoliths and calcitic microfossil analyses (dung spherulites and wood ash pseudomorphs) for comparative purposes. The results obtained provided direct evidence regarding the type of fuel sources: dung, wood and a mixing of dung and vegetal matter (wood and agricultural by-products). Dung was used as source of fuel material across time (from the Early Numidian occupation phase, 10th–9th century BC, to the last centuries BC) and space (in different excavation areas and type of installations). Such integrated studies demonstrate the value of combining different microarchaeological techniques and the use of ethnoarchaeological material from site areas.

1. Introduction

It is well known that livestock dung is a valuable source of fuel in many rural communities across the world (Miller, 1984; Anderson and Ertug-Yaras, 1998; Reddy, 1998; Sillar, 2000). Among traditional societies dung is an important secondary product that can be used in varied range of ways (i.e. fertilizer either in its organic form or after being burned, building material, container making, etc.), in addition to fuel for domestic uses. The use of dung as fuel has been commonly related to situations of deforestation, in areas where the

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woody vegetation is sparse or not available (Bottema, 1984; Miller, 1984; Anderson and Ertug-Yaras, 1998). However, ethnographic studies on fuel selection show how it may relate not only to availability and economic factors (i.e. cost, efficiency and redundancy, as this material may be needed for other main purposes such as manure), but also by other cultural choices or social values (i.e. taboo on using specific materials) (Shahack-Gross et al., 2004; Picornell et al., 2011). Ethnographic research in the Moroccan Rif, an area in western Maghreb where Mediterranean woodlands are still abundant, illustrates that despite wood has traditionally been the main source of fuel for domestic purposes, the use of dung cakes (primarily mixed cow and goat dung) is linked to the firing of pottery (Zapata et al., 2003). In this later example the use of dung cakes responds to technical reasons related to their burning properties (slower and more regular than wood), and shows a limited consumption, as only a partial amount of the household dung production is used for firing and most of the production is devoted to other main purposes, such as manure and tempering.

In our research area, the site of Althiburos and its surroundings, located in a small fluvial valley on the northern edge of the Ksour massif, in northwestern Tunisia (Fig. 1), livestock dung is the main source of fuel for domestic use, primarily the processing and cooking of foods, in addition to ceramic production. The area, where firewood is sparse, is particularly interesting because the present-day rural communities use ovicaprine dung as the main fuel source, including daily cooking and baking in mud cylindrical *tannur* type ovens, locally called *tabouna* (Portillo and Albert, 2011).

A variety of archaeological domestic cooking installations from all time periods have been studied in the Mediterranean region. Many studies have focused mainly in prehistoric and protohistoric ovens and hearths, based on macroscopic descriptions and analogies to ethnographic parallels. A number of recent studies have explored such fire installations using microarchaeological techniques (Weiner, 2010 and references therein), thus emphasizing on the identification of the mineralogical signatures of heating associated to the installations, and taking into account formation and degradation processes that are critical for interpreting the archaeological record (Albert et al., 2000, 2003; Albert and Cabanes, 2007; Berna et al., 2007; Gur-Arieh et al., 2012, 2014). Possible depositional route-ways and taphonomic histories for such firing contexts may relate to fuels used, foods accidentally burnt during preparation and cooking, as well as materials accidentally or deliberately discarded into the fire (i.e. destroying infested seeds) (Van der Veen, 2007; Matthews, 2010). In addition, secondary depositional pathways and re-use for storage or trash may introduce burnt and un-burnt materials that are unrelated to the original function of the installations (i.e. fill deposits, inclusion of building materials).

Mud constructed cooking installations are also common in Numidian archaeological contexts belonging to the first millennium BC (Belarte, 2011; Ramon and Maraoui, 2011). In previous studies at Numidian Althiburos we have addressed plant and dung exploitation, including food processing activities, through the combined use of opal phytoliths– microscopic bodies composed of pure silica present in the tissues of many vegetal species (Piperno, 1988, 2006; Pearsall, 1989) and dung spherulites– calcitic particles that form in animal guts and can be found in dung (Brochier et al., 1992; Canti, 1997, 1998, 1999). Livestock dung assemblages have been examined through such microfossils in varied contexts belonging to different occupational phases of the site (covering most of the 1st millennium BC), including room floors and midden deposits, but also in combustion structures such as hearths and ovens (Portillo and Albert, 2011, 2016; Portillo et al., 2012). The aim of this previous research was to evaluate the potential use of plant and dung microfossils, in integration with other bioarchaeological evidence from faunal and charred plant macro-remains, for delineating domestic activities being carried out at the site, including food processing and grazing and foddering of herds. The presence of phytolith-rich layers in association with large amounts of fecal spherulites in certain areas of the site suggested that plants were deposited onsite as livestock dung or dung-products. Thus, such microfossil associations in combustion structures suggested the use of plant and dung material for fuel purposes. Additionally, we carried out a pilot ethnoarchaeological study in order to better understand the manner in which both vegetal and dung microfossils were embedded in the archeological assemblages and, more widely, their role in site formation processes (Portillo et al., 2012). For this purpose, the research included the study of selected

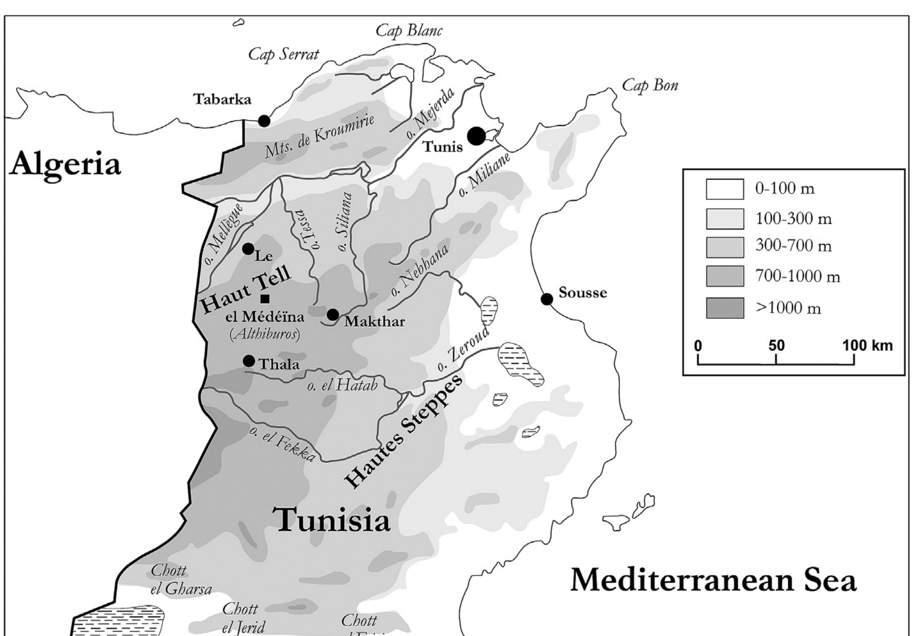

Fig. 1. Map showing the general location of Althiburos, in northern Tunisia.

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modern dung materials obtained from the surroundings of the site, such as fresh dung pellets, penning soils and dung sub-products (i.e. building material and burned dung pellets from a *tabouna* oven). Sampling of modern materials, as well as laboratory extraction procedures, was conducted in a manner similar to that of archaeological contexts for comparative purposes.

The research reported upon here represents the continuation of these earlier studies focusing on fuel exploitation and food processing in cooking installations using similar integrated micro-archaeological and ethnoarchaeological approaches. This study examines phytolith and calcitic microfossil assemblages from a selection of archaeological installations, primarily hearths and mud ovens, in addition to modern fuel materials from the site area. The current study includes the analyses of calcitic ash pseudomorphs (calcite pseudomorphs after calcium oxalate crystals' heating to at least 450 °C, primarily originating from wood and dicotyledonous leaves) (Wattez and Courty, 1987; Brochier and Thinon, 2003; Canti, 2003). For this purpose, a pilot reference collection from selected modern woody specimens is also presented here. Thus, following the recently developed methods of Gur-Arieh et al. (2013, 2014), based on the calculation of the ratio of ash pseudomorphs to dung spherulites, we intend to discriminate between wood *versus* dung-dominated ashes.

The present work addresses the taphonomy of all three microfossil lines of evidence (phytoliths, spherulites and ash pseudomorphs) based on the comparison between archaeological results and those obtained from the ethnographic study of dung fuel materials from the site area. Fieldwork included ethnographic observations and informal interviews (dung collection, management, storage, waste disposal and cooking and baking activities), in addition to time measurements from the initial fire lighting and the end of cooking and temperature measurements within the burning *tabouna* fuels. The later issue, which has not been previously addressed in our research, is critical for evaluating taphonomic questions related with microfossil preservation (i.e. melting of phytoliths, the impact on ash pseudomorphs and dung spherulites total abundances). Our ethnographic work treated the modern installations and materials as if they were archeological. The comparison of these new reference modern materials to the results of the archaeological material from this study, as well as from previous studies of such archaeological installations (hearths and ovens), will provide the opportunity of characterizing the type of fuel matter and food processing behaviors. Additionally, it may allow us to assess whether there is continuity or change of the tradition in the use of fuel sources across time (from the Early Numidian occupation phase, 10th–9th century BC, to the last centuries BC), as well as in different site areas and types of firing installations (Fig. 2).

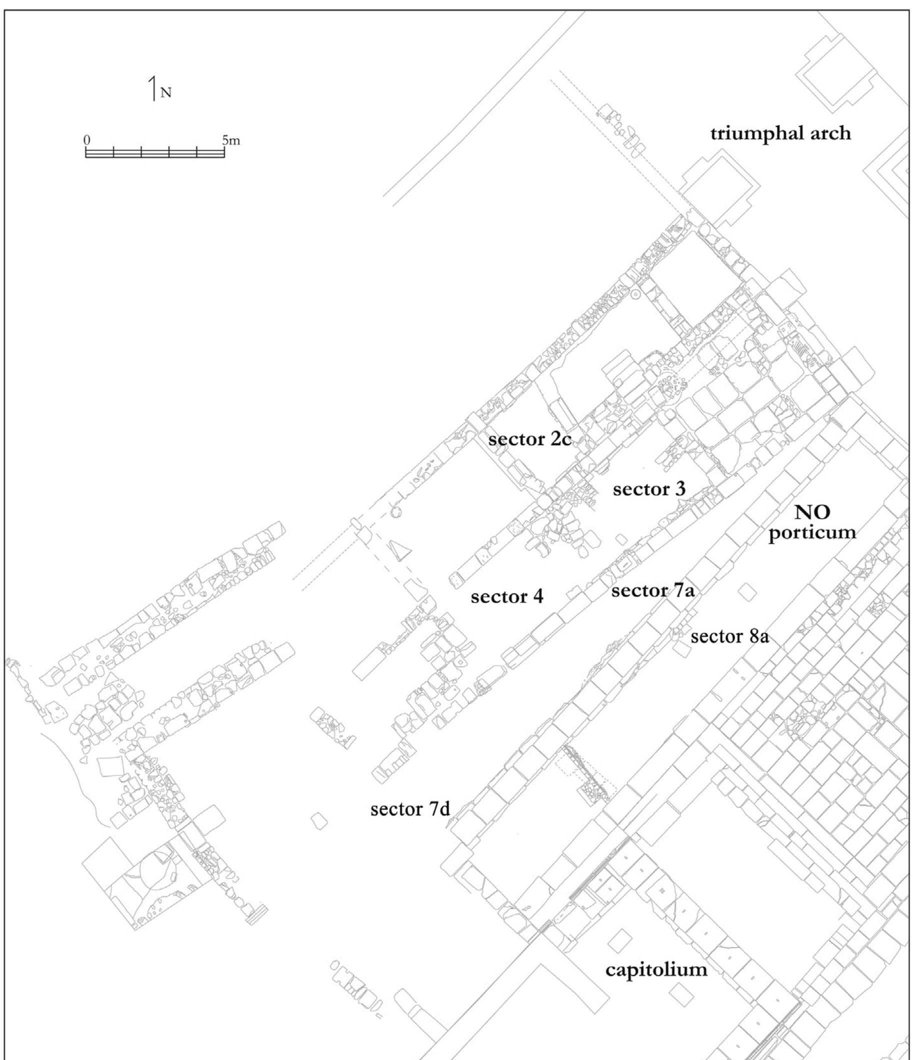

Fig. 2. General plan of the site showing the locations of the excavation areas (zone 2, northern edge of the *capitolium*).

1.1. Research area

The ethnoarchaeological study was conducted at the site area, now el Médéïna (meaning the "small town"), located in the High Tell region (Governorate of El Kef), less than 50 km from the Algerian border (Fig. 1). The High Tell region is characterized by a succession of alluvial plains, valleys and *plateaux*, with an average altitude of 700 m.a.s.l. At present the landscape is open due to deforestation. The area receives ca. 400–600 mm of annual rain on average, with high annual variability (El Kef rainfall station), and is situated within the continental Mediterranean climate belt, with wet winters and dry summers (average temperatures around 7.3 °C in winter and 26.5 °C in summer) (Kallala and Sanmartí, 2011). The economic production of the area is based on cereal agriculture, although small permanent rivers in the valley also allow horticultural crops, in addition to livestock farming of ovicaprines and cattle. Rain-fed arable crops include primarily free-threshing wheat and barley, and yields are subject to high year-to-year variation (Latiri et al., 2010).

Our research was carried out in two small villages, El Souidat and Gouasdya (about 10 km from Dahmani), both inhabited by families of the *Ouarten* tribe that maintain a certain traditional way of life in many aspects. *Ouarten* families subsist on farming, mostly sheep and goats, and cows to a lesser extent, in addition to cereal agriculture. Their diet is based on cereals prepared in a wide range of ways, and commonly accompanied by legumes and vegetables, whereas meat and eggs are consumed to a lesser extent. Traditional households commonly comprise a main house for a nuclear family and separate houses for married sons and their families. Households include central courtyards where varied activities are carried out daily, as well as small vegetable back-gardens, cooking and storage installations, and livestock pens (Fig. 3). Electricity was only introduced recently, and they do not benefit from running water.

1.2. The site

Althiburos is a multi-period urban settlement site, mainly known as a Roman city. It is located on a relatively large plateau (about 28 ha) surrounded by limestone hills and defined by the courses of the Wadi el Médéïna and the Sidi Baraket streams (Fig. 1). Recent excavations close to the *capitolium* have revealed a complete occupation sequence dating from the Early Numidian phase (10th–8th century cal BC) to the Middle Ages. Ongoing research focuses on the formation and development of Numidan states, about which little is known archaeologically (Kallala and Sanmartí, 2011; Sanmartí et al., 2012). Ancient Numidians followed economic strategies based on mixed farming practices which integrated cereal agriculture, wheat (*Triticum aestivum/durum*) and barley (*Hordeum vulgare*), and to a lesser extent emmer wheat (*T. dicoccum*) and common millet (*Panicum miliaceum*), legumes including lentils (*Lens culinaris*) and peas (*Pisum sativum*), and fruits such as vine (*Vitis vinifera*) and figs (*Ficus carica*), in addition to husbandry, sheep (*Ovis aries*), goats (*Capra hircus*), cattle (*Bos taurus*), and pig (*Sus domesticus*) (Kallala and Sanmartí, 2011; López-Reyes and Cantero, 2016; Valenzuela, 2016).

Two main types of cooking installations have been reported in the field as hearths and ovens. Such broader categories show many variants in size and shape. Interestingly, some of these features were cylindrically-shaped and described as mud ovens similar to modern *tabounas* (Kallala et al., 2008; Ramon and Maraoui, 2011).

2. Materials and methods

2.1. Ethnoarchaeological fieldwork and modern materials

Fieldwork was carried out during the summers of 2008, 2010 and 2014 (periods of around 7–10 days per year) and included

Fig. 3. Livestock dung management, storage and fuel use at El Souidat, June 2010. a) Household surrounded by open-air dung drying spaces. Arrows point at the location of main penning areas. The inset (b) shows a detail of swept areas. c) Livestock dung storage structures, locally called *Kamur*, close to drying spaces. d–e) *Tabouna* ovens usually located outdoors close to penning areas; note the placement of a *tabouna* in use within a pen in the same household (e).

ethnographic observations, informal interviews and sampling materials from rural communities from site vicinity, in which traditional non-mechanized farming practices on the verge of extinction are still common. This study builds on previous work on livestock dung materials, including burned sheep/goat pellets from a *tabouna* oven from Gouasdya (Portillo et al., 2012). The present work enlarges the study of dung exploitation, management and storage, as well as waste disposal and cooking and baking activities with the sampling of new fuel materials from El Souidat. The samples examined comprised ovicaprine fresh dung from a pen in the same household, non-burned mixed fuel, burned dung pellets within a *tabouna* oven, fuel ashes from its bottom part, and fuel trash residues stored in a metal bin (Table 2). Additionally, we conducted time and temperature measurements in the same *tabouna* installation (El Souidat, June 2014, Fig. 4). Temperature along the cooking activity, in this case bread (*Khobz*) baking, was recorded every few minutes using a portable digital thermometer (Dostman Serie P615) equipped with two detectors: one was placed within the burning dung fuel at the bottom; the second as close as possible to the oven's wall, in order to record the baking temperature (Figs. 4a and 5). Note that a few branches of woody shrubs growing in the same location were used for lighting the fire.

2.2. Archaeological materials

Eighteen archaeological samples were selected for phytolith and calcitic microfossil studies (Table 1). The contexts investigated here belong to the excavation area located in the northern edge of the *capitolium* (zone 2, Fig. 2) and to different occupation phases, from the Early Numidian (sub-phases EN2: 9th century BC, and EN 3: 8th–early 7th century BC) to the last centuries BC (Late Numidian phases, LN1: 4th–mid 2nd century BC, and LN2: mid 2nd–1st century BC), thus offering the opportunity to learn more about fuel use and food processing activities through time. These contexts were described in the field as combustion fillings and fire installations corresponding to six well-defined hearths and two ovens (Belarte, 2011; Ramon and Maraoui, 2011). Eight control sediment samples from their vicinity were also analyzed for comparative purposes. Samples were taken during the 2007, 2008, 2009 and 2014 excavation seasons.

The hearths examined differed in diameter and shapes (round/ovoid). They were built from alluvial pebble layers, or had a foundation surface of compacted clay material. All six hearths were covered by gray ashy sediments that included wood charcoal and charred seeds (Belarte, 2011; Ramon and Maraoui, 2011) (Table 1, Fig. 6a–b). Like the ethnographic installations, ovens were

Table 1
Location and field descriptions of sediment samples from ovens (FR), hearths (FY) and *in situ* vase (VP), including control samples (C) from their vicinity (Early Numidian sub-phases EN2: 9th century BC and EN3: 8th–early 7th century BC; Late Numidian sub-phases LN1: 4th century–146 BC and LN2: 146–27 BC).

Feature	Sector	Phase	Unit-Sample	Description
FR2640	4b	LN2	2641	Ashy black upper fill with abundant charcoal, varied seeds, faunal remains and pottery
			2692	Soft ashy oven fill with abundant charcoal, seeds, bones and ceramic fragments
			2712	Soft ashy sediment with abundant charcoal fragments, bottom oven fill
			2670-C	Yellowish compacted sediment with lime nodules and pottery, SL 6070, control FR2640
FR270223	7a	LN1	270224	Oven fill containing *tabouna* pieces and charred seeds
			270219-C	Soft black pit fill with abundant charcoal, ash and seeds, control FR270223
FY2710	2d	EN3	2710	Ashy black sediment with abundant charcoal fragments
			2708-C	Compact gray–green sediments with ashes, varied pottery and animal bones, SL2708, control FY2710
FY270355	8a	LN1	270355	Ashy black sediment composed of charcoal
			270353-C	Light brown layer with lime nodules and clay material, control FY270355
FY280208	3–4	EN3	280208	Burnt stony and clay material with abundant charcoal, faunal remains and pottery
FY290401	3–4	EN2	290401	Ashy black sediment with abundant charcoal and pottery
			290412-C	Ashy black thick layer with ceramic fragments, control FY290401 and FY290416
FY290416	3–4	EN2	290416	Compacted burnt clay material and ceramic fragments
FY290411	3–4	EN2	290411	Compacted burnt clay material, about 5 cm thick
			290409-C	Compact gray–green sediments with ashes, varied pottery and animal bones, control FY290411
VP2069	7d	LN1	2075	Ashy black ceramic vase fill with abundant charcoal fragments and seeds
			2072-C	Soft black pit fill containing an *in situ* ceramic vase, composed of abundant charcoal, ash and seeds, control VP2069

Table 2
Provenance, description of samples and main phytolith, ash pseudomorph and dung spherulite results obtained from modern fuel samples.

Sample description	AIF (%)	Phytoliths 1 g of AIF (million)	Grass phytoliths (%)	Phytoliths weathering (%)	Multicelled phytoliths (%)	Ash pseudomorphs 1 g of ashed material (million)	Spherulites 1 g of ashed material (million)	Ratio ash pseudomorphs/ spherulites
Sheep/goat fresh dung from livestock penning	41.1	135.9	91.3	5	32.5	0.5	529	0.001
Non-burned mixed ovicaprine dung/woody (*Marrubium*) *tabouna* fuel	32	100.6	90.3	4.3	22.3	0.15	338	0.005
Sheep/goat fuel from a *tabouna* oven, close to upper wall	39.1	62.7	84.6	8.7	14.1	0.49	314	0.002
Sheep/goat fuel from a *tabouna* oven, bottom part	37.7	119.3	80.8	12.9	29.5	0.95	164	0.006
Trash burned fuel residues stored in a bin, close to *tabouna* oven	42	138.1	84.8	9.1	16.7	0.59	153	0.004

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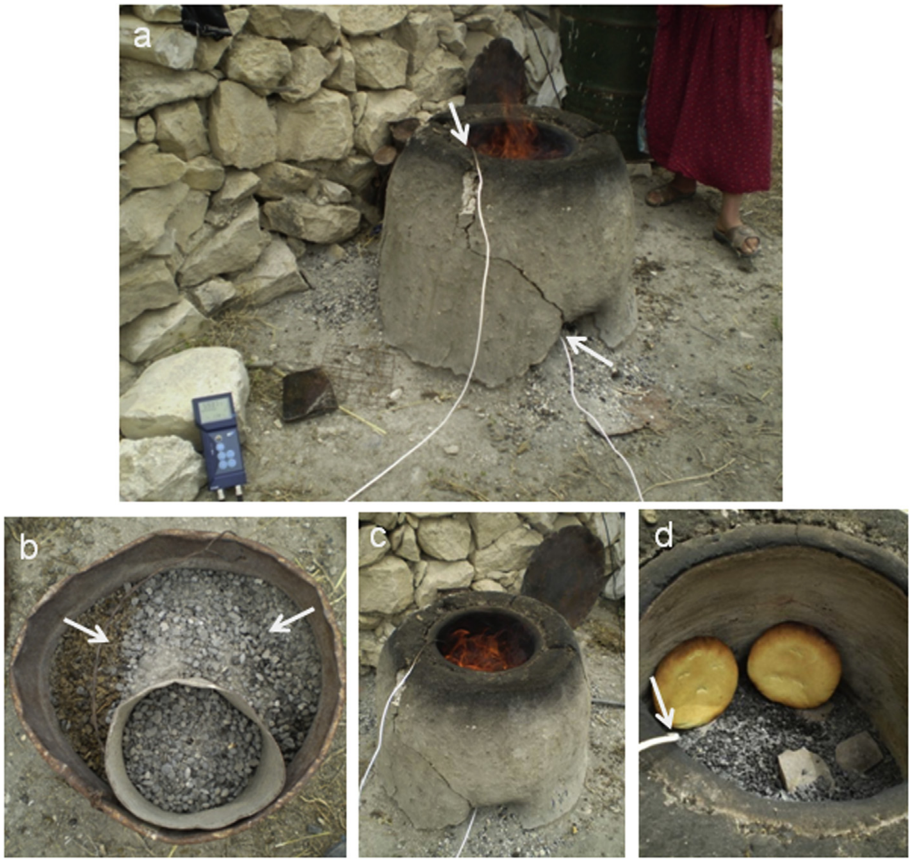

Fig. 4. a) *Tabouna* baking measurements, El Souidat, June 2014. Note the placement of the thermometer detectors (arrows): one within the burning fuel at the bottom ventilation hole, and the second as close as possible to the inner oven's wall in order to record the baking temperatures. b) A metal bin close to the oven containing a mixing of non-burned fuel (primarily ovicaprine dung, left) and the same type of burned-fuel material (right) re-used in the same installation. c) Initial stages of firing. d) Bread cakes (*Khobz*) being baked. Also note the placement of the thermometer detector (arrow).

cylindrically-shaped. Oven FR270223 (Late Numidian sub-phase, LN1) was described as a mud oven similar to modern *tabounas* (Ramon and Maraoui, 2011) (Table 1, Fig. 6c–d). Gray and/or white ash was found, with abundant macroscopic remains from charcoal, seeds and pottery fragments in their upper fillings, as well as concentrations of charred botanical remains at their bottom. A similar macroscopic composition was also attested in the filling of an *in situ* ceramic vessel found in an indoor domestic space that was

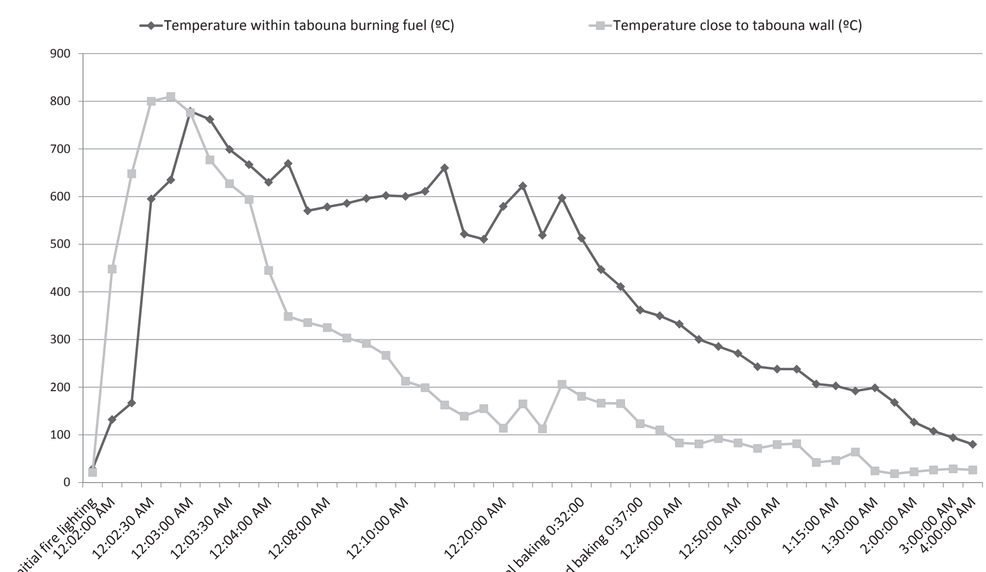

Fig. 5. Histogram showing the temperatures measured during the *Tabouna* baking using two detectors, within the burning fuel at the bottom and close to the oven's inner wall (temperatures in C° and time expressed in hh:mm:ss). Note that the baking started 30 min after the lighting and only took 5 min for baking 12 *Khobz* cakes.

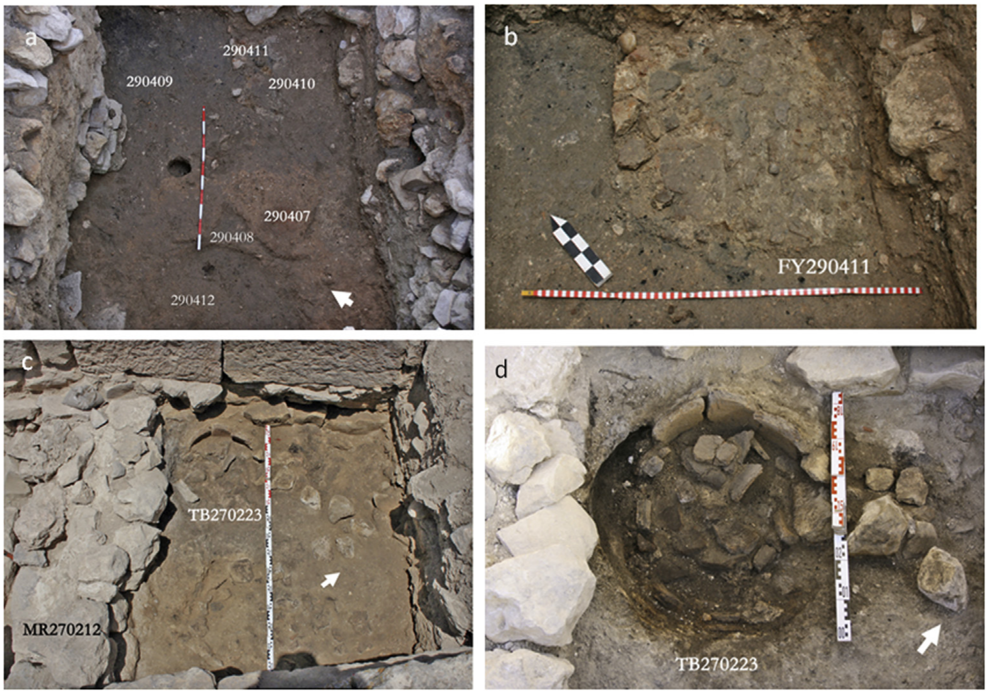

Fig. 6. a–b) Hearth FY290411, EN2; c–d) Mud oven FR270223, LN1. Extracted from Ramon and Maraoui, 2011: a–b) Figs. 4.58 and 4.59, pp. 224, a–b; c–d) Figs. 4.136 and 4.138, pp. 243.

interpreted by the excavators as a storage area (VP2069, sub-phase LN1) (Fig. 7). The latter is included here for the sake of comparison; it may relate to dumping episodes from nearby installations, and/or perhaps the storage of fuel remains, as observed in traditional households in the site area today.

2.3. *Phytolith analyses*

Phytolith extraction and quantitative analyses from archaeological and modern samples followed the methods of Albert et al. (1999). A weighed aliquot of 1 g of dried sediment was treated with an equivolume solution of 3 N HCl and 3 N HNO_3. Organic matter was oxidized with 33% H_2O_2. Phytoliths were concentrated using 2.4 g/ml sodium polytungstate solution [$Na_6(H_2W_{12}O_{40})\cdot H_2O$]. Microscope slides were mounted with 1 mg of dried sample using Entellan New (Merck). A minimum of 200 phytoliths with diagnostic morphologies were counted at 400×. Phytolith quantification was based on the acid insoluble fraction (AIF), which is the fraction that remains after the acid and peroxide treatment. AIF allows comparisons between samples independently of the diagenesis suffered by the sediment. Phytoliths that were unidentifiable because of dissolution were counted and recorded as weathered morphotypes. Morphological identification was based on modern plant reference collections from the Mediterranean area (Albert and Weiner, 2001; Tsartsidou et al., 2007; Albert et al., 2008, 2011; Portillo et al., 2014) and standard literature (Twiss et al., 1969; Brown, 1984; Piperno, 1988, 2006; Mulholland and Rapp, 1992; Rosen, 1992; Twiss, 1992). The terms used follow the International Code for Phytolith Nomenclature (Madella et al., 2005). Slides were examined using an Olympus BX41 optical microscope and digital images were taken with an Olympus Color View Ilu camera.

Fig. 7. *In situ* vase VP2069, LN1.

2.4. *Calcitic microfossils: dung spherulite and ash pseudomorph analyses*

The methods used are similar to those developed by Canti (1999). An accurately weighed amount of between 0.5 and 1 mg of dried sediment was placed on a microscope slide using a pipette. Slides were mounted using Entellan, as described above for phytoliths. Note that if the sediment is rich in clays or aggregates, they can be dispersed by sonication (Gur-Arieh et al., 2013). This was not necessary in the present study. Slides were examined at 400× magnification under the optical microscope with crossed polarized light (XPL) for spherulites, whereas pseudomorphs where examined in plane polarized light (PPL). Both microfossil numbers found in a known number of randomly chosen fields were recorded and then related to the initial sample weight. The initial weight in modern samples should be around 0.5 mg in order to avoid microfossil overloading.

The data of the ash pseudomorph and spherulite quantification were used to calculate ratio values, which may allow the distinction

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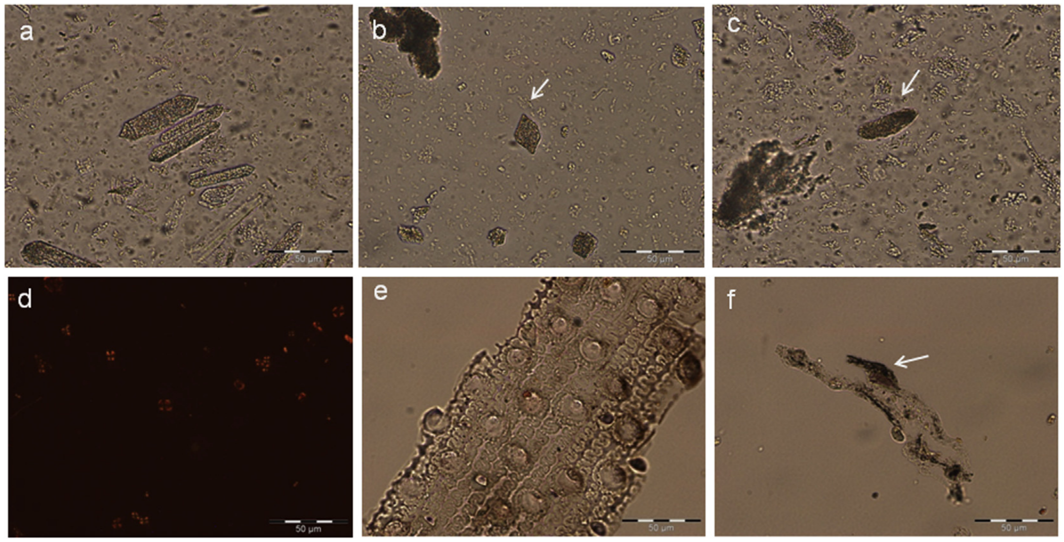

Fig. 8. Photomicrographs of phytoliths and calcitic microfossils identified in modern samples. The photographs have been taken at 400×. (a–b–c) ash pseudomorphs obtained from small branches, *Oued Mellègue,* NO Le Kef, June 2014: a) Aleppo pine (*Pinus halepensis*), b) mastic (*Pistacia lentiscus*), c) olive tree (*Olea europaea*); (d–e–f) microfossils obtained from modern fuel samples, El Souidat, June 2014: d) dung spherulites, e) multicellular structure of dendritic long cells with papillae from the husks of *Hordeum* sp., f) melted multicelled phytoliths from grasses.

between wood and dung-dominated ashes (Gur-Arieh et al., 2013, 2014). Additionally, ash pseudomorphs were compared to a pilot modern plant reference collection (Table 3, Fig. 8a–b–c). The selected species includes Aleppo pine (*Pinus halepensis*) and olive tree (*Olea europaea*), which were common in the Numidian layers' macro-botanical record (Kallala and Sanmartí, 2011; Cantero, 2016; López-Reyes and Cantero, 2016). Samples were processed by burning small dried branches in an oven furnace (at 550 °C for 4 h), after washing in deionized water and sonication for 10 min to remove external contamination. The estimated pseudomorph numbers is based in abundances per weight of ashed plant material.

exclusively the domain of women. The *tabouna* is usually built with soil mixed with organic materials (primarily chaff, agricultural by-products and dung). Most households have their own out-doors ovens for daily bread production. In addition to bread cakes (*Khobz*) preparation, these installations are used for cereal processing, including de-husking hulled barley by roasting. The main source of fuel is air-dried ovicaprine dung pellets.

Livestock penning supply a regular and predictable production of dung, which can be exploited by these communities in many ways, including fuel, in addition to manure and building material. In summer, herds graze on cereal stubble in fallow agricultural

Table 3
Provenance, description of samples and quantities of ash pseudomorphs obtained from modern plant species.

Species	Family	Provenance	Ash pseudomorphs 1 g of ashed material (million)
Juniperus oxycedrus	Cupressaceae	Oued Mellègue	166
Marrubium sp.	Lamiaceae	Souidat	171
Olea europaea	Oleaceae	Oued Mellègue	226
Pinus halepensis	Pinaceae	Oued Mellègue	502
Pistacia lentiscus	Anacardiaceae	Oued Mellègue	569

Archaeological samples were compared to the modern fuel materials listed in Table 2. Modern dried dung pellets were also ashed in laboratory-controlled conditions (at 500 °C for 4 h using a muffle furnace). After ashing, all three microfossils (phytoliths and calcitic spherulites and pseudomorphs) from modern dung samples were treated and examined following the above-described methodology.

3. Results

The main results are described separately below.

3.1. Ethnographic observations

Traditional means of cooking and baking among *Ouarten* families are mud cylindrical *tabouna* ovens. These daily activities are

fields, and on wild vegetation in stream margins. Dung is left to dry in open-door spaces for a few days, usually close to penning areas, and once dried it is stored in specific stone-made installations, locally called *kamur*, primarily for winter fuel purposes (Fig. 3a-b-c). These materials are used for firing local pottery, which is female work as well. The sub-products of different domestic structures and various firing episodes can be re-used, and then discarded in trashing areas or used as manure in household gardens. Fresh dung pellets from cattle, but also from donkeys— depending on the wealth of the family, or on exceptional periods when such animals are needed (i.e. threshing crops) are used for plastering walls and floors. Threshing floors are also tempered during the summer with a mixture of fresh dung, chaff and water. Similar patterns concerning livestock dung exploitation have been reported in ethnographic studies conducted in western Maghreb (i.e. drying and storage, firing pottery, plastering walls and floors, container

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making, fertilizing) (Zapata et al., 2003; Peña-Chocarro et al., 2009, 2015).

3.2. Burning experiments and modern fuel materials

Fig. 5 shows temperature and time measurements obtained from the *tabouna* bread (*Khobz*) baking. The woody material used for lighting the fire produces a fast increase of temperature (up to 800 °C in a few minutes). Then, it stays relatively steady between 500 and 600 °C within the burning dung fuel placed in the bottom, and decreases to around 400 °C during the cooking time. The baking starts 30 min after the lighting, and it takes only 5 min to prepare 12 bread cakes. The bread is baked by placing *Khobz* cakes on the oven's inner walls (Fig. 4d). Temperatures measured within the oven's wall decreased much faster, and were around 100–150 °C during the cooking process. Thus, temperatures were measured also after the baking was completed. Fuel within the oven's bottom was about 200 °C 2 h later. This data is consistent with previous experiments conducted in Uzbekistan by Gur-Arieh et al. (2013), on mud traditional installations using different fuel materials (wood, mixed cow/sheep-goat dung cakes and mixed wood/dung). Similar observations have been made on *tannur* baking measurements within the burning fuel in the Upper Khabur (northeastern Syria), where the main fuel source is woody material from cotton production, while ovicaprine dung is only residually used (Portillo et al., 2014).

Samples obtained from the same *tabouna* installation and fuel materials, including ovicaprine fresh dung, non-burned mixed wood material for the initial fire lighting, burned pellets, dung ashes and trash paths, were also examined (Table 2). Concentrations of all three types of micro-remains (phytoliths, spherulites and ash pseudomorphs) vary significantly between burned and non-burned fuel materials. Phytoliths were abundantly identified in all samples (over 100 million phytoliths in 1 g of AIF in most of the samples, Table 2). Most of these microfossils belonged to a livestock early summer grass-rich diet (agricultural by-products, primarily from barley, Fig. 8e). In general, phytoliths were well preserved and noted in anatomical connection (multi-celled phytoliths constitute between 14 and 32%), but with a higher dissolution degree in burned samples (phytoliths weathering reaching around 13% in ashes form the oven bottom). Phytoliths showing evidence for partial melting, resulting in deformations due to high temperatures (although the morphology of most original cells may be preserved and therefore identified, Fig. 8f) were also observed. These were common in samples from the oven's bottom and from the stored burned fuel residues located in a metal bin for re-use purposes (Fig. 4b). As expected, strong differences were noted between the calcitic microfossil abundances. Accordingly to previous studies showing that spherulite concentrations are particularly high in fresh dung ovicaprine pellets (over 500 million spherulites per gram of ashed dung, Table 2), much smaller amounts were found in ashy fuel remains (about 300 million in the upper part, and around 100 million spherulites 1 g of sediment in the bottom and stored remains for re-use). It should be noted that dung spherulites are well preserved at temperatures lesser than ~650–700 °C (Matthews, 2010; Shahack-Gross, 2011). In contrast, all samples contained low amounts of pseudomorphs (related both to the animal's diet– barley chaffs, and the dung-dominate fuel type). Pseudomorphs included druses and prisms, as well as rhombs to a lesser extent. The calculation of the pseudomorphs/spherulites ratios showed distinctive low values (around 0, Table 2), which in conjunction with large phytolith concentrations are characteristic of rich-dung ashes, according to quantitative models proposed by Gur-Arieh et al. (2013, 2014).

Additionally, modern samples from small branches of selected woody species were also analyzed for comparative purposes. Table 3 details all the analyzed woody species according to their different families and provenance, with indication of the number of ash pseudomorphs per gram of ashed organic material. Ash pseudomorph abundances were relatively high in most of the samples (over one hundred million pseudomorphs per 1 g of ashed material). Pseudomorphs included prismatic crystals and occasionally druses; and, significantly, no raphides or styloids, which are commonly produced by monocotyledonous plants. The results of this pilot study are also in agreement with published data (Wattez and Courty, 1987; Brochier, 1996; Brochier and Thinon, 2003; Canti, 2003). Interestingly, fresh ashes of Aleppo pine (*Pinus halepensis*) showed abundant characteristic large and regular-shaped rhomboids (ranging 15–50 μm long and 2–5 μm width, Fig. 8a). The presence of such characteristic elongated prisms in *Pinus* has been previously reported (Brochier and Thinon, 2003, and references therein). These morphologies were also commonly observed in our archaeological samples. It should be noted that Aleppo pine is the most common woody species in the Numidian occupation of the site (Cantero, 2016). These rhomboids were larger than those noted in *Juniperus oxycedrus* and *Pistacia lentiscus* (ranging 10–25 μm long), but also in *Olea europaea* (around 10–35 μm long and 3 μm width, Fig. 8b–c). These later genera are also present in the archaeological charred assemblages.

3.3. Archaeological results

Table 4 shows the location and field descriptions of the samples analyzed, together with the quantitative phytolith and calcitic microfossil results (ovens– FR, hearths–FY, *in situ* vessel–VP and corresponding control samples–C). The mineralogical results, which are expressed as the acid insoluble fraction, showed a similar mineralogical distribution (AIF average around 26%, Table 4), indicating that carbonates, phosphates and other non-siliceous materials were major components of the sediments examined. Phytoliths, ash pseudomorphs and dung spherulites were noted in different amounts in all the samples, with two exceptions, control samples 2670-C and 290412-C (from the vicinity of two installations, FR and FY respectively), where calcitic microfossils were scarce or even absent.

Phytoliths were abundant in most of the samples (from 1 to 71 million phytoliths per gram of AIF, Table 4). The only exceptions are again control samples 2670-C and 290412-C, in addition to hearths FY290411 and FY290416, which yielded a lesser amount (400–700.000 phytoliths/1 g of AIF). These latter hearth samples, belonging to the Early Numidian phase, were composed of compacted burnt clay material and also showed a higher dissolution index of phytoliths (16–19%). Partially melted phytoliths, which were common in our modern *tabouna* fuel ashes, were also observed in the bottom filling oven sample 2712 (oven FR2640). The morphological results indicated that grasses dominated in most of the samples with around 70–80% of all the counted morphotypes (Table 4), whereas wood, bark and dicotyledonous leaf phytoliths constitute around 5–10% of the assemblages. Multicellular structures– multi-celled or interconnected phytoliths, from both floral parts of cereals, primarily wheat and barley (Fig. 9a), and the leaves and the stems of grasses (Fig. 9b–c), were also noted in most of the samples in different amounts. Again, it is worth noting here that multi-celled phytoliths were not observed in those samples with the highest rate of dissolution (FY290411 and FY290416, Table 4). In contrast, samples corresponding to fillings yielded multi-celled phytoliths in higher amounts (around 10–20%).

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Table 4
Location and main phytolith, ash pseudomorph and dung spherulite results obtained from ovens (FR), hearths (FY) and *in situ* vase (VP) sediments, including control samples (C) from their vicinity.

Feature	Unit- sample	AIF (%)	Phytoliths 1 g of AIF	Grass phytoliths (%)	Phytoliths weathering (%)	Multicell phytoliths (%)	Ash pseudomorphs 1 g of sediment	Spherulites 1 g of sediment	Ratio ash pseudomorphs/ spherulites
FR2640	2641	23.1	28.900.000	82.2	12.2	14.2	520.000	2.080.000	0.25
	2692	28.9	55.600.000	81.9	10.5	17.9	340.000	332.000	1.02
	2712	32.3	38.300.000	78.8	14.1	18	2.290.000	306.000	7.48
	2670-C	14.8	470.000	73.2	16.1	5.1	0	0	0
FR270223	270224	26.4	27.100.000	85.7	6.1	4.7	191.000	58.000	3.29
	270219-C	29.5	50.500.000	83.8	8.3	23	40.000	13.000	3.08
FY2710	2710	22.3	25.000.000	85.3	8	2.3	130.000	69.000	1.88
	2708-C	29.7	22.000.000	72.6	17.9	8.4	322.000	610.000	0.53
FY270355	270355	30.7	53.500.000	89.6	6.1	16.7	272.000	148.000	1.84
	270353-C	24	6.300.000	88.6	4.9	7.2	18.000	54.000	0.33
FY280208	280208	20.9	5.700.000	82.5	9.8	15.4	111.000	230.000	0.48
FY290401	290401	33.4	1.100.000	80	9.9	2.1	193.000	331.000	0.58
	290412-C	21.7	560.000	85.6	7	9.5	0	36.000	0
FY290416	290416	28.2	397.000	71	16.3	0	20.000	99.000	0.20
FY290411	290411	30.9	781.000	65.8	19	0	52.000	350.000	0.15
	290409-C	29	17.800.000	81.5	10.3	4.3	78.000	410.000	0.19
VP2069	2075	36.1	71.100.000	83.7	8	8.9	85.000	2.900.000	0.03
	2072-C	19.6	27.300.000	74.1	17.5	8.2	2.700.000	496.000	3.08

Concentrations of ash pseudomorphs range between 18.000 and 2.7 million per 1 g of sediment (Table 4). Again, control samples 2670-C and 290412-C were the only exceptions. Samples 2712 and 2072, from oven (FR2640) and vessel fillings (VP2069) respectively, were by far the richest (over 2.2 million/1 g of sediment). Pseudomorphs included mostly prisms and rhombs. These latter were morphologically similar to those observed in our *Pinus halepensis* reference samples obtained from burned branches (Fig. 9e). In turn, dung spherulites were noted also in all samples, again with the exception of control sample 2670-C. Concentrations of dung spherulites constitute between 13.000 and 2.9 million per 1 g of sediment (Table 4, Fig. 9f). The richest samples corresponded to oven (FR2640, sample 2641) and vase fillings (VP2069, sample 2075).

The data obtained from ash pseudomorph and spherulite absolute numbers were then used to calculate ratio values, following the quantitative models developed by Gur-Arieh et al. (2013, 2014). The results indicated distinctive low values (around 0) in most of the samples within installations (n = 6), which can be interpreted as dominated by dung ash. Most of our control samples from the vicinity of the same installations showed similar ratio values around 0 (n = 4). These values are consistent with modern dung fuel standards obtained from ethnoarchaeological research in central Asia (Gur-Arieh et al., 2013), as well as our reference *tabouna* fuel materials from the site area, as previously argued. In contrast, only one of the samples showed values higher than 5 and can be confidently interpreted as dominated by wood ash (oven FR2640, sample 2712). Based in further dissolution experiments conducted by Gur-Arieh et al. (2014), the so-called "gray area" may indicate either well-preserved ashes composed of dung mixed with wood, or partially dissolved dung ashes. This is the case for the rest of our samples within installations with ratio values around 1–3 (n = 4), and some of the control samples as well (n = 2). Our results reveal that most of the sediments examined within installations are

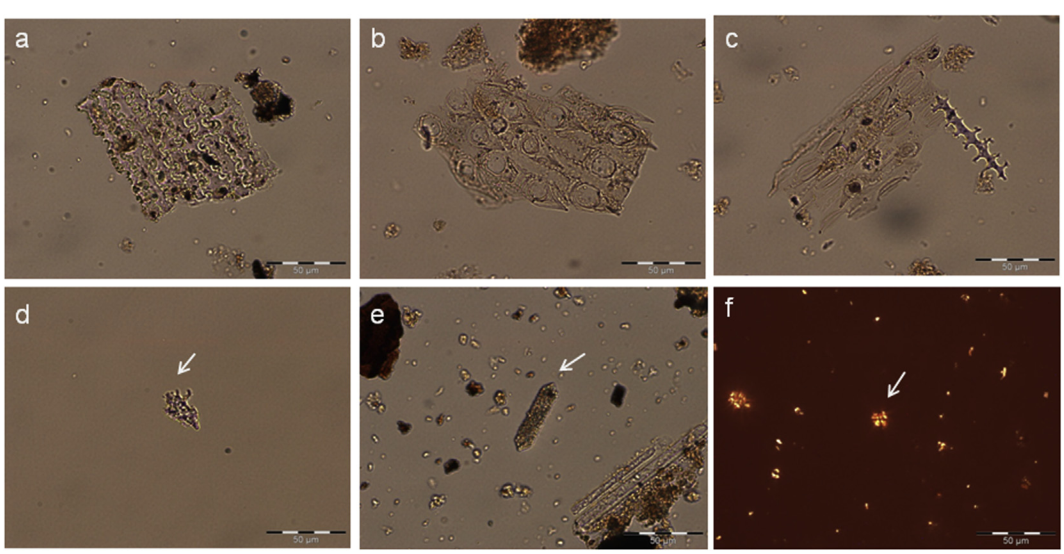

Fig. 9. Photomicrographs of phytoliths and calcitic microfossils identified in archeological samples (at 400×). a) multicellular phytoliths of dendritic long cells with rondels from the husks of *Hordeum* sp., b) multicellular phytoliths with hairs form grass leaves/stems, c) multicellular phytoliths with hairs and stomata cells from grass stems, d) weathered phytolith, e) ash pseudomorph resembling to *Pinus* morphologies, f) dung spherulite.

composed by dung ash, in addition to mixtures of well-preserved dung and wood or partially dissolved dung-dominated ash.

4. Discussion

Two general issues have been addressed in this study: i) establishing the nature of fuel sources, preservation and formation processes; ii) tracing fuel use and domestic activities (i.e. food processing, storage, dumping) at Numidian Althiburos through time. These overall trends are discussed below.

In this study, using microfossil plant evidence from phytoliths and wood ash pseudomorphs, in addition to dung direct indicators from spherulites, we were able to identify fuel sources. The presence of spherulites within all installations examined confirms that the use of dung as fuel was practiced in all the studied occupation phases, covering most of the first millennium BC (at least from the 9th to the 1st centuries BC). However, the range of results obtained from the absolute quantities of calcitic micro-remains, particularly ash pseudomorphs to dung spherulites, shows significant differences between both main types of studied installations, ovens (FR) and hearths (FY).

Our ethnographic observations revealed that the choice of dung for fueling in traditional mud ovens (both for cooking and firing pottery) is a common practice followed by *Ouarten* families living at the site area today. The modern materials examined and the baking temperatures recorded from such cooking installations provided a reference assemblage for dung-dominated fuels. One of the main traits noted is that both plant and fecal microfossil abundances are significantly lower in archaeological assemblages compared to modern dung fuel materials. This general pattern is consistent with data obtained from ethnoarchaeological studies that have followed similar quantitative approaches (Tsartsidou et al., 2008; Portillo et al., 2012; Gur-Arieh et al., 2013; Portillo et al., 2014). This is especially true for calcitic micro-remains, both dung spherulites and wood ash pseudomorphs, which are dramatically lower in archaeological ashes compared to modern ashes (Gur-Arieh et al., 2014).

In previous studies we have addressed particularly the case of one of these cooking/baking installations described as a mud oven similar to modern *tabounas*, dating to the Late Numidian sub-phase LN1 (FR270223, 4th–2nd century BC, Fig. 6c–d). The oven filling contained *tabouna* pieces, ashy sediments and abundant macro-botanical remains. In the same domestic context, findings from a small pit located near the oven yielded abundant concentrations of free-threshing wheat (*Triticum aestivum/durum*), and hulled barley (*Hordeum vulgare*) seeds to a lesser extent (Kallala et al., 2008; Ramon and Maraoui, 2011; López-Reyes and Cantero, 2016). The morphometric study of distinctive dendriform phytoliths from both oven and pit fillings, allowed the identification of the processed cereal as bread wheat (*T. aestivum*) (Portillo and Albert, 2011). Consistently with this previous study, the microfossil data reported here indicated that oven fillings are also composed by mixtures of dung and wood or partially dissolved dung-dominated ash. This is consistent with findings from charred macro-botanical weeds and legumes, which are commonly related to livestock feeding (i.e. *Medicago* sp., *Melilotus* sp.) and woody specimens such as *Ficus carica* and *Vitis vinifera* in the same oven fillings. The leaves of these later species are also used as leafy hay by modern rural communities in the western Maghreb, and the slow burning temperatures of *Ficus* wood are appreciated for firing pottery, while dried vine branches are also used in bread ovens as fuel (Zapata et al., 2003). Interestingly, flotation samples also provided direct evidence from a well-preserved charred ovicaprine dung pellet (López-Reyes and Cantero, 2016). Similar to the modern mud constructed cooking installations from the site area, it was fueled with dung (likely ovicaprine) and perhaps also mixed dung-wood. The use of this oven can be related to baking and cereal processing (i.e. dehusking hulled cereals).

A recent microarchaeological study on cooking installations from Late Bronze and Iron Age Levantine contexts has proved that the use of dung as fuel was practiced in both periods, although wood-dominated fuel material was the most common source (Gur-Arieh et al., 2014). This is also the case of the second oven installation examined in this study (FR2640), which was excavated in 2014. Oven FR2640 is dated to the Late Numidian (LN2, mid 2nd–1st century BC). Interestingly, the stone wall in direct contact with the installation showed evidence of burning on its surface, thus indicating its exposure to flames. The upper filling included abundant faunal and vegetal charred remains, especially cereal seeds (sampled for further zooarchaeological and archaeobotanical analyses), varied pottery fragments, building material and large concentrations of dung micro-remains. On the contrary, the bottom fill did not provide evidence of pottery or bones, but it was composed of abundant charred wood pieces. Our results showed high concentrations of pseudomorphs, indicative of wood-dominated ash. Interestingly, their morphologies compared favorably to Aleppo pine (*Pinus halepensis*) pseudomorphs. The results from the macro-botanical dataset may confirm the use of pinewood within the installation. In addition, evidence from partially melted phytoliths (indicative of high temperatures, above 700 °C, for a long time exposure) was also noted within the oven bottom filling. Their presence may provide some insights into burning temperatures within the installation. Partial melting of phytoliths was also noted in our modern *tabouna* fuel residues, both within the bottom of the installation, as well as within the burned fuel stored in a metal bin for re-use purposes placed close to the oven (Fig. 4b). As previously argued, maximal temperatures reached around 800 °C in the initial fast firing, related to the use of woody material, and between 700 and 600 °C during the following 30 min (Figs. 5 and 8f). In the above mentioned study on Levantine cooking installations, Fourier Transform Infrared spectroscopy (FTIR) indicated that within the so-called "Canaanite ovens" maximal temperatures ranged between 500 and 900 °C, and that they were operated in a similar way to most *tannurs* in the Levant, that is, internally fueled (Gur-Arieh et al., 2014). Previous ethnographic research in the Upper Khabur (northern Syria) showed that modern *tannurs* are operated similarly (from their interior) and fueled with wood-dominated materials (primarily cotton branches), whereas ovicaprine dung sporadically used within the installations bottom. The recorded baking temperatures were above 600 °C (Portillo et al., 2014).

Another point to emerge from this study is the presence of dung-dominated ashes in most of the hearths examined belonging to different site areas and occupational phases, regardless of their morphological characteristics. Most of the hearth assemblages yielded plant charred remains. In contrast, animal bones were scarce or completely absent in these domestic installations, thus indicating that bones were not used as fuel, and not even discarded into the fire (Portillo et al., 2012). Because all of the installations examined here included direct microfossil evidence from dung spherulites, we conclude that the use of fecal material for fuelling hearths was a common practice in the Numidian settlement through time. The results reported here show that only two of the studied installations indicate either mixed wood-dung fuel and/or partially dissolved dung-dominated ashes (FY2710 and FY270355, NA3 sub-phase and NR1 sub-phase, respectively, Table 1). Here again, the noted calcitic rhomboid microfossils compared favorably to Aleppo pine (*Pinus halepensis*) pseudomorphs common in our modern plant reference material. It should be noted that the charred-wood dataset obtained from combustion installations and related filling deposits revealed that *P. halepensis* was the most

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common source of fuel plant material in the Numidian settlement through all its occupational phases (Cantero, 2016). Findings from other woody species, including juniper (*Juniperus* sp.) and olive tree (*Olea europaea*), were also noted in hearth assemblages from the Late Numidian phase (LN1), although to a lesser extent. According to our ethnographic observations, olive wood is commonly used for building materials and crafts (i.e. for the central piece of rotary querns). A similar use is reported in the Moroccan Rif, although dead wood may be used for fuel as well (Zapata et al., 2003). In order to explore wood fuel use, further research will address burning experiments and sampling in modern traditional ovens used for pine nut exploitation following a similar methodological approach. Although it is no longer common in the site area due to deforestation, *P. halepensis* occupies more than 56% of the total forested area of Tunisia (around 297.000 ha, Sghaier and Ammari, 2012), mostly in its northwest and central parts. Aleppo pine plays a major ecologic, economic and social role in this country. It is exploited for wood and seeds, and its so-called *zgougou* nuts are widely consumed (Morales et al., 2015).

As previously argued, a key question is whether the assemblages examined represent originally *in situ* remaining burnt fuel of the last use/s of the installations, or rather post-abandonment dumping events. This is especially important in such type of features whose closed structure may allow secondary uses as bins. This may be the case at least of the upper oven fillings, characterized by typical fill-like materials related to household domestic waste (i.e. animal bones, charcoal, seeds, building materials and ceramics), in addition to dung material, as described above. It is clear that micromorphological analyses would provide clues to a more detailed interpretation, thus defining indicators that may be useful in assessing the integrity of the fill sediments associated to the cooking installations, including preservation. They may also provide an insight into whether or not ashes were formed *in situ*. As pointed out by micromorphological evidence, both installation type (hearths *vs* ovens or walled features) and location (in-door *vs* outdoor), in addition to burial conditions (fast *vs* slow) may determine microfossil preservation. We therefore assume that walled (ovens or walled features, such as ceramic vessels and bins) and in-door installations may be less exposed to dissolution, and microremains may be better preserved, as noted in recent studies (i.e. Gur-Arieh et al., 2014; Kadowaki et al., 2015). The last case exposed here addresses some insights regarding preservation questions, in addition to storage and dumping fuel behaviors.

We also examined the filling sediments of an *in situ* large ceramic vessel (VP2069) from an indoor space that is described as a storage area by the excavators, since another large pottery container was also found within it (Fig. 7). It is dated to the Late Numidian (LN1, 4th to mid-2nd century BC). VP2069 was especially rich in charred remains, particularly seeds. The vase itself was deposited in a pit, whose fillings were also examined for comparative purposes. Both were reported in the field as ashy black fill sediments with abundant charcoal fragments and well-preserved seeds, primarily from crops. The macro-botanical dataset from both vase fillings is dominated by *Hordeum vulgare* and *Triticum aestivum/durum*, in addition to weeds and legumes (i.e. *Lens culinaris*, *Vicia faba*, *Medicago sativa*, *Melilotus* sp.) and fruit seeds that include *Ficus carica* and *Vitis vinifera* (López-Reyes and Cantero, 2016). Well-preserved charred cereal stems were also noted, in addition to clusters of complete charred ovicaprine dung pellets. These fillings were also rich in microfossil evidence from dung spherulites. Additionally, our phytolith results indicate concentrations of multi-celled or interconnected phytoliths, from both floral parts of cereals, primarily wheat and barley, and from leaves and the stems as well (Fig. 9a–b–c), with a low dissolution rate. Overall, these findings indicate that the vase filling corresponds to well-preserved dung-dominated ashes with abundant charred plant material, mostly related to agricultural crops and their subproducts. These assemblages provide us with a good example of the excellent preservation conditions inside close walled-indoors. In contrast, the associated pit fillings showed a higher phytolith dissolution rate, in addition to evidence of partial melting, which is indicative of exposure to high temperatures. Additionally, dung spherulite abundances decreased dramatically and charred ovicaprine dung pellets were not present either. Both micro and macrobotanical remains were similar to the vase fillings, in addition to concentrations of wood ash pseudomorphs, which are indicative of dung fuel and mixed wood-dung material and/or partially dissolved dung-dominated ashes; the latter may be the case outside the vase. In general, the vase fillings examined compare favorably to the above-described oven *tabouna* assemblages from the same Late Numidian phase. We conclude that the context examined may relate to dumping episodes from nearby firing installations (likely including domestic ovens) and/or perhaps the storage of fuel remains for burned fuel use purposes (i.e. manure, fuel re-use), as observed in traditional households in the site area and in other areas of the Maghreb today (Zapata et al., 2003).

5. Conclusions

These studies have shown how phytoliths and calcitic microfossil associations (dung spherulites in addition to wood ash pseudomorphs) provide direct evidence from the nature of fuel matter in a selection of cooking installations from Numidian Althiburos, primarily ovens and hearths. The results indicated different types of fuel sources: livestock dung (at least from ovicaprines), wood (mainly *Pinus halepensis*), and a mixing of dung and vegetal matter (wood and agricultural by-products). Dung was used as source of fuel material across time (at least from the 9th to the last centuries BC), and in different site areas and types of cooking installations, both hearths and ovens.

Additionally, this study examines ways in which ethnoarchaeological approaches contribute to addressing taphonomic issues, which are fundamental for interpreting archaeological contexts. Our ethnographic study shows that the temperatures recorded within *tabouna* oven dung-fuels reached around 800 °C in the initial firing, related to the use of woody material in the lighting, and decreased to 600–700 °C during most part of the cooking activity. The modern materials examined from the same oven installation provided a reference assemblage for dung-dominated fuels (i.e. partial melting of phytoliths which were also noted in archeological oven samples and indicative of high combustion temperatures in such walled installations).

We have also addressed a comparative case of vase fillings containing abundant well-preserved mixed wood-dung material from an in-door building space. This latter context may relate to dumping and/or perhaps the storage of fuel remains for re-use or fertilizing, common practices also observed in modern households. We therefore conclude that installation type (hearths/ovens or walled features, such as ceramic vessels and bins) may determine both micro and macro-remains preservation. Although depending on burial conditions and other post-depositional processes, it is clear that potentially walled and indoor installations may be less exposed to dissolution and microfossils may be better preserved.

The results reported upon here demonstrate the value of integrating microarchaeological and ethnoarchaeological techniques to traditional macroscopic archaeological research. We assume that, despite present-day conditions are not completely analogous to those of past times, ethnoarchaeological approaches provides us with a reference framework for better understanding farming practices in this still poorly investigated region in northern Africa.

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References

Albert, R.M., Cabanes, D., 2007. Fire in prehistory: an experimental approach to combustion processes and phytolith remains. Israel Journal of Earth Sciences 56, 175–189.

Albert, R.M., Weiner, S., 2001. Study of phytoliths in prehistoric ash layers using a quantitative approach. In: Meunier, J.D., Colin, F. (Eds.), Phytoliths, Applications in Earth Sciences and Human History. A.A. Balkema Publishers, Lisse, pp. 251–266.

Albert, R.M., Lavi, O., Estroff, L., Weiner, S., Tsatskin, A., Ronen, A., Lev-Yadun, S., 1999. Mode of occupation of Tabun Cave, Mt Carmel, Israel during the Mousterian period: a study of the sediments and phytoliths. Journal of Archaeological Science 26, 1249–1260.

Albert, R.M., Bar-Yosef, O., Meignen, L., Weiner, S., 2000. Phytoliths in the Middle Paleolithic deposits of Kebara cave, Mt. Carmel, Israel: Study of the plant materials used for fuel and other purposes. Journal of Archaeological Science 27, 931–947.

Albert, R.M., Bar-Yosef, O., Goldberg, P., Meignen, L., Weiner, S., 2003. Phytolith and mineralogical studies of hearths from the Middle Paleolithic levels of Hayonim cave (Galilee, Israel). Journal of Archaeological Science 30, 461–480.

Albert, R.M., Shahack-Gross, R., Cabanes, D., Gilboa, A., Lev-Yadun, S., Portillo, M., Sharon, I., Boaretto, E., Weiner, S., 2008. Phytolith-rich layers from the late Bronze and Iron Ages at Tel Dor (Israel): mode of formation and archaeological significance. Journal of Archaeological Science 35, 57–75.

Albert, R., Esteve, X., Portillo, M., Rodríguez-Cintas, A., Cabanes, D., Esteban, I., Hernández, F., 2011. Phytolith CoRe, Phytolith Reference Collection. Retrieved Jan 21, 2015, from. http://phytcore.org/phytolith/index.

Anderson, S., Ertug-Yaras, F., 1998. Fuel fodder and faeces: an ethnographic and botanical study of dung fuel use in central Anatolia. Environmental Archaeology 1, 99–110.

Belarte, M.C., 2011. Les sondages dans la zone 1. In: Kallala, N., Sanmartí, J. (Eds.), Althiburos I. La fouille dans l'aire du capitole et dans la nécropole méridionale. Serie Documenta. Institut Català d'Arqueologia Clàssica, Tarragona, pp. 45–151.

Berna, F., Behar, A., Shahack-Gross, R., Berg, J., Boaretto, E., Gilboa, A., Sharon, I., Shalev, S., Shilshtein, S., Yahalom-Mack, N., Zorn, J.R., Weiner, S., 2007. Sediments exposed to high temperatures: reconstructing pyrotechnological practices in Late Bronze and Iron Age strata at Tel Dor (Israel). Journal of Archaeological Science 34, 358–373.

Bottema, S., 1984. The composition of modern charred seed assemblages. In: van Zeist, W., Casparie, W. (Eds.), Plants and Ancient Man. A.A. Balkema, Rotterdam, pp. 207–211.

Brochier, J.E., 1996. Feuilles ou fumiers? Observations sur le rôle des poussières sphérolitiques dans l'interprétatation des dépôts archaéologiques holocènes. Anthropozoologica 24, 19–30.

Brochier, J.E., Thinon, M., 2003. Calcite crystals, starch grains aggregates or…POCC? Comment on 'calcite crystals inside archaeological plant tissues'. Journal of Archaeological Science 30, 1211–1214.

Brochier, J.E., Villa, P., Giacomarra, M., Tagliacozzo, A., 1992. Shepherds and sediments: geo-ethnoarchaeology of pastoral sites. Journal of Anthropological Archaeology 11, 47–102.

Brown, D.A., 1984. Prospects and limits of a phytolith key for grasses in the central United States. Journal of Archaeological Science 11, 345–368.

Cantero, F.J., 2016. Ressources forestières à *Althiburos* à partir de l'étude des charbons de bois. In: Kallala, N., Sanmartí, J., Belarte, M.C. (Eds.), Althiburos II. L'aire du capitole et la nécropole méridionale: études. Institut Català d'Arqueologia Clàssica, Tarragona (in press).

Canti, M.G., 1997. An investigation of microscopic calcareous spherulites from herbivore dungs. Journal of Archaeological Science 24, 219–231.

Canti, M.G., 1998. The micromorphological identification of faecal spherulites from archaeological and modern materials. Journal of Archaeological Science 25, 435–444.

Canti, M.G., 1999. The production and preservation of faecal spherulites: animals, environment and taphonomy. Journal of Archaeological Science 26, 251–258.

Canti, M.G., 2003. Aspects of chemical and microscopic characteristics of plant ashes found in archaeological soils. Catena 54, 339–361.

Gur-Arieh, S., Boaretto, E., Maeir, A., Shahack-Gross, R., 2012. Formation processes in philistine hearths from tell es-Safi/Gath (Israel): an experimental approach. Journal of Field Archaeology 37, 121–131.

Gur-Arieh, S., Mintz, E., Boaretto, E., Shahack-Gross, R., 2013. An ethnoarchaeological study of cooking installations in rural Uzbekistan: development of a new method for identification of fuel sources. Journal of Archaeological Science 40, 4331–4347.

Gur-Arieh, S., Shahack-Gross, R., Maeir, A.M., Lehmann, G., Hitchcock, L.A., Boaretto, E., 2014. The taphonomy and preservation of wood and dung ashes found in archaeological cooking installations: case studies from Iron Age Israel. Journal of Archaeological Science 46, 50–67.

Kadowaki, S., Maher, L., Portillo, M., Albert, R.M., Akashi, Ch, Guliyev, F., Nishiaki, Y., 2015. Geoarchaeological and palaeobotanical evidence for prehistoric cereal storage in the southern Caucasus: the Neolithic settlement of Göytepe (mid. 8th millennium BP). Journal of Archaeological Science 53, 408–425.

Kallala, N., Sanmartí, J., 2011. Synthèse des résultats: deux mille ans d'histoire d'Althiburos. In: Kallala, N., Sanmartí, J. (Eds.), Althiburos I. La fouille dans l'aire du capitole et dans la nécropole méridionale. Serie Documenta. Institut Català d'Arqueologia Clàssica, Tarragona, pp. 31–43.

Kallala, N., Sanmartí, J., Belarte, M.C., Ramon, J., Álvarez, R., Moussa, M.B., Bechrifiia, S., Bermúdez, X., Campillo, J., Chebbi, N., Fadrique, T., Jornet, R., López, D., Loum, Z.B.H.N., Maraoui, B., Noguera, J., Puche, J.M., Revilla, V., Tarradell, N., Torchani, M., Valenzulea, S., 2008. Recherches sur l'occupation d'Althiburos (région de Kef, Tunisie) et de ses environs à l'époque numide. Pyrenae 39 (1), 67–113.

Latiri, K., Lhomme, J.P., Annabi, M., Setter, T.L., 2010. Wheat production in Tunisia: progress, inter-annual variability and relation to rainfall. European Journal of Agronomy 33, 33–42.

López-Reyes, D., Cantero, F.J., 2016. Agriculture et alimentation à *Althiburos* à partir de l'étude des graines et des fruits. In: Kallala, N., Sanmartí, J. (Dir.), Belarte, M.C. (Eds.), Althiburos II. L'aire du capitole et la nécropole méridionale: études. Institut Català d'Arqueologia Clàssica, Tarragona (in press).

Madella, M., Alexandre, A., Ball, T.B., ICPN Working Group, 2005. International code for phytolith nomenclature 1.0. Annals of Botany 96, 253–260.

Matthews, W., 2010. Geoarchaeology and taphonomy of plant remains and microarchaeological residues in early urban environments in the Ancient Near East. Quaternary International 214, 98–113.

Miller, N.F., 1984. The use of dung as a fuel: an ethnographic example and an archaeological application. Paléorient 10 (2), 71–79.

Morales, J., Mulazzani, S., Belhouchet, L., Zazzo, A., Berrio, L., Eddargach, W., Cervi, A., Hamdi, H., Saidi, M., Coppa, A., Peña-Chocarro, L., 2015. First preliminary evidence for basketry and nut consumption in the Capsian culture (ca. 10,000–7500 BP): archaeobotanical data from new excavations at El Mekta, Tunisia. Journal of Anthropological Archaeology 37, 128–139.

Mulholland, S.C., Rapp Jr., G., 1992. A morphological classification of grass silicabodies. In: Rapp Jr., G., Mulholland, S.C. (Eds.), Phytolith Systematics: Emerging Issues, Advances in Archaeological and Museum Science. Plenum Press, New York, pp. 65–89.

Pearsall, D.M., 1989. Paleoethnobotany: a Handbook of Procedures. Academic Press, San Diego.

Peña-Chocarro, L., Zapata, L., González Urquijo, J.E., Ibáñez, J.J., 2009. Einkorn (*Triticum monococcum* L.) cultivation in mountain communities of the western Rif (Morocco): an ethnoarchaeological project. In: Fairbainn, A.S., Weiss, E. (Eds.), From Foragers to Farmers. Gordon Hillman Festschrift. Oxbow, Oxford, pp. 103–111.

Peña-Chocarro, L., Pérez Jordà, G., Morales Mateos, J., Zapata, L., 2015. Storage in traditional farming communities of the western Mediterranean: ethnographic, historical and archaeological data. Environmental Archaeology 20, 379–389.

Picornell, Ll, Asouti, E., Allué, E., 2011. The ethnoarchaeology of firewood management in the Fang villages of Equatorial Guinea, central Africa: Implications for the interpretation of wood fuel remains from archaeological sites. Journal of Anthropological Archaeology 30, 375–384.

Piperno, D.R., 1988. Phytolith Analysis: an Archaeological and Geological Perspective. Academic Press, San Diego.

Piperno, D.R., 2006. Phytoliths: a Comprehensive Guide for Archaeologists and Paleoecologists. AltaMira Press, Lanham.

Portillo, M., Albert, R.M., 2011. Husbandry practices and livestock dung at the Numidian site of Althiburos (el Médéina, Kef Governorate, northern Tunisia): the phytolith and spherulite evidence. Journal of Archaeological Science 38, 3224–3233.

Portillo, M., Albert, R.M., 2016. Les activités domestiques de la période numide à travers de l'étude des microrestes végétaux et fécaux : phytolithes et sphérolithes. In: Kallala, N., Sanmartí, J. (Dir.), Belarte, M.C. (Eds.), Althiburos II. L'aire du capitole et la nécropole méridionale: études. Institut Català d'Arqueologia Clàssica, Tarragona (in press).

Portillo, M., Valenzuela, S., Albert, R.M., 2012. Domestic patterns in the Numidian site of Althiburos (northern Tunisia): the results from a combined study of animal bones, dung and plant remains. Quaternary International 275, 84–96.

Portillo, M., Kadowaki, S., Nishiaki, Y., Albert, R.M., 2014. Early Neolithic household behavior at Tell Seker al-Aheimar (Upper Khabur, Syria): a comparison to ethnoarchaeological study of phytoliths and dung spherulites. Journal of Archaeological Science 42, 107–118.

Ramon, J.R., Maraoui, B., 2011. Les sondages dans la zone 2. In: Kallala, N., Sanmartí, J. (Eds.), Althiburos I. La fouille dans l'aire du capitole et dans la nécropole méridionale. Serie Documenta. Institut Català d'Arqueologia Clàssica, Tarragona, pp. 153–391.

Reddy, S.N., 1998. Fueling the hearths in India: the role of dung in paleoethnobotanical interpretation. Paléorient 24 (2), 61–70.

Rosen, A.M., 1992. Preliminary identification of silica skeletons from Near Eastern archaeological sites: an anatomical approach. In: Rapp Jr., G., Mulholland, S.C. (Eds.), Phytolith Systematics: Emerging Issues, Advances in Archaeological and Museum Science. Plenum Press, New York, pp. 129–147.

Sanmartí, J., Kallala, N., Belarte, M.C., Ramon, J., Maraoui, B., Jornet, R., Miniaoui, S., 2012. Filling gaps in the protohistory of the Eastern maghreb: the althiburos archaeological project (El Kef, Tunisia). Journal of African Archaeology 10, 21–44.

Sghaier, T., Ammari, Y., 2012. Croissance et production du pin d'Alep (*Pinus halepensis* Mill.) en Tunisie. Ecologia Mediterranea 38 (1), 39–57.

Shahack-Gross, R., 2011. Herbivorous livestock dung: formation, taphonomy, methods for identification, and archaeological significance. Journal of Archaeological Science 38, 205–218.

Shahack-Gross, R., Marshall, F., Ryan, K., Weiner, S., 2004. Reconstruction of spatial organization in abandoned Maasai settlements: implications for site structure in the pastoral Neolithic of East Africa. Journal of Archaeological Science 31, 1395–1411.

Sillar, B., 2000. Dung by preference: the choice of fuel as an example of how Andean pottery production is embedded within wider technical, social and economic practices. Archaeometry 42 (1), 43–60.

Tsartsidou, G., Lev-Yadun, S., Albert, R.M., Miller-Rosen, A., Efstratiou, N., Weiner, S., 2007. The phytolith archaeological record: strengths and weaknesses based on a quantitative modern reference collection from Greece. Journal of Archaeological Science 34, 1262–1275.

Tsartsidou, G., Lev-Yadun, S., Efstratiou, N., Weiner, S., 2008. Ethnoarchaeological study of phytolith assemblages from an agro-pastoral village in Northern Greece (Sarakini): development and application of a Phytolith Difference Index. Journal of Archaeological Science 35, 600–613.

Twiss, P.C., 1992. Predicted world distribution of C_3 and C_4 grass phytoliths. In: Rapp Jr., G., Mulholland, S.C. (Eds.), Phytolith Systematics: Emerging Issues, Advances in Archaeological and Museum Science. Plenum Press, New York, pp. 113–128.

Twiss, P.C., Suess, E., Smith, R.M., 1969. Morphological classification of grass phytoliths. Soil Science Society of America Proceedings 33, 109–115.

Valenzuela, S., 2016. Alimentation et élevage à *Althiburos* à partir des restes fauniques. In: Kallala, N., Sanmartí, J., Belarte, M.C. (Eds.), Althiburos II. L'aire du capitole et la nécropole méridionale: études. Institut Català d'Arqueologia Clàssica, Tarragona (in press).

Van der Veen, M., 2007. Formation processes of desiccated and carbonized plant remains – the identification of routine practice. Journal of Archaeological Science 34, 968–990.

Wattez, J., Courty, M.A., 1987. Morphology of ash of some plant remains. In: Fédoroff, N., Bresson, L.M., Courty, M.A. (Eds.), Micromorphologie des sols – Soil Micromorphology. Association Francaise pour l'Étude du Sol, Plaisir, pp. 677–682.

Weiner, S., 2010. Microarchaeology. Beyond the Visible Archaeological Record. Cambridge University Press, New York.

Zapata, L., Peña-Chocarro, L., Ibáñez Estévez, J.J., González Urquijo, J.E., 2003. Ethnoarchaeology in the Moroccan Jebala (Western Rif): wood and dung as fuel. Africa Praehistorica 15, 163–175.

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