



Investigating fuel for firing pottery at the end of the 3rd mill. BCE: The case of Logardan, northern Iraq

C. Douché^{*}, M. Charles

Institute of Archaeology – University of Oxford, 34–36 Beaumont Street, OX1 2PG Oxford, UK

ARTICLE INFO

Keywords:

Archaeobotany
Dung
Pottery kilns
northern Iraq
3rd millennium BCE

ABSTRACT

Fieldwork carried out by the French Qara Dagh Archaeological Mission at the tell site of Logardan in northern Iraq, has revealed an extensive pottery workshop (levels 3a-b), characterised by hundreds of pottery kilns dated to the end of the 3rd millennium BCE. This paper presents the archaeobotanical results related to these firing structures and associated contexts. Despite the location of the site on the foothills of the Qara Dagh mountains where wood fuel is expected to be available, wood charcoal is present in small quantities and is poorly preserved making it difficult to assess its role. Instead, the charred plant remains recovered are dominated by numerous tiny grass seeds (<1mm) or seeds possessing a thick (hard) seed coat that characterise livestock dung. Multivariate comparison of the kiln deposits with the other contexts leads us to conclude that dung was used as the primary fuel for firing pottery. Reasons for this selection are considered based on ethnographic accounts of traditional pottery manufacture.

1. Introduction

The importance of pyrotechnology for human communities pertains to its fundamental functions such as heating, lighting, cooking and burning. Plant material—including wood, charcoals and a wide range of herbaceous plants – represent the primary fuel source for this pyrotechnology in prehistory though other source such as animal products including bones may be used (Costamagno et al., 2005, p. 56; Huot and Delcroix, 1972; Théry-Parisot, 2002). Archaeobotanical studies in Southwest Asia show two major fuel types were used for domestic contexts: firewood (Bouchaud et al., 2018; Deckers, 2010; Kabukcu, 2018a, 2018b; Willcox, 2002) and animal dung (Bogaard et al., 2014, 2013; Douché, in press; Miller, 1984; Portillo et al., 2014; Spengler, 2019). Initial studies that identified the use of animal dung as a fuel proposed that its use reflected the low availability of wood (Miller, 1984; Miller and Smart, 1984), but more recent work has shown that dung is also used as fuel due to its availability and local abundance, making it an “easily harvested fuel resource” (Miller and Marston, 2012; Spengler, 2019).

While in Europe, both the structure and the fuel use of pottery kilns have been widely investigated (Chabal, 2001; Fajal et al., 2015; Vaschalde and Chabal, 2020), this is rarely the case in Southwest Asia (Hansen Streily, 2000; Huot and Delcroix, 1972). In this paper, we

analyse archaeobotanical samples collected from the late 3rd mill. BCE pottery workshop from Logardan (northern Iraq) to determine fuel selection and supply of the pottery kilns and to understand the production process given the large-scale and intensive nature of production.

1.1. Environmental settings

The site of Logardan (Lat. 35°31'42.17"N/S – Long. 44°52'34.78"E/W) lies on a natural hill, on the foothills of the Zagros mountains in north-east Iraq (Fig. 1a). The tell is located on the western bank of the Tavuk Çay river that runs parallel to the Jebel Qara Dagh (Vallet, 2020). The area is characterised by a mediterranean climate with warm dry summers and cold rainy winters (Fig. 1b). Minimum and maximum temperatures are reached in January and August respectively. Mean annual rainfall is 745 mm, concentrated during the winter, from November to April. Conversely, summer months from June to September are very dry, with little or no rain.

The site lies in the Irano-Turanian floristic region as defined by Zohary (Zohary, 1973, 1950) and according to *The Flora of Iraq*, it is located in the lower zone of the mountain forest (alt. 500–1800 m) (Guest, 1966). The long history of climate changes and human activities in the region has impacted the distribution of the vegetation and its margins. Nowadays the site is in grassland (steppe) with scattered

^{*} Corresponding author.

E-mail addresses: caroline.douche@arch.ox.ac.uk (C. Douché), michael.charles@arch.ox.ac.uk (M. Charles).

<https://doi.org/10.1016/j.jasrep.2023.104259>

Received 15 May 2023; Received in revised form 31 August 2023; Accepted 13 October 2023

Available online 9 November 2023

2352-409X/© 2023 The Authors. Published by Elsevier Ltd. This is an open access article under the CC BY license (<http://creativecommons.org/licenses/by/4.0/>).

shrubs and goat-face grasses (*Aegilops* sp.), wild barley, small legumes and occasional trees (especially *Astragalus* sp.) (Ghazanfar and McDaniel, 2016; Guest, 1966). These derive from over-exploitation of the open woodland park characterised by oak (*Quercus* spp.), wild pistachio (*Pistacia atlantica* and *P. khinjuk*) and pine trees (*Pinus brutia* var. *eldarica*), that occurs further east towards the Zagros mountains. The relict vegetation of the dense oak forest is observable at higher altitude. Two species of oak (*Quercus aegilops* and *Q. infectoria*) occur locally, constituting the main arboreal species of its forest and open woodland. Logardan is currently located at a distance of c. 100 km from the dense oak forest but climate change and human activities has likely shrunk its margins. The nearby banks of the Tavuk Çay river offer access to riparian vegetation comprising reed, sedge, clurbush and grasses such as *Phalaris* sp.

1.2. The site

Surveys and excavations were carried out under the direction of R. Vallet between 2015 and 2019 in the framework of the Qara Dagħ Archaeological Mission (Vallet, 2020; Vallet et al., 2019, 2017). Fieldwork on this high tell (27 m) allowed to identify a long occupation, from the Halaf to the Late Bronze Age (LBA). In addition, scarce evidence of parthian and islamic re-occupations were found at the top of the tell (Table 1). The site covers an area of c. 3.7 ha. Excavation was carried out in five archaeological trenches, but only two (D and E) were opened extensively. At the end of the 2019's campaign, the excavated area was more approximately 600 m² (Vallet, 2019, p. 8).

In the northern part of the tell (Trench D), the seven successive levels represent an occupation spanning from the early 4th mill. BC (Early Uruk phase) to the late 3rd mill. BC. For further details about the stratigraphy, see Baldi this volume. The Late Chalcolithic period (Early-Middle Uruk phase) is represented by a monumental acropolis (Vallet, 2020; Vallet et al., 2017). The site was reoccupied by a military compound during the Early Dynastic III (EDIII, c. 2500 BCE) and then, by a monumental building, probably with a ceremonial function, during the Late/Post-Akkad period. At the end of the Early Bronze Age (EBA), a workshop area took over the monumental building, that was destroyed and dismantled (Table 1) (Baldi, 2022; Baldi and Zingarello, 2021). No residential area associated to this manufacture area yet has been found. But this is often the case, as pottery kilns are usually built at a distance

Table 1
Synthetic chronology of Logardan and its main features.

	Period	Dates (BCE)	14C Dates (BP)	Main feature
Iron Age (IA)	Hellenistic	4th–3rd cent. BCE		Burials
Late Bronze Age (LBA)				Industrial pottery workshop (level 1a)
Middle Bronze Age (MBA)		c. 1900 BCE		Pits
Early Bronze Age (EBA)	Late/Post-Akkad	c. 2200–2000 BCE	3725 ± 35	Industrial pottery workshop (levels 3b, 3a2, 3a1, 2, 1)
		c. 2200 BCE	4080 ± 35	Monumental Building (level 3c)
	Early Dynastic III	c. 2600–2350 BCE		Stronghold (level 3d)
Late Chalcolithic	Middle Uruk		4825 ± 35	Stronghold (level 4a)
	Early Uruk	c. 3900–3600 BCE		Monumental Complex (level 4b, 4c)
Early Chalcolithic	Halaf-Ubaid transition	c. 5500–5200 BCE		Probably domestic architecture and pottery kilns

from the habitat (Gonzalez-Urquijo et al., 2001).

2. Pottery production and fuel selection

2.1. The pottery workshop of Logardan

The extensive area dedicated to the manufacture of pottery in Trench D is dated to the Post-Akkad/Ur III period, with the earliest level radiocarbon dated to 2145–2119 BCE (Vallet, 2018, pp. 167–168, Appendix B). The working complex is characterised by hundreds of ovoid kilns (Fig. 2), some with a dome and some with preserved chimneys, located between mudbrick platforms and workbenches. The space is densely occupied by kilns of various sizes, many of which overlap in a complex arrangement. Three distinct levels were identified, each one characterised by clusters of kilns, of several morphotypes (Baldi, this

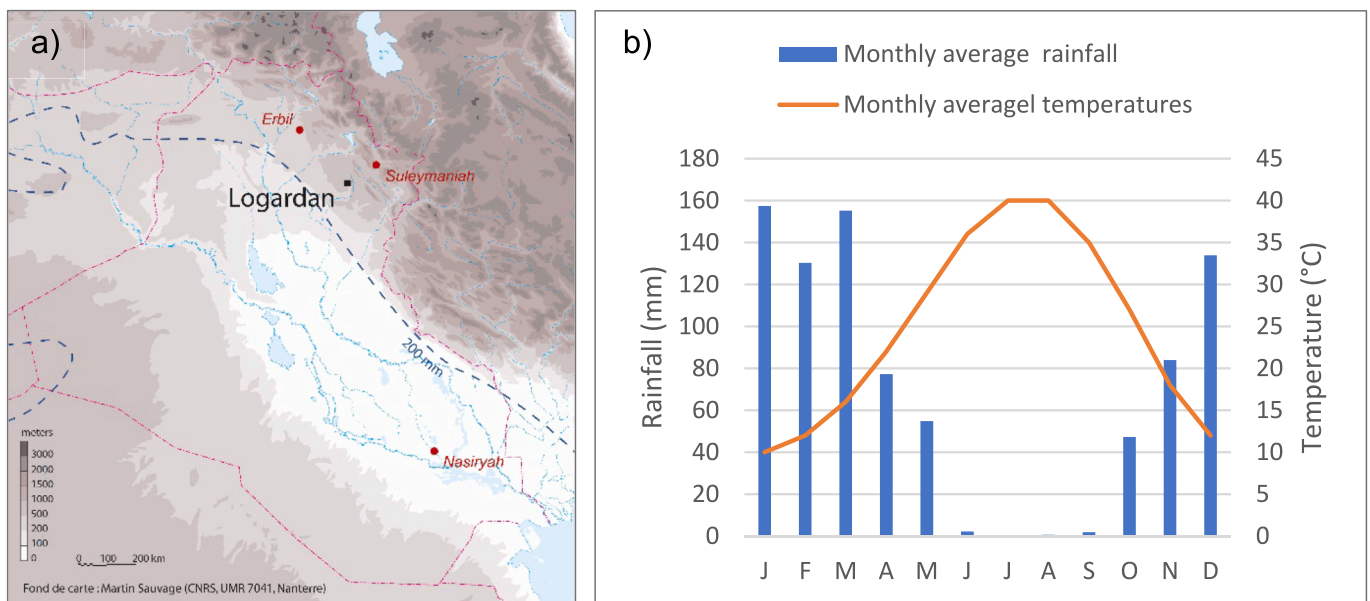


Fig. 1. (a) Map showing the location of the site and some modern cities in Iraq. (b) Graph presenting the monthly average rainfall and temperatures recorded at Suleymaniah (Source: <https://www.climatestotravel.com/climate/iraq>).

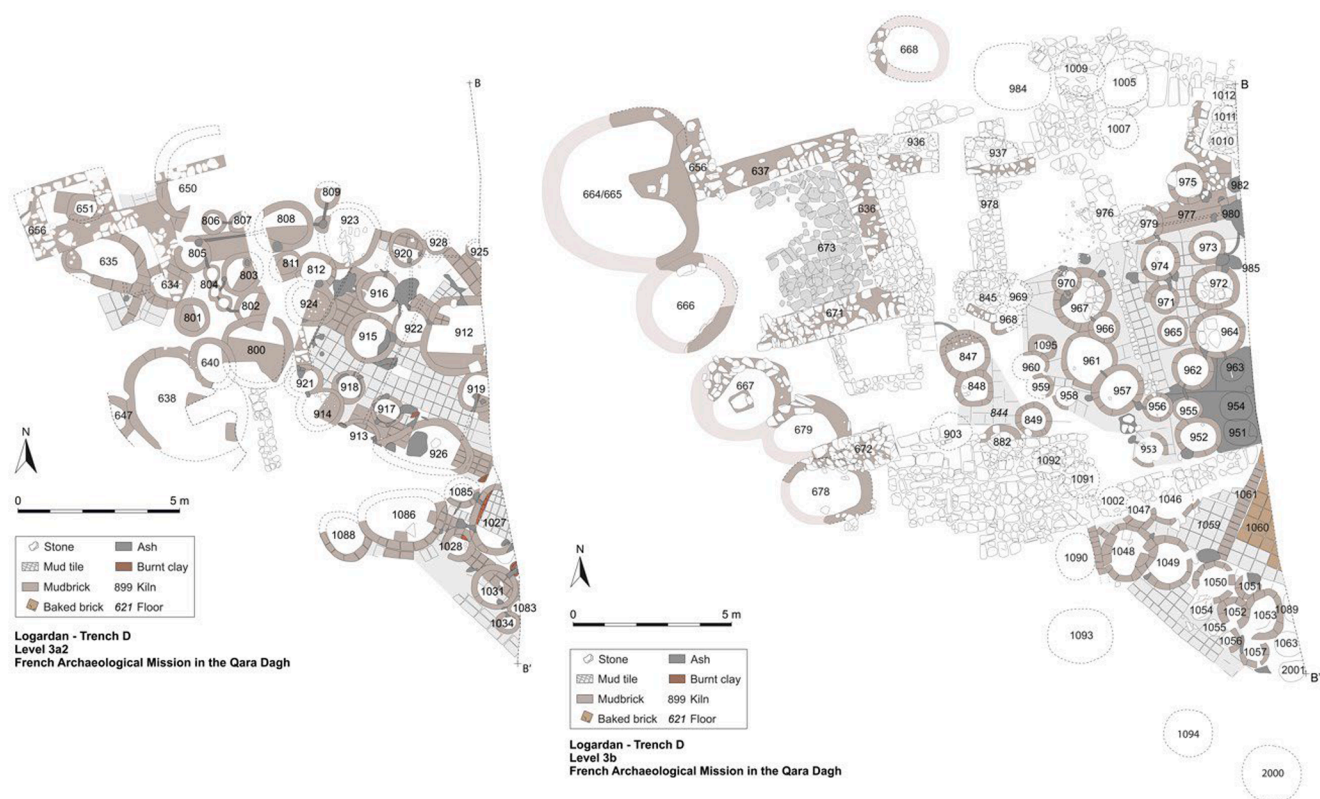


Fig. 2. Plans of the pottery workshops from Logardan D, levels 3a2 (left) and 3b (right) (©F.Ar.M.Qa.D).

volume):

- In level 3b “each cluster had at least one two-storey up-draught kiln as its main firing installation, and each cluster had several single-room kilns used as external heating chambers.”
- In level 3a2 “all the groups of furnaces also included several horizontal-draught kilns”.
- In level 3a1 “Single-room kilns were no longer attested and the area was increasingly dominated by a network of interconnected vertical and horizontal draught furnaces”.

The pipes and ducts connecting the kilns of each cluster allowed for the diffusion and sharing of heat and draught (Padovani, 2023). Kilns could thus be run individually or collectively (potentially saving fuel). While some kilns presented traces of redness and contained lumps of slag showing the high temperatures reached inside some of the chambers (Baldi et al., 2018, p. 65), it has been estimated that most of the ceramics were fired at an average temperature of 750–850 °C (Baldi, pers. comm.).

Despite the diversity of kiln morphotypes, the ceramic material recovered *in situ* suggests they were used to fire a wide range of everyday ceramics, such as beakers, jars and bowls (Baldi and Zingarello, 2021; Zingarello, 2018, in press). For each phase, however, the clusters of kilns are distinguished by the *chaîne opératoire* of the pottery they contained, reflecting distinct technical traditions (Baldi, this volume). This diversity of tradition show signs of decreasing through time, suggesting a technical homogenisation of the production. Based on the large number of kilns and the typology and quantity of the pottery recovered at the site, a model of centralised production has been proposed (Baldi and Zingarello, 2021; Vallet et al., 2019). Nevertheless, recent investigations carried out on the spatial and technical evolution of the workshop suggest that the production was carried-out by different groups of producers (operating within the same workspace) and was then, progressively controlled by a “gang” of highly specialised potters and not

necessarily by the state (Baldi, this volume).

2.2. Firing pottery in kilns

The replacement of open structure pottery firing with kilns, of the sort present in Logardan, is seen as a development primarily aimed at reducing temperature variation and reducing fuel consumption by regulating heat distribution within the kiln (Rehder, 2000; Théry-Parisot et al., 2020, p. 116). Minimum temperatures for pottery manufacture are c. 500–600 °C^[1], with firing duration from one to several hours, depending on kiln structure, fuel type (although poorly correlated) and the weather (Livingstone Smith, 2001).

Kilns with a dome allow to reach temperatures up to c. 1300 °C (Nicholson, 2010) but all types of kilns – covered or not – can reach relatively high temperatures (at least 800 °C) (Gosselain, 1992; Livingstone Smith, 2001; Thér et al., 2019). Ethnographic accounts of pottery production in this type of kiln describe the vessels being stacked in the kiln with fuel placed beneath (below the perforated floor of vertical kilns), in front (horizontal kilns), around/between them (single-room kilns) (Chávez, 1984, p. 171), or covered by fuel (Nicholson, 1989). Heating to the desired temperature and to remove the remaining clay moisture without cracking is the time consuming process, requiring careful control (Arnold, 1972; Nicholson, 1989). Gradual temperature rise is achieved by the slow insertion of fuel through the stoke-hole (and/or a top opening). Once the kiln exceeds 370 °C (Norsker, 1987; Roux, 2016) temperatures are increased by adding fuel. Inter-connected kilns such as at Logardan, allow shared heating (Baldi, this volume; Baldi and Padovani, 2019) with single-room kilns used to pre-heat other kiln chambers (Baldi, this volume) before the fuel in other sections were fired, reducing fuel consumption.

During the firing process, the fuel can be levelled out, raked to remove the ashes or thrown “onto the kiln top possibly as a means of preventing flames [...] or perhaps as some form of insulation” (Nicholson and Patterson, 1989, p. 78). In a recent firing experimentation in single

chamber kilns, Thér and colleagues (2019, p. 1153) explained that as free space was left between the vessel and the wall of the kiln, “the burning fuel was moved to these places during the firing”. During firing, the ashes can be used to cover the sherds placed on the top of the kiln to secure insulation (Arnold, 1972, p. 869). Once the desired temperature is achieved, no more fuel is added into the kiln and it is left to cool down for 24 h to 48 h. The pottery can then be collected, although still hot. Before each firing process, the kiln is cleared out from the previous firing, ashes are removed and thrown around or away (Gonzalez-Urquijo et al., 2001). These ashes are often seen to be valuable as fertiliser or the charcoal used in other burning events (Anderson and Ertüg-Yaras, 1998).

2.3. Fuel sources for pottery production: Ethnographic records

Ethnographic work carried out in Southwestern Asia, often in association with archaeological projects, have investigated the choice of fuel types for use in domestic and small-scale [traditional] production settings. This work has highlighted the important role livestock dung has, as a fuel source, in these arid settings along with other plant-based fuels including wood, straw, etc. (Elliott and Matthews, 2023; Gur-Arieh et al., 2013; Katz et al., 2007; Laugier et al., 2021; Portillo et al., 2020). Dung is often used as fuel when (1) woody plants are relatively scarce, (2) animal producing dung in sufficient quantity are available or if specific conditions are required (like temperature, constancy) (Miller and Smart, 1984; Spengler, 2019). Ethnographic works also highlight that different dung types are ascribed different properties as a fuel source. Anderson and Ertüg-Yaras for example, indicate that in Central Anatolia, light and unprocessed dung is preferred to start a fire, whereas the heavy, compact type is used for a “slower, longer-lasting heat” (1998, p. 101) and the selection of the appropriate fuel is believed to impact the firing cycle (Arnold, 1972; Gonzalez-Urquijo et al., 2001, p. 15).

Descriptions of fuel used to fire pottery in open air structures, show a wide range of fuel types being employed, such as dung in Central America (Sillar, 2000) or in Egypt (Nicholson and Patterson, 1989); Livingstone Smith mentions three categories of fuel (grass/chaff, wood/bark and dung) in pottery bonfires (2001) and multiple fuel sources including wood, cork oak bark and dung were used in Morocco (Gonzalez-Urquijo et al., 2001; Zapata Peña et al., 2003). The combination of wood and dung is often reported by ethnographic studies; e.g., fuelwood as the first fuel and once the fire has started, followed by dung (Arnold, 1972; Gonzalez-Urquijo et al., 2001).

Ethnographic studies investigating the specific fuel used for craft production in kilns are scarce though Zapata et al. (2003) mention wood being selected for its burning properties in pottery kilns (*duar*). Fig wood was the first choice as it burns at a lower temperature and « produces a slow fire, particularly good for firing pottery » (Zapata Peña et al. 2003, p. 170). Wood of pistachio (*Pistacia lentiscus*) and oak (*Quercus ilex*) that grow in the nearby forest are also considered as good fuel by the farmers. Fuelwood is placed in the bottom of the kiln, the ceramics are placed on the top of it and covered with dried dung cakes from cattle and goat (sometimes combined with fresh dung to avoid strong fire and secure the regular distribution of the heat) (Gonzalez-Urquijo et al., 2001, p. 15). When the fire starts, dried dung is added and the intensity is controlled by adding dried or fresh dung. In Iraq as in adjacent areas (Turkey, Syria, Iran), dung was and is still widely used as fuel especially for domestic activities (ovens, *tannurs*) (Anderson and Ertüg-Yaras, 1998; Charles, 1998; Miller, 1984; Portillo et al., 2017, 2014; Ramsay and Parker, 2016). This is, for example, the case at the modern village of Shorsh, located c. 1.5 km from the archaeological site of Logardan. The inhabitants store dried dung cakes together with logs of wood, branches and herbaceous plants (tinders) collected in the surrounding landscape (Douché and Padovani, 2019). Everything is dried and stored in a shelter located next to the hearth and the *tannur*, for a later use (cooking). These results provide some evidence of the complexity involved in selecting and using fuel in pottery production, that will be investigated in this

paper.

3. Methods

During the 2018–2019 seasons, thanks to the large-scale sampling strategy, 95 soil samples (total volume 1079 L) were collected across the site (Trenches D and E) and in various archaeological contexts. Sixty five samples dating to the Early Bronze Age (Early Dynastic to the Late/Post-Akkad) of secure contexts from Trench D are discussed here, 38 samples from kilns (and chimneys when present) and 27 from non-kiln contexts, sometimes associated with the workshop area (fill above the floor, pot contents, ashy fill, corridor and a duct).

The soil samples were processed by mechanical water flotation, with a 2 mm mesh set up to capture the heavy fraction, and a 0.3 mm mesh placed to collect the floating remains (light fraction). Both fractions were dried in the shade to limit damage to the remains. The entire heavy fraction was sorted by eye during the fieldwork season. The macro-remains such as animal bones, shells and any archaeological material (including bead) were separated and then given to specialists, and the plant remains were added to their respective flots. After preliminary scanning during fieldwork, all the flots was sorted under a low-power microscope at the University of Oxford (Motic-SMZ 171, magnification 0.75–5x). Manuals, atlases and drawings (Cappers et al., 2012; Jacomet et al., 2006; Nesbitt, 2017; van Zeist, 1999; Van Zeist and Vynckier, 1984), the *Flora of Iraq* and the reference collection from the Institute of Archaeology of Oxford were used to help with identifications.

Archaeobotanical items were recorded as follows: whole grains and fragments were counted and converted into a minimum number of individuals (MNI). Chaff items were counted and converted to MNI of rachis internodes (for free-threshing wheat and barley) and glumes bases (for glume wheats). Multi-variate Correspondence Analysis (CA) was carried out to investigate patterns in the plant macrofossils. The original data was cleaned by combining the scores of morphologically overlapping taxa (e.g. small legumes). Unidentified cereal grains were reassigned proportionally to other identified cereal grains. After preliminary analyses cutoff levels were set to include only taxa present in at least 3 samples and samples with at least 10 items in the final runs.

Previous work has shown that livestock digestion, especially of caprines (Valamoti and Charles, 2005; Wallace and Charles, 2013) and to a lesser extent cattle (Anderson and Ertüg-Yaras, 1998; Schepers and Van Haaster, 2015; Wallace and Charles, 2013), is very efficient at breaking down seeds and chaff. Accordingly, taxa groups were classified, according to their ability to survive livestock digestion (1 – very unlikely to 5 – very likely) based on their recorded presence in dung, as well as seed size (<2 mm) and seed coat hardness, features known to affect survivability (Miller, 1984; Valamoti and Charles, 2005; Wallace and Charles, 2013). Samples were classified according to their origin: kilns were divided according to their morphology (vertical, horizontal and single room) to explore the possible relation between the type of kiln and the fuel used. All other samples were labelled as “non-kilns”. Samples were then plotted using CANOCO 5 (version 5.04) (ter Braak and Šmilauer, 2018).

4. Results

4.1. Overview

Overall, the preservation of the charred remains was relatively poor, especially for cereal grains, with many too damaged for identification though smaller taxa are better preserved. Some taxa (*Buglossoides tenuiflora*, *Heliotropium europaeum* or *Papaver cf. somniferum*) were mineralised, occurring in 16 samples (8 kilns and 8 non-kilns). The density of remains varies greatly (from 0.4 to 53.3 per litre) between the archaeobotanical samples but is low overall, with 50 samples (76.92%) having less 10 items per litre. Fragments of wood charcoal are rare and poorly preserved, small fragments (<2 mm) present in 25 samples (38.6%) and

large fragments (>2 mm) in only 5 samples (7.7%). Identification was not possible but selected fragments for radiocarbon dating were classified as oak (*Quercus* spp.) and dicotyledon (M. Tengberg UMR 7209 MNHN-AASPE/CNRS pers comm.).

In general, the non-woody assemblage of Logardan is characterised by a relatively broad-spectrum of plants (Table 3, Suppl. Table 1 & Fig. 3), dominated by wild taxa and cereals. Wild seeds and chaff remains, represent 55% (n = 2982) of the identified items, followed by cereal grain (16.6%, n = 899) and chaff (24.0%, n = 1302), and minor components including pulses (2.5%), fruits (1.1%) and animal dung pellets (0.8%). Whilst the majority of cereal grains were unidentifiable (71.9%, n = 936), hulled two-row barley (*Hordeum vulgare* subsp. *distichum*) is the main identifiable taxa (20.3%, n = 265), followed by glume wheats (6.1%, n = 79) that include emmer (*Triticum turgidum* subsp. *dicoccum*) and einkorn (*T. monococcum* subsp. *monococcum*), and free-threshing wheat (1.7%, n = 22). Within the cereal chaff remains, in contrast, glume wheat is considerably more abundant (86.3%, n = 1566) than barley (7.7%, n = 140) or free-threshing wheat (2.3%, n = 41) among which, hard wheat (*Triticum turgidum* subsp. *durum*) was

identified. Pulses are of minor importance and dominated by lentil (*Lens culinaris*) and by numerous unidentified Fabaceae, while chickpea (*Cicer*-type), grasspea (*Lathyrus sativus*), bitter vetch (*Vicia ervilia*), faba bean (*Vicia faba*) and *Vicia/Lathyrus* are also present. Fruits are represented by achenes of fig (*Ficus carica*), grape pip (*Vitis vinifera*), almond (*Amygdalus orientalis*) and pistachio (*Pistacia* sp.) nutshell fragments, a possible cupule of oak (*Quercus*-type) as well as unidentified fruits.

The major wild plant family is Poaceae (75.7%, n = 2256), here divided by size into three groups: tiny, medium and large, of which the first is most abundant (n = 1129), with *Digitaria/Dinebra*-type the main taxa (n = 1087) but also including Panicoideae and *Eragrostis* sp. Medium size seeds are the next commonest (n = 1122), including ray-grass (*Lolium* cf. *temulentum*, *L. cf. multiflorum* and *L. rigidum*), *Hordeum murinum*, *Taeniatherum* sp., *Bromus* sp., wild oat (including *Avena fatua*), *Phalaris* sp. and *Poa bulbosa*-type and a large number of unidentified grains (n = 594). Large seeded Poaceae (n = 663), mainly comprising goat-grass (as well as their chaff) including *Aegilops* cf. *tauschii* and *A. cf. squarrosa* and a single grain of *Piptatherum*-type. Legumes constitute the second most important family among the wild taxa (n = 299) and

Table 2

Summarized table presenting the list of taxa identified in the Early Bronze Age occupation of Logardan (65 samples). The table also presents the dung class attributed to each taxa (except when discarded) and the name used for the Correspondence Analysis (CA). The same name is used for various taxa that have been grouped (see Suppl. Mat. X for detailed counts). The occurrence represents the number of samples in which a taxa occurs. *Items for which the amount of spikelet bases has been converted into glume bases for the CA.

Taxa	Category	Dung Class	Group for CA	Total count	Occurrence
<i>Hordeum vulgare</i> ssp. grain	Crop	1	Barley_Gr	265	1–38
<i>Triticum aestivum/durum</i> grain	Crop	1	FTW_Gr	22	2–10
<i>Triticum monococcum/dicoccum</i> grain	Crop	1	GW_Gr	79	1–10
<i>Lens culinaris</i>	Crop	1	Lens	81	16
Large Legumes indeterminate & <i>Lathyrus sativus</i> & <i>Vicia ervilia</i> & <i>V. faba</i> & <i>Vicia/Lathyrus</i> & <i>Prosopis/Ceratonia</i> -type	Crop	1	PVL_Group	56	1–21
Cerealia indeterminate grain	Crop	1	reassigned	936	54
<i>Aegilops</i> ssp. & <i>Piptatherum</i> -type grain	Wild	1	Lpoaceae_Gr	52	1–14
<i>Hordeum vulgare</i> glume	Crop	2	Barley_Glm	4	3
<i>Hordeum vulgare</i> ssp. rachis	Crop	2	Barley_Spk	136	1–18
Cerealia indeterminate & <i>Secale</i> -type spikelet base/rachis	Crop	2	Cer_Spk	70	2–6
<i>Triticum aestivum/durum</i> rachis	Crop	2	FTW_Spk	33	1–7
<i>Triticum monococcum/dicoccum</i> spikelet base & glume base	Crop	2	GWt_GB*	656	1–20
<i>Aegilops</i> ssp. glume base & rachis	Wild	2	Aegilops_GB	179	1–14
<i>Adonis</i> ssp.	Wild	3	Adonis	20	1–11
Asteraceae & <i>Centaurea</i> sp.	Wild	3	Asterac	24	1–3
Brassicaceae & <i>Capsella bursa-pastoris</i>	Wild	3	Brassic	22	1–8
Characeae oogone (mineralised)	Wild	3	Chara	21	5
<i>Galium</i> sp.	Wild	3	Galium	51	15
<i>Lolium</i> ssp.	Wild	3	Lolium	110	1–26
<i>Amygdalus orientalis</i> & <i>Pistacia</i> sp. & indeterminate nutshell fragment	Fruit	3	Nut	52	1–15
<i>Bellevalia</i> sp. & <i>Ornithogalum</i> sp.	Wild	3	OrniBell	5	1–3
Papaveraceae & <i>Papaver</i> spp.	Wild	3	Papaverac	147	1–4
<i>Avena fatua</i> floret & <i>Taeniatherum</i> sp. & Small Poaceae indeterminate rachis/spikelet base & glume base	Wild	3	Poac_Chf	20	1–4
<i>Bromus</i> sp. & <i>Stipa</i> sp. & <i>Taeniatherum</i> sp. grain	Wild	3	TaeStiBro_Gr	17	2–4
<i>Ficus carica</i> achene	Fruit	4	Ficus	6	4
<i>Vaccaria</i> ssp.	Wild	3	Vaccaria	9	2–3
Apiaceae & <i>Ammi majus</i> -type	Wild	4	Apiac	24	2–9
<i>Heliotropium europaeum</i> (charred & mineralised)	Wild	4	Helio	14	1–7
<i>Phalaris</i> sp. & <i>Poa bulbosa</i> -type & Small Poaceae indeterminate grain	Wild	4	PoacPhaPoa_Gr	597	1–49
<i>Plantago</i> sp. & Verbenaceae	Wild	4	VerbPlant	10	1–3
<i>Asperula involucrata</i>	Wild	5	Asper_inv	8	5
Asteraceae-type [very short]	Wild	5	AsteracSm	19	5
<i>Astragalus</i> sp. & <i>Astragalus/Medicago</i> & <i>Coronilla</i> sp. & <i>Coronilla/Scorpiurus</i> & <i>Medicago</i> sp. & <i>Medicago radiata</i>	Wild	5	AstMedCorScorp	86	1–11
<i>Atriplex</i> -type perianth & <i>Chenopodium</i> sp. & <i>Chenopodiaceae</i>	Wild	5	Chenopodiac	12	1–4
<i>Bolboschoenus</i> sp. & <i>Bulbostylis</i> -type & <i>Schoenoplectus</i> -type & <i>Cyperaceae</i> & <i>Scirpus</i> sp. achene	Wild	5	Cyperaceae	28	1–6
<i>Digitaria/Dinebra</i> -type & <i>Eragrostis</i> -type & Panicoideae	Wild	5	DinEraPan	1129	4–43
Small Legumes indeterminate	Wild	5	Sleg	31	1–10
<i>Medicago astroites</i> & <i>Melilotus</i> sp. & <i>Trifolium</i> sp. & <i>Trigonella</i> sp. & <i>Trigonella/Astragalus</i>	Wild	5	TrigoMelTrif_Group	180	1–26
<i>Cicer</i> -type	Crop		discarded	1	1
<i>Vitis vinifera</i> pip	Fruit		discarded	1	1
Various wild taxa seed	Wild		discarded	59	1–2
Floral part (culmnode, stem, tuber)	Wild		discarded	110	1–16
Caprine & Rodent pellet	Pellet		discarded	45	4–13

Table 3

List of the taxa/group of taxa use for the Correspondence Analysis (CA) and their respective flowering/fruitlet time, habitat and potential uses as fodder/grazing plant (based on the Flora of Iraq). In addition, the table presents the recovery of these taxa in various animal dung (from experimental studies). The column in grey represent the crop harvesting season. (x) means potentially. Refer to [Table 2](#) and Suppl. Table 1 for further details on the names of taxa/groups of taxa.

Taxa/group of taxa	Dung class	Months of Flowering/Fruiting								Annual (A)/ Perennial (P)	Habitat					Fodder/grazed				Survives digestion				Reference
		Mar	Apr	May	Jun	Jul	Aug	Sep	Oct		Arable weeds	Steppe	Wetland	Forest	Mount.	sheep	goat	cattle	equid	sheep	goat	cattle	equid	
L_Poaceae	1		x	x	x	x	(x)			A/P	x	x	x	x	x	x	(x)	(x)	x	(x)	(x)	(x)		Oveisi et al. (2021); Ramos et al. (2006); Wallace and Charles (2013); Walther (2011)
Aegilops_GB	2		x	x						A	x	x								(x)	(x)	(x)		Oveisi et al. (2021); Ramos et al. (2006); Walther (2011)
Poac_Chf	2	x	x	x	x					A	x	x			x					x				Schoenbaum et al. (2009)
Lolium	3	x	x	x	x	x				A	x	x	x	x	x	x	x	x	x	(x)		x		Walther (2011); Schoenbaum et al. (2009)
PoacPhaPoa_Gr	3	x	x	x	x	x	x			A/P	x	x	x	x	x	x	(x)	x	(x)	(x)		(x)		Schoenbaum et al. (2009); Burton & Andrews (1948)
Papaverac	3	x								A								x		x		x		Ramos et al. (2006); Walther (2011)
Brassic	3	x	x	x						A	x	x	x		x					x		x		Ramos et al. (2006); Walther (2011)
TaeStiBro_Gr	3	x	x	x	x	x	x			A/P	x	x	x	x	x	x	(x)	(x)	x	x		x		Walther (2011); Ramos et al. (2006); Wang et al. (2017); Schoenbaum et al. (2009)
Vaccaria	3	x	x	x	x					A	x	x	x	(x)	x					x				Ramos et al. (2006)
Galium	3	x	x	x	x	x	x	x		A/P	x	(x)	x	x	x					x		x		Walther (2011); Schoenbaum et al. (2009)
Asterac	3			x	x	x				A				x	x					(x)				Schoenbaum et al. (2009); Wallander et al. (1995)
Adonis	3		x	x						A		x			x									Guest (1980)
OrniBell	3	x	x	x	x	x	x			P		x		x	x									Ahmad and Salih (2019)
Apiac	4		x	x	x					A	x	x	x											Ahmad and Salih (2019)
Helio	4									A	x											x		Walther (2011)
Chenopodiac	5	x	x	x	x	x	x	x	x	A	x	x	x		x					x	x		x	Walther (2011); Wessels (2008); Kuiters and Huiskes (2010); Treitler et al. (2017); Schoenbaum et al. (2009); Wallace and Charles (2013)
Asper_inv	5				x															x				Wessels (2008)
VerbPlant	5	x	x	x	x	x	x			A/P	x		x	x	x	x	x	x		x	x		x	Walther (2011); Treitler et al. (2017); Schoenbaum et al. (2009); Kuiters and Huiskes (2010)
TrigoMelTrif_Group	5	x	x	x	x	x	x			A/(P)	x	x	x	x	x	x		x	x	x	x	x	x	Schoenbaum et al. (2009); Ramos et al. (2006); Walther (2011); Wessels (2008); Treitler et al. (2017); Kuiters and Huiskes (2010); Russi et al. (1992); Gardener et al. (1993); Wallace and Charles (2013)
AstMedCorScorp	5	x	x	x	x	x	x	x		A/P	x	x	x	x	x	x				x	x	x	x	Treitler et al. (2017); Schoenbaum et al. (2009); Walther (2011); Wessels (2008)
DinEraPan	5	x	x	x	x	x	x	x	x	A/P	x	(x)	x	(x)	(x)	x	x	x		(x)		x		Gardener et al. (1993); Wang et al. (2017)
Cyperaceae	5	x	x	x	x	x	x	x	x	A/P	x	(x)	x	(x)	x			x		x				Wallace and Charles (2013)



Fig. 3. A. *Hordeum vulgare* subsp. *distichum* grain, b. *Triticum aestivum/durum* grain, c. *Triticum turgidum* subsp. *durum* rachis, d. *Triticum turgidum* subsp. *dicoccum* spikelet base, e. *Triticum turgidum* subsp. *dicoccum* glume base, f. *Triticum monococcum/dicoccum* glume base, g. *Lens culinaris* seed, h. *Lathyrus sativus* seed, i. *Digitaria/Dinebra*-type, j. *Eragrostis*-type, k. *Lolium* cf. *rigidum*, l. *Aegilops* spikelet base, m. *Medicago astroites*, n. *Astragalus* sp., o. *Galium* sp., p. *Epilobium*-type, q. *Asteraceae* (short type), r. *Brassicaceae*, s. *Adonis* cf. *aestivalis*, t. *Chenopodium* sp.

include the common taxa occurring in the region such as *Astragalus* sp., *Coronilla* sp., *Melilotus* sp., *Medicago astroites*, *M. radiata*, *Trifolium* sp., *Trigonella* sp. and *Scorpiurus* sp. Wild grasses and legumes are ubiquitous as well as abundant, occurring in 60 (92.31%) and 40 (61.5%) of samples respectively.

Other important families (present in 5 to 18 samples with a total of 10–150 items) include Rubiaceae (*Galium* sp. and *Asperula involucreta*), Ranunculaceae (*Adonis* sp., *A. cf. aestivalis*), Cyperaceae, Asteraceae (*Centaurea* sp. and unidentified), Apiaceae (e.g. *Ammi majus*), Papaveraceae (e.g. *Papaver cf. somniferum*), Boraginaceae (*Buglossoides tenuiflora* and *Heliotropium europaeum*), Characeae, Chenopodiaceae (*Chenopodium* sp. and *Atriplex* sp.), Caryophyllaceae (including *Silene* sp., *Vaccaria* sp., *V. pyramidata*). Minor taxa include *Plantago* sp., Asparagaceae (*Bellevia* sp., *Ornithogalum* sp.), Euphorbiaceae, *Rumex* sp., *Ajuga* sp., *Malva* sp., *Epilobium*-type, Rosaceae and Verbenaceae.

4.2. Data analysis

Fig. 4 presents the broad composition of these two classes of samples with a minimum of 30 plant items, from kilns ($N = 19$) and non-kilns ($N = 16$). Overall, the patterns are broadly similar with samples dominated by the wild taxa, on average exceeding 50% of all plant remains but with most samples comprising >30% cereal grain and chaff. These preliminary results do not show substantial difference between the two groups, that might be explained by the relative space/function from where the samples were collected.

To further explore any differences in the association of taxa and archaeological deposits, a series of correspondence analyses were carried out (see Suppl. Table 2). Fig. 5a–d shows the patterns for 38 samples containing 10 or more items per sample and taxa occurring in at least 3 samples. The eigenvalues of the first and second axes are respectively 0.22 and 0.10, explaining 21.9% and 32.3% of the cumulative variation. Fig. 5a shows the pattern of sample composition for taxa classified according to likely derivation displayed as sample pie-charts. This clearly shows the difference in composition across the first axis, samples towards the left hand side are characterised by high percentages of taxa from class 5 (and 4), typically exceeding 50% of all items. Moving towards the centre of the axis, class 5 (dung-derived taxa) values decrease

while class 4 and class 3 (weeds) increase. In contrast, samples on the right hand side of the axis have lower percentages of class 5, instead samples are dominated by class 1 (crop, mostly cereal grain) and class 2 (cereal chaff).

In taxa terms (Fig. 5b), the axis shows some separations between wild taxa (classes 3, 4 and 5) to the left hand side and crops and crop weeds to the right hand side. Samples of both kilns and non-kilns contexts occur along the first axis but there is some separation between kilns (especially single-room and horizontal types) towards the negative, left hand side, and non-kilns in the centre or towards the positive, right hand end (Fig. 5c). On the second axis (vertical), there is a similar separation of kilns (positive) and non-kilns (negative) samples though again there are several exceptions to this pattern. Similarly, samples from the different levels are plotted along the first axis but again, there is some separation between levels 3b and 3a – mainly represented by pottery kilns – towards the negative, left hand side, and levels 3c–d (from the monumental building occupying the area prior to the workshop area) in the centre or towards the positive, right hand end (Fig. 5d). On the second axis (vertical), there is a similar separation of levels 3b and 3a (positive) and 3c–d (negative) samples though again, there are several exceptions to this pattern.

These results suggest a correlation between kilns and dung-derived taxa such as tiny and small seeds such as *Digitaria/Dinebra*-type, *Eragrostis* sp., Panicoideae but also those seeds with hard seed coats, small legumes (*Astragalus* sp., *Medicago* sp., *Trigonella* sp., etc.), *Chenopodium* sp. and *Asperula involucreta*. Many taxa included in class 3 refer to potential weed taxa (like *Lolium* sp., *Galium* sp. or *Vaccaria* sp.). Similarly, the correspondence analysis suggests a correlation between non-kilns contexts (mostly fill above floors) and crop seeds, mainly cereal grains. Despite these observations, it should be noted that the various categories of contexts as well as the different classes of taxa overlap, suggesting that the plant remains recovered in these different archaeological contexts may have a similar origin. In particular class 2, mainly represented by cereal chaff (rachis and glume bases), are widespread along axis 1, overlapping other classes.

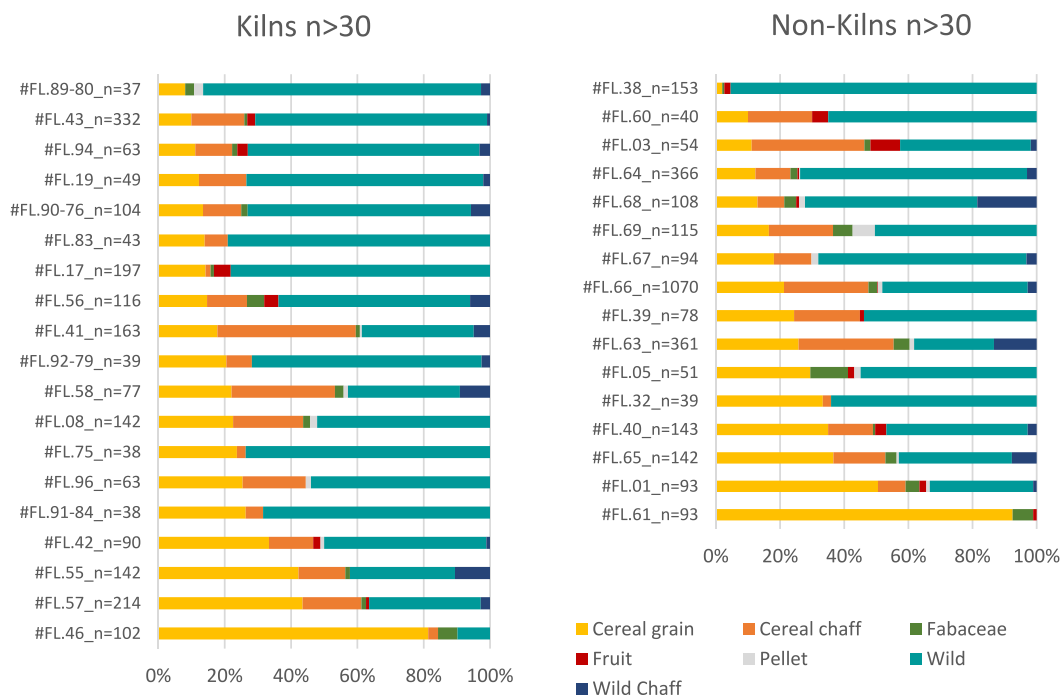


Fig. 4. Stacked bar charts presenting the broad composition of the richest samples ($n > 30$) from kilns and non-kilns contexts.

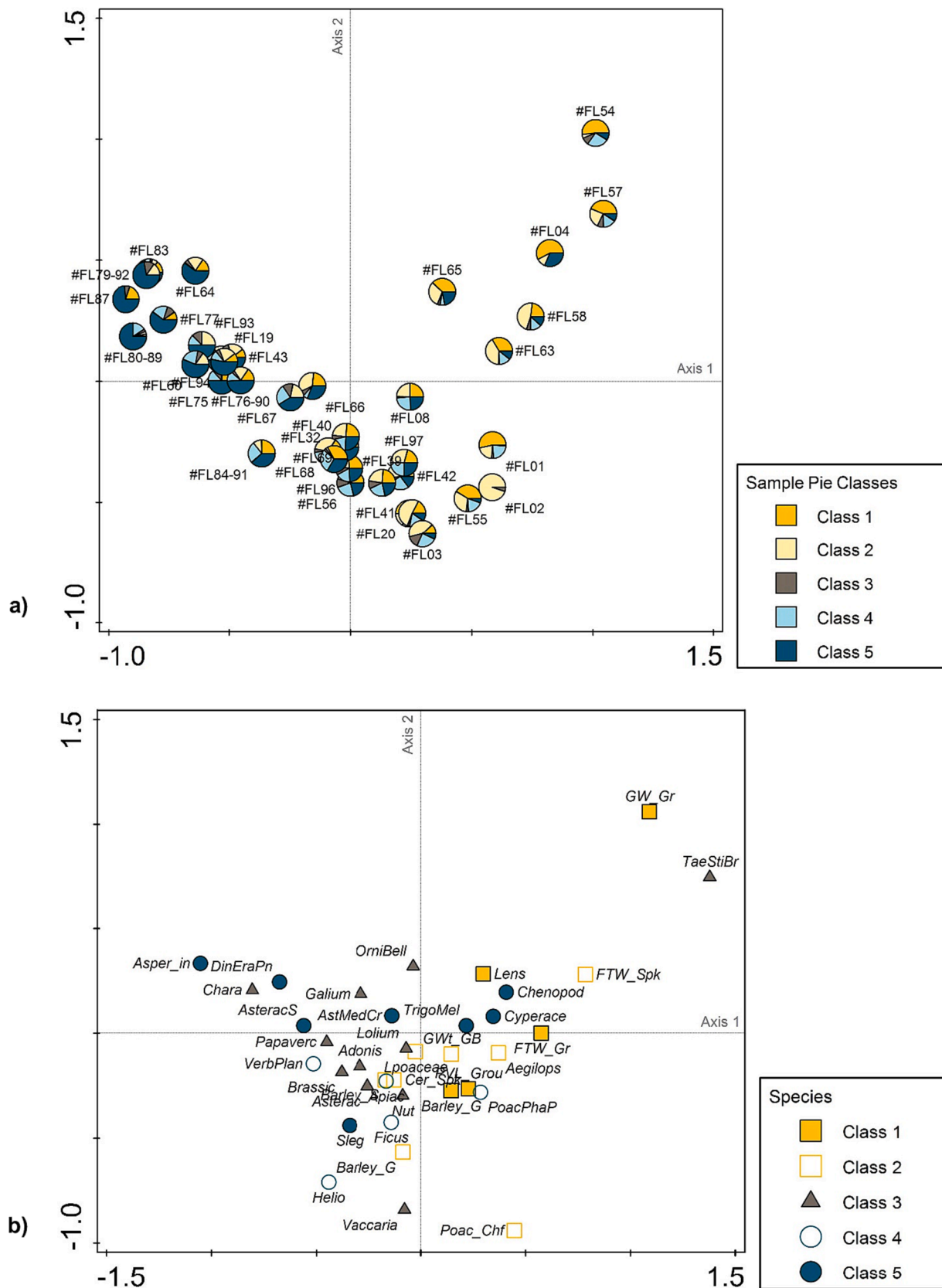


Fig. 5. Correspondence analysis biplots presenting the distribution of (a) the samples and their composition in the form of pie charts (presenting the percentage of each class of taxa). (b) Selected taxa or groups of taxa categorised according to the probability they survive animal digestion (from class 1 = very unlikely to class 5 = very likely), (c) samples classified according to archaeological contexts (kilns are divided into four morphotypes), (d) samples classified according to archaeological levels. For the full name of taxa/groups of taxa, see Table 2 and Suppl. Table 1.

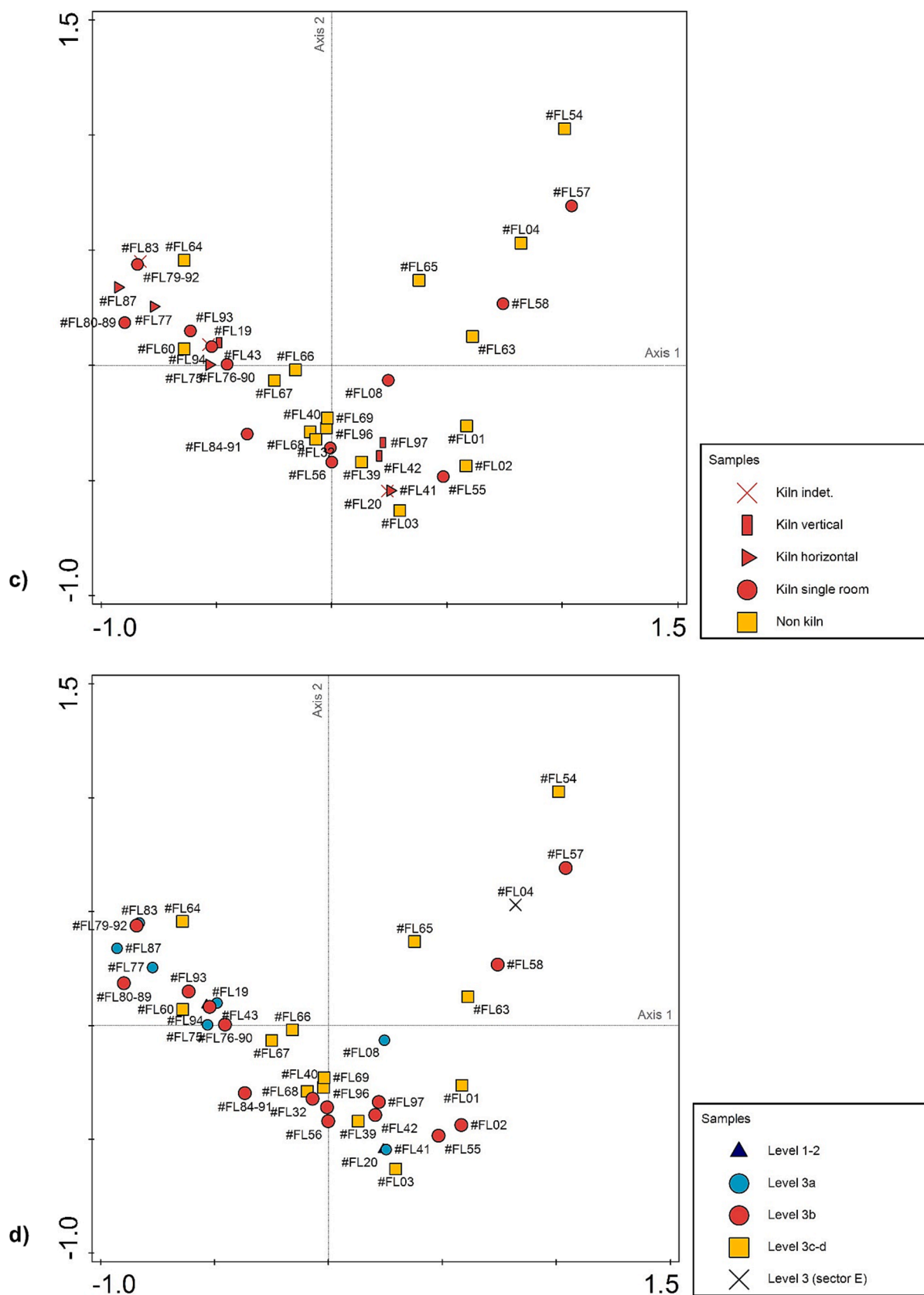


Fig. 5. (continued).

5. Discussion

Archaeobotanical results from Logardan suggest that many charred

plant remains recovered in the Late Akkadian pottery kilns likely derive from dung fuel. In the absence of other data, such as spherulites, phytoliths, or micromorphology, confirming the presence of dung as for

other archaeological sites in the region (Elliott and Matthews, 2023; Proctor et al., 2022), caution is needed. However, to date, the present study is the first highlighting the large-scale (“industrial”) use of dung as fuel, associated to the craft production (e.g. pottery), for about three centuries.

5.1. Fuel for kilns: Taphonomic issues

The absence of wood charcoal fragments > 2 mm in the kilns could reflect either the minor importance of wood fuel (at least for kilns) or careful collection and reuse of charcoal. The estimated temperatures for firing pottery at Logardan is 750–850 °C (Baldi, pers. comm.) and the ceramics were fired under oxidation conditions (excess of oxygen). This would seem to exclude the complete disintegration of wood into ashes due to high temperatures (>1200 °C) (Braadbaart and Poole, 2008; Charles et al., 2015).

The preservation of charred plant remains in the kilns of Logardan suggests they had been exposed to temperatures below 300 °C, more likely <260 °C (Charles et al., 2015), too low for firing pottery. But potentially within the range experienced in a single kiln (Gosselain, 1992; Karacic et al., 2016; Livingstone Smith, 2001; Thér et al., 2019). The edges of the kilns – against the wall – could provide favourable conditions for the preservation of plant remains (c. 230 °C). In addition, experiments (Copper et al., 2021) have demonstrated that the combustion of sheep dung for example, creates a “blanket” of burnt-out fuel, allowing for a slow cooling down or a protective layer over plant material. There is, however, a lack of detailed studies recording the effect of dung burning in various conditions on the preservation of seeds, though Hastorf and Wright (Hastorf and Wright, 1998) observed no differences on the preservation of seeds between oxidizing and reducing conditions. The fuel may have been added to a cooling furnace. Indeed, pottery kilns are continuously stocked during the firing process but once it is stopped, the temperatures drop first rapidly and then remain low for a while. The recovery of mineralised plant remains has sometimes been used as evidence for the presence of dung (Spengler, 2019) but at Logardan, they are not strongly associated with kilns. Similarly, a few caprine dung pellets were recovered, but not in the kilns, making their presence unreliable as evidence of dung burning (Miller, 1984). Whereas cattle, pig and equid skeletal elements were identified in addition to sheep and goat (Vila, 2018), the recognition of their dung in archaeobotanical samples is more difficult.

5.2. Why livestock dung?

The present-day vegetation surrounding the site of Logardan has few trees, except fruit trees growing in orchards along the Tavuk Cay river and occasional willows and poplars. Due to the lack of sources of local long-term environmental data, it is difficult to reconstruct the local landscape during the post-Akkadian occupation. Environmental studies carried out in the region provides evidence for the expansion of oak woodlands from the 5th mill. BCE and have shown that arboreal species such as oak, pistachio and ash were maintained until recently (Safaierad et al., 2023; Van Zeist and Wright, 1963; van Zeist and Bottema, 1977). Earlier pottery production is attested at Logardan (Baldi, 2022; Baldi and Zingarello, 2021; Vallet et al., 2017, 2019) and this could have had an impact on the local vegetation by the regular removal of wood fuel.

The end of the 3rd mill. BCE is marked by the 4.2 BP aridification event that may have impacted the vegetation and acquisition strategies, as woodland was reduced. Along the Euphrates and in the eastern Zagros, archaeobotanical studies have suggested the selection of « less preferred » fuelwoods, followed by a more common use of dung (Miller, 1984, 1982; Miller and Smart, 1984; Smith et al., 2015). Experimental work indicates that livestock dung can have a number of advantages over wood as a fuel in pottery firing by shortening the firing process (Copper et al., 2021), showing less variability between different types of dung (Rehder, 2000, pp. 30–36), burning more evenly and reaching

higher temperatures by decreasing release of excess air (Rehder, 2000; Sillar, 2000). Evidence for the selection of dung as fuel source even when woodland is available come from the site of Surezha (NE Iraq) where dung was the predominant fuel in domestic contexts (Proctor et al., 2022); Akkadian *tannurs* of Tell Leilan (NE Syria) were fuelled largely by dung (Smith, 2012), and ten pyrotechnical features resembling kilns excavated at the earlier Ubaid site of Tell Zeidan (Syria), yielded large numbers of spherulites, phytoliths and a few macrobotanical remains (Smith et al., 2019).

5.3. Plants, dung and animals

The biology and ecology of wild plant species recovered in the samples can be used to reconstruct livestock feeding (Charles, 1998; Riehl, 2006). The plant macro-fossils from Logardan provides an initial insight into vegetation accessed, though further work to refine identifications is ongoing. The assemblage is dominated by potential weeds, plants likely deriving from steppic vegetation, and disturbed environments. The potential weeds such as *Galium* sp., *Asperula involucrata*, *Vaccaria pyramidata*, *Lolium* spp., *Aegilops* spp. are typically annuals that flower in spring/early summer, coinciding with crop harvest (see Table 3). In the region around the site, sheep, goat, cattle and equids (mainly donkey) are often brought to cereal fields to graze the ‘leftovers’ (i.e. crop stubble and weeds) after the harvest. Steppic vegetation, is often represented by a mix of annuals and perennials wild grasses (*Digitaria* sp., *Dinebra* sp., *Eragrostis* sp.) and small legumes (*Medicago astroites*, *Astragalus* sp., *Coronilla* sp.) which tend to continue flowering until later in the year. Nowadays, many farmers of Shorsh - the modern village near Logardan - cultivate alfalfa (*Medicago sativa*) and barley as a fodder crop (Douché and Padovani, 2019). But many of the plants retrieved at Logardan, such as *Trigonella* sp. (Townsend, 1974, p. 87), *Astragalus* sp. (Amiri et al., 2020), *Digitaria* [sanguinalis] and *Dinebra* [retroflexa] (Bor and Guest, 1968, pp. 432 and 478), are known to be grazed or used as forage plants for livestock (Table 3). Experimental work has also indicated that many of these taxa have a high survival rate through livestock digestion, like *Digitaria ciliaris* (Gardener et al., 1993).

The preliminary archaeozoological results from Logardan have identified the site’s livestock in the post-Akkadian assemblage as sheep, goat, pig, cattle and equid (Vila, 2018), making their dung available and accessible as fuel resource. The archaeobotanical data from Logardan suggests animals were grazing nearby the site (dung was likely collected at a short distance) most of the year. Nonetheless, owing to the presence of potential weed seeds of small size and cereal chaff remains, it is also possible that plants discarded during the final stages of crop processing (sieving and winnowing) were either added later in the preparation of dung cakes, or given as fodder to the livestock. Weeding fields to provide animal fodder is a common practice carried out by local farmers of Shorsh. The animals identified in the post-Akkadian occupation of Logardan are all considered as suitable dung-producer animals. But was the dung from one specific animal preferred as fuel for firing pottery? Several studies have discussed the survival of seeds through animal digestion (by controlling the diet or evaluating the germination rate from dung). Studies reporting the process for sheep and goat are more abundant (Kuiters and Huiskes, 2010; Oveisi et al., 2021; Ramos et al., 2006; Treitler et al., 2017; Wang et al., 2017; Wessels, 2008), than for cattle and pig (Schepers and Van Haaster, 2015; Walther, 2011). Most of the wild/weed taxa recovered at Logardan can survive livestock digestion (Table 3). The archaeobotanical assemblage includes numerous taxa having either hard seed coats – legumes, Cyperaceae and Chenopodiaceae – and/or tiny seeds such as *Digitaria*/*Dinebra*-type, *Eragrostis* sp. or *Asperula involucrata*, characteristics allowing them to survive digestion. Other, larger (including cereals) and softer seeds (such as wild grasses) are much less likely to pass through animals, though cattle digestion is not as damaging. Among the wild taxa/groups identified at Logardan, those capable of surviving sheep digestion are dominant (N = 18, 81.8%), followed by cattle (N = 12, 54.5%). Sheep dung pellets

allow to reach higher temperatures than cow dung (Winterhalder et al., 1974) but it creates more smoke, and M.-L. Sidoroff (1991, p. 56) reported that inhabitants of Acoma use it less as it « *burns too hot* » and damages the pottery (colour). Different dung types can also be used at different time in the firing process (Anderson and Ertüg-Yaras, 1998). Considering the high skills of the potters of Logardan, they were presumably able to manage the specific properties of each type of fuel, during firing. However, further work is required for both, the identification of taxa in archaeological assemblages and in experimental burning of fuel.

5.4. Kilns and crops

Apart from the strong correlation between kilns and dung-derived taxa, the analysis also highlights the overlap of kilns and crops, mainly cereals. Indeed, kilns can be divided into two groups, those dominated by (wild) taxa of class 5 and those dominated by crop grains (class 1) and chaff (class 2). Whereas the plotted samples indicate all types of kilns overlap, a distinction can be made according to archaeological levels; kilns from level 3a being more associated to class 5 and kilns from level 3b being more associated to class 1 and 2.

Experiments indicate that grains (and chaff) rarely survive caprines digestion (Valamoti and Charles, 2005; Wallace and Charles, 2013) whereas a better survival rate is recorded for cattle (Schepers and Van Haaster, 2015; Walther, 2011). There is no ethnographic record of use of pig manure as fuel but despite their diet and digestion process (omnivores), seeds can survive pig digestion (Walther, 2011). Thus, the difference in the plant composition from the kilns of Logardan could be attributed to change in animal husbandry (and the dung providers) or dung preference, with a 'switch' from cattle in level 3b to sheep and goat in level 3a. The switch can also be in the proportion of the types of dung used: as sheep dung produces high heat (Chávez, 1984), its use either required a lower quantity, or a better experience (Copper et al., 2021, p. 130), a skill that the highly specialised potters from Logardan had (Baldi, this volume). Preliminary analysis of the faunal remains doesn't allow this hypothesis to be confirmed yet. In addition, the preparation of dung cakes for fuel usually includes the addition of organic material, often agricultural by-products deriving from crop-processing (Anderson and Ertüg-Yaras, 1998; Barnard and Kristoferson, 1985). Thus, the variations in the botanical composition can also reflect changes in the recipe used to prepare the cakes. Similarly, some taxa could have been used as temper in the construction of the kilns (walls and dome). In this case, the « *temper taxa* » could have been charred during the firing process, when internal fragments of the wall collapsed, or merely by pyrolysis at 150–250 °C. Thus, they would have been mixed with taxa deriving from dung inside the kilns.

It is also possible that the kilns were used for domestic cooking once the firing process was completed and the ceramics removed. Using a single structure for both, domestic cooking and craft activities is attested for Neolithic ovens (Barbaro et al., 2021), when the structures were smaller and activities unspecialised. Such a practice would have the advantage of using heat retained in the kiln after production though it should be noted that the design of the kilns in the Logardan workshop area is highly specialised and not necessarily suitable for food preparation.

6. Conclusion

The large-scale sampling for archaeobotanical remains instigated at Logardan provides valuable data on the plant economy of the site. In particular, the unique opportunity to investigate the fuel management strategy associated with the industrial production of the ceramics at the end of the 3rd mill. BCE. The scale and intensive nature of ceramic production at Logardan, would have required reliable access to large quantities of fuel on a regular basis. Dung on its own or combined with small quantities of wood was the fuel of choice for the local potters. This

choice has a number of advantages, including the reliable and large-scale availability of dung from the sites' livestock (cattle, sheep and goat), and the thermal properties of dung fuel such as its burning constancy, and the ability to adjust the temperature by varying the ingredients incorporated into the manufactured dung fuel. The virtual absence of wood charcoal in the samples may well imply that local environments had already been significantly impacted by woodland clearance (Arnold, 1972; Sillar, 2000, p. 51) making livestock dung an even more inevitable fuel source. Further studies will allow investigation on fuel use based on multi-proxy analysis (spherulites, phytoliths, micromorphology). It will certainly help to confirm archaeobotanical observation on the fuelling of the kilns and to refine our understanding of the impact of human and climate change on the landscape and vegetation.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

Acknowledgments

We would like to thank the reviewers for their advice and comments, which have helped us improve the paper. We are very grateful to J.S. Baldi and C. Padovani for providing information on the pottery workshop contexts of Logardan and their enlightening comments on the discussion. We also would like to thank the Directorate of Antiquities of Suleymaniah and the General Directorate of Kurdistan for allowing us to export the samples to carry out the archaeobotanical analysis.

Funding

This project has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie grant agreement No 101018916. Work was carried out at the University of Oxford.

Appendix A. Supplementary material

Supplementary material to this article can be found online at <https://doi.org/10.1016/j.jasrep.2023.104259>.

References

- Ahmad, S.A., Salih, S., 2019. Qara Dagh mountain plant field guide. Kurdistan Botanical Foundation, Suleymaniah.
- Amiri, M.S., Joharchi, M.R., Nadaf, M., Nasseh, Y., 2020. Ethnobotanical knowledge of *Astragalus* spp.: The world's largest genus of vascular plants. *Avicenna J. Phytomed.* 10, 128–142.
- Anderson, S., Ertüg-Yaras, F., 1998. Fuel fodder and faeces: An ethnographic and botanical study of dung fuel use in Central Anatolia. *Environ. Archaeol.* 1, 99–109.
- Arnold, D.E., 1972. Native Pottery Making in Quinua, Peru. *Anthropos* 67, 858–872.
- Baldi, J.S., Zingarello, M., 2021. "A ceramic tale for three oikumenai" from the Qara Dagh area (Iraqi Kurdistan). In: Lebeau, M. (Ed.), *Identity, Diversity & Contact: From the Southern Balkans to Xinjiang, from the Upper Paleolithic to Alexander*, International Congress "The East" (ICE). Brepols, Turnhout, Belgium, pp. 41–72.
- Baldi, J.S., Naccaro, H., Padovani, C., Halkawt, Q., 2018. Logardan Trench D: Stratigraphy and Architecture. In: Vallet, R. (Ed.), *Report on the Fourth Season of Excavations at Girdi Qala and Logardan*. Directorate of Antiquities of Suleymaniah, pp. 39–66.
- Baldi, J.S., Padovani, C., 2019. Logardan Trench D: Stratigraphy and Architecture. In: Vallet, R. (Ed.), *Report on the Fifth Season of Excavation at Girdi Qala and Logardan*. Directorate of Antiquities of Kurdistan Regional Government, Suleymaniah, pp. 23–49.
- Baldi, J.S., 2022. Bits of Uruk Before and Outside the Uruk Colonial Sphere: The Qara Dagh Area and Some Early Thoughts on a Reassessment of the Uruk Expansion. In:

- Sconzo, P., Iamoni, M., Peyronel, L., Baldi, Johnny Samuele (Eds.), Late Chalcolithic Northern Mesopotamia in Context: Papers from the Workshop Held at the 11th ICAANE in Munich, April 5th 2018, Subartu. Brepols, Turnhout, pp. 123–150.
- Baldi, J.S., this volume. Putting chaînes opératoires back in their workspace and tracking down their entanglements. The evolution of the Logardan workshop (Iraqi Kurdistan) at the end of the Early Bronze Age. *J. Archaeol. Sci. Rep.*
- Barbaro, C.C., Forte, V., Muntioni, I.M., Eramo, G., 2021. A Multidisciplinary Approach to the Study of Early Neolithic Pyrotechnological Structures. The Case Study of Portonovo (Marche, Italy). *Open Archaeol.* 7, 1160–1175. <https://doi.org/10.1515/opar-2020-0198>.
- Barnard, G., Kristoferson, L.A., 1985. Agricultural residues as fuel in the Third World, Technical report. Energy Information Programme. Earthscan, London.
- Bogaard, A., Charles, M., Livarda, A., Ergun, M., Filipović, D., Jones, G., 2013. The Archaeobotany of Mid-late Occupation Levels at Neolithic Çatalhöyük. In: Hodder, I. (Ed.), *Humans and Landscapes of Çatalhöyük: Reports from the 2000–2008 Seasons*, Çatalhöyük Project Series. British Institute at Ankara, London, pp. 93–128.
- Bogaard, A., Ryan, P.D., Yalman, N., Twiss, K., Mazzucato, C., Farid, S., 2014. Assessing outdoor activities and their social implications at Çatalhöyük. In: Hodder, I. (Ed.), *Integrating Çatalhöyük: Themes from the 2000–2008 Seasons*, BIAA Monograph & Monumenta Archaeologica. Los Angeles, London, pp. 23–148.
- Bor, N.L., Guest, E., 1968. Flora of Iraq: Gramineae. Ministry of Agriculture of the Republic of Iraq, Baghdad.
- Bouchaud, C., Newton, C., Veen, M.V. der, Vermeeren, C., 2018. Fuelwood and Wood Supplies in the Eastern Desert of Egypt during Roman Times. In: Brun, J.-P., Faucher, T., Redon, B., Sidebotham, S. (Eds.), *The Eastern Desert of Egypt during the Greco-Roman Period: Archaeological Reports*. Collège de France. <https://doi.org/10.4000/books.edf.5237>.
- Braadbaart, F., Poole, I., 2008. Morphological, chemical and physical changes during charcoalification of wood and its relevance to archaeological contexts. *J. Archaeol. Sci.* 35, 2434–2445. <https://doi.org/10.1016/j.jas.2008.03.016>.
- Burton, G.W., Andrews, J.S., 1948. Recovery and viability of seeds of certain southern grasses and lespedeza passed through the bovine digestive tract. *J. Agric. Res.* 76, 95–103.
- Cappers, R.T.J., Bekker, R.M., Jans, J.E.A., 2012. *Digitale zadenatlas van Nederland = Digital seed atlas of the Netherlands*, Groningen archaeological studies. Barkhuis Publishing: Groningen University Library, Eelde, Groningen.
- Chabal, L., 2001. Les potiers, le bois et la forêt à l'époque romaine, à Sallèles d'Aude (Ier - IIe s. ap. J.-C.). In: 20 Ans de Recherches à Sallèles d'Aude. Colloque Des 27–28 Septembre 1996 (Sallèles d'Aude), Collection « ISTA ». Institut des Sciences et Techniques de l'Antiquité, Besançon, pp. 93–110.
- Charles, M., 1998. Fodder from dung: The recognition and interpretation of dung-derived plant material from archaeological sites. *Environ. Archaeol.* 1, 111–122. <https://doi.org/10.1179/env.1996.1.1.111>.
- Charles, M., Forster, E., Wallace, M., Jones, G., 2015. "Nor ever lightning char thy grain" I: establishing archaeologically relevant charring conditions and their effect on glume wheat grain morphology. *Sci. Technol. Archaeol.* 1, 1–6. <https://doi.org/10.1179/2054892315y.0000000008>.
- Chávez, K.L.M., 1984. Traditional Pottery of Raqch'i, Cuzco, Peru: A Preliminary Study of Its Production, Distribution, and Consumption. *Nawpa Pacha: J. Andean Archaeol.* 22 (23), 161–210.
- Copper, M., Griffin, G., Batt, C., 2021. An experimental approach to the properties of sheep dung as a pot firing fuel and identification of its use in archaeological contexts. In: *Expérimentons La Protohistoire (Néolithique-Âges Des Métaux) : Dialogues Interdisciplinaires*. Presented at the 3ème journée thématique de l'APERA, Bulletin de l'APERA, pp. 123–136.
- Costamagno, S., Théry-Parisot, I., Brugal, J.-P., Guibert, R., 2005. Taphonomic consequences of the use of bones as fuel. Experimental data and archaeological applications. In: O'Connor, T. (Ed.), *Biosphere to Lithosphere: New Studies in Vertebrate Taphonomy*. Oxbow Books, Oxford, pp. 51–62.
- Deckers, K., 2010. Vegetation and wood use in the Bronze Age based on charcoals from Emar. In: Finkbeiner, U., Sakal, F. (Eds.), *Emar After the Closure of the Tabqa Dam. The Syrian-German Excavations 1996–2002*, Subartu. Brepols, Turnhout, pp. 225–244.
- Douché, C., Padovani, C., 2019. Ethnographic study: exploitation of the natural resources in the Tavuk Cay valley. In: Vallet, R. (Ed.), *Report on the Fifth Season of Excavation at Girdi Qala and Logardan*. Directorate of Antiquities of Kurdistan Regional Government, Sulaymaniah, pp. 63–72.
- Douché, C., in press. Living and cultivating on a lakeshore during the PPNB: archaeobotanical evidence from Tell Aswad, southern Syria. *SENEPSE. Neolithic in Syria*.
- Elliott, S., Matthews, W., 2023. Dung detective! A multi-scalar, multi-method approach to identification and analysis of ancient faecal material. *Quat. Int.*, S1040618223000356 <https://doi.org/10.1016/j.quaint.2023.02.005>.
- Fajal, B., Marguerie, D., Bucur, I., Bernouis, P., 2015. L'atelier de potier médiéval de la Picaudière (La Haute-Chapelle, Orne): four, soles et combustible. *ArcheoSciences. Revue d'archéométrie* 177–184. <https://doi.org/10.4000/archeosciences.4485>.
- Gardner, C.J., McIvor, J.G., Jansen, A., 1993. Passage of legume and grass seeds through the digestive tract of cattle and their survival in faeces. *J. Appl. Ecol.* 30, 63–74. <https://doi.org/10.2307/2404271>.
- Ghazanfar, S.A., McDaniel, T., 2016. Floras of the Middle East: a quantitative analysis and biogeography of the flora of Iraq. *Edinb. J. Bot.* 73, 1–24.
- Gonzalez-Urquijo, J., Ibáñez, J., Zapata, L., Peña-Chocarro, L., 2001. Estudio etnoarqueológico sobre la cerámica Gzaa (Marruecos). Técnica y contexto social de un artesanado arcaico. *Trab. Prehist.* 58, 5–27. <https://doi.org/10.3989/tp.2001.v58.i1.231>.
- Gosselain, O.P., 1992. Bonfire of the Enquiries. Pottery Firing Temperatures in Archaeology: What For? *J. Archaeol. Sci.* 19, 243–259.
- Guest, E., 1966. Flora of Iraq: Introduction to the flora: an account of the geology, soils, climate and ecology of Iraq with gazetteer, glossary and bibliography. Ministry of Agriculture, Baghdad.
- Guest, E., 1980. Flora of Iraq: Cornaceae - Resedaceae, vol 4/2. Kew Royal Botanic Gardens, London.
- Gur-Arie, 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. *J. Archaeol. Sci.* 40, 4331–4347.
- Hansen Streily, A., 2000. Early pottery kilns in the Middle East. *Paleo* 26, 69–81. <https://doi.org/10.3406/paleo.2000.4711>.
- Hastorf, C.A., Wright, M.F., 1998. Interpreting wild seeds from archaeological sites, a dung charring experiment from the Andes. *J. Ethnobiol.* 18, 211–227.
- Huot, J.-L., Delcroix, G., 1972. Les fours dits de potier dans l'Orient ancien. *Syria* 49, 35–95. <https://doi.org/10.3406/syria.1972.6331>.
- Jacomot, S., et al., 2006. Identification of cereal remains from archaeological sites. IPAS, Basel University.
- Kabukcu, C., 2018a. Identification of woodland management practices and tree growth conditions in archaeological fuel waste remains: A case study from the site of Catalhöyük in central Anatolia, Turkey. *Quat. Int.* 463, 282–297. <https://doi.org/10.1016/j.quaint.2017.03.017>.
- Kabukcu, C., 2018b. Wood Charcoal Analysis in Archaeology. In: Pişkin, E., Marciniak, A., Bartkowiak, M. (Eds.), *Environmental Archaeology, Interdisciplinary Contributions to Archaeology Book Series (IDCA)*. Springer-Nature, Davis, pp. 133–154.
- Karacis, S., Jameson, M., Weil, A.B., 2016. A burning issue: Firing temperatures and the production of late bronze age pottery from Tarsus-Gözlükule, Turkey. *J. Archaeol. Sci. Rep.* 9, 599–607. <https://doi.org/10.1016/j.jasrep.2016.08.046>.
- Katz, O., Gilead, I., Bar (Kutiel), P., Shahack-Gross, R., 2007. Chalcolithic Agricultural Life at Grar, Northern Negev, Israel: Dry Farmed Cereals and Dung-Fueled Hearths. *Paléorient* 33, 101.
- Kuiters, A.T., Huiskes, H.P.J., 2010. Potential of endozoochorous seed dispersal by sheep in calcareous grasslands: correlations with seed traits | WorldCat.org. *Appl. Veg. Sci.* 13, 163–172. <https://doi.org/10.1111/j.1654-109X.2009.01058.x>.
- Laugier, E.J., Casana, J., Glatz, C., Sameen, S.M., Cabanes, D., 2021. Reconstructing agro-pastoral practice in the Mesopotamian-Zagros borderlands: Insights from phytolith and FTIR analysis of a dung-rich deposit. *J. Archaeol. Sci. Rep.* 38, 103106 <https://doi.org/10.1016/j.jasrep.2021.103106>.
- Livingstone Smith, A., 2001. Bonfire II: The Return of Pottery Firing Temperatures. *J. Archaeol. Sci.* 28, 991–1003. <https://doi.org/10.1006/jasc.2001.0713>.
- Miller, N.F., 1982. *Economy and Environment of Malyan, A Third Millennium BC urban center in southern Iran*. The University of Michigan, Ann Arbor.
- Miller, N.F., 1984. The use of dung as fuel: An ethnographic example and an archaeological application. *Paleo* 10, 71–79. <https://doi.org/10.3406/paleo.1984.941>.
- Miller, N.F., Marston, J.M., 2012. Archaeological fuel remains as indicators of ancient west Asian agropastoral and land-use systems. *J. Arid Environ.* 86, 97–103. <https://doi.org/10.1016/j.jaridenv.2011.11.021>.
- Miller, N.F., Smart, T.L., 1984. Intentional burning of dung as fuel: A mechanism for the incorporation of charred seeds into the archaeological record. *Record* 4, 15–28.
- Nesbitt, M., 2017. *Identification Guide for Near Eastern Grass Seeds*. Routledge, London.
- Nicholson, P., 1989. Experimental Determination of the Purpose of a Box Oven. In: Kemp, B. (Ed.), *Amarna Reports, Occasional Publications*. Egypt Exploration Society, London, pp. 241–252.
- Nicholson, P., 2010. Kilns and firing structures. *UCLA Encycloped. Egyptol.* 1, 1–10.
- Nicholson, P.T., Patterson, H.L., 1989. Ceramic technology in Upper Egypt: A study of pottery firing. *World Archaeol.* 21, 71–86.
- Norsker, H., 1987. Self-reliant potter: refractories and kilns. *Deutsche Gesellschaft für Technische Zusammenarbeit. F. Vieweg, Braunschweig*.
- Oveisi, M., Ojaghi, A., Rahimian Mashhadi, H., Müller-Schärer, H., Reza Yazdi, K., Pourmorad Kaleibar, B., Soltani, E., 2021. Potential for endozoochorous seed dispersal by sheep and goats: Risk of weed seed transport via animal faeces. *Weed Res.* 61, 1–12. <https://doi.org/10.1111/wre.12461>.
- Padovani, C., 2023. Kiln Technology and Potters' Agency in the Early Bronze Age: The Social Construct of Logardan Firing Areas, Western Qara Dag. In: Marchetti, N., Campeggi, M., Cavaliere, F., D'Orazio, C., Giacosa, G., Mariani, E. (Eds.), *Field Reports. Environmental Archaeology. Hammering the Material Word*. Presented at the Proceedings of the 12th International Congress on the Archaeology of the Ancient Near East. 6th–9th April 2021, Bologna, Harrassowitz, Wiesbaden.
- 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. *J. Archaeol. Sci.* 42, 107–118. <https://doi.org/10.1016/j.jas.2013.10.038>.
- Portillo, M., Belarte, M.C., Ramon, J., Kallala, N., Sanmartí, J., Albert, R.M., 2017. An ethnoarchaeological study of livestock dung fuels from cooking installations in northern Tunisia. *Quat. Int. Archaeol. Fuels: Social Environ. Fact. Behav. Strateg. Multi-resource Manage.* 431, 131–144. <https://doi.org/10.1016/j.quaint.2015.12.040>.
- Portillo, M., García-Suárez, A., Matthews, W., 2020. Livestock faecal indicators for animal management, penning, foddering and dung use in early agricultural built environments in the Konya Plain, Central Anatolia. *Archaeol. Anthropol. Sci.* 12, 40. <https://doi.org/10.1007/s12520-019-00988-0>.
- Proctor, L., Smith, A., Stein, G.J., 2022. Archaeobotanical and dung spherulite evidence for Ubaid and Late Chalcolithic fuel, farming, and feasting at Surezha, Iraqi

- Kurdistan. *J. Archaeol. Sci. Rep.* 43, 103449 <https://doi.org/10.1016/j.jasrep.2022.103449>.
- Ramos, M.E., Robles, A.B., Castro, J., 2006. Efficiency of endozoochorous seed dispersal in six dry-fruited species (Cistaceae): From seed ingestion to early seedling establishment. *Plant Ecol.* 185, 97–106.
- Ramsay, J.H., Parker, S.T., 2016. A diachronic look at the agricultural economy at the Red Sea Port of Aila: An archaeobotanical case for hinterland production in arid environments. *Bull. Am. Sch. Orient. Res.* 376, 101.
- Rehder, J.E., 2000. *The Mastery and Uses of Fire: A Sourcebook on Ancient Pyrotechnology*. McGill-Queen's University Press, Montreal.
- Riehl, S., 2006. Nomadism, Pastoralism and Transhumance in the Archaeobotanical Record—Examples and Methodological Problems. In: Hauser, S.R. (Ed.), *Die Sichtbarkeit von Nomaden Und Saisonaler Besiedlung in Der Archäologie. Multidisziplinäre Annäherungen an Ein Methodisches Problem, Orientwissenschaftliche Hefte. Orientwissenschaftliches Zentrum der Martin-Luther-Universität Halle-Wittenberg*, Halle, pp. 105–125.
- Roux, V., 2016. *Des céramiques et des hommes. Décoder les assemblages archéologiques*. Presses universitaires de Paris Nanterre, Nanterre.
- Russi, L., Cocks, P.S., Roberts, E.H., 1992. The Fate of Legume Seeds Eaten by Sheep from a Mediterranean Grassland. *J. Appl. Ecol.* 29, 772–778. <https://doi.org/10.2307/2404487>.
- Safaierad, R., Matthews, R., Dupont, L., Zolitschka, B., Marinova, E., Djamali, M., Vogt, C., Azizi, G., Lahijani, H.A.K., Matthews, W., 2023. Vegetation and climate dynamics at the dawn of human settlement: multiproxy palaeoenvironmental evidence from the Hashilan Wetland, western Iran. *J. Quat. Sci.* 1–16. <https://doi.org/10.1002/jqs.3557>.
- Schepers, M., Van Haaster, H., 2015. Dung matters: An experimental study into the effectiveness of using dung from hay-fed livestock to reconstruct local vegetation. *Environ. Archaeol.* 20, 66–81. <https://doi.org/10.1179/1749631414Y.0000000030>.
- Schoenbaum, I., Kigel, J., Barkai, D., Landau, S., 2009. Weed infestation of wheat fields by sheep grazing stubble in the Mediterranean semi-arid region. *Crop Pasture Sci.* 60, 675. <https://doi.org/10.1071/CP08283>.
- Sidoroff, M.-L., 1991. Acoma Pueblo Pottery. *Bull. Prim. T.* 1, 55–57.
- 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, 43–60.
- Smith, A., 2012. Akkadian and post-Akkadian Plant Use at Tell Leilan. In: Weiss, H. (Ed.), *Seven Generations since the Fall of Akkad, Studia Chaburensia*. Harrassowitz, Wiesbaden, pp. 225–240.
- Smith, A., Graham, P.J., Stein, G.J., 2015. Ubaid plant use at Tell Zeidan, Syria. *Paleo* 41, 51–69. <https://doi.org/10.3406/paleo.2015.5675>.
- Smith, A., Proctor, L., Hart, T.C., Stein, G.J., 2019. The burning issue of dung in archaeobotanical samples: a case-study integrating macro-botanical remains, dung spherulites, and phytoliths to assess sample origin and fuel use at Tell Zeidan, Syria. *Veget. Hist. Archaeobot.* 28, 229–246. <https://doi.org/10.1007/s00334-018-0692-9>.
- Spengler, R.N., 2019. Dung burning in the archaeobotanical record of West Asia: where are we now? *Veg. Hist. Archaeobot.* 28, 215–227.
- ter Braak, C.J.F., Šmilauer, P., 2018. *Canoco reference manual and user's guide: software for ordination (version 5.10)*. Biometris. Wageningen University & Research, Wageningen.
- Thér, R., Kallistová, A., Svoboda, Z., Května, P., Lisá, L., Burgert, P., Bajer, A., 2019. How was neolithic pottery fired? An exploration of the effects of firing dynamics on ceramic products. *J. Archaeol. Method Theory* 26, 1143–1175. <https://doi.org/10.1007/s10816-018-9407-x>.
- Théry-Parisot, I., 2002. Fuel management (bone and wood) during the lower Aurignacian in the pataud rock shelter (lower Palaeolithic, les eyzies de Tayac, Dordogne, France). *Contribution of experimentation. J. Archaeol. Sci.* 29, 1415–1421. <https://doi.org/10.1006/jasc.2001.0781>.
- Théry-Parisot, I., Henry, A., Rageot, M., 2020. Artisanats du feu, gestion des combustibles et paléoenvironnements: de la compréhension des dépôts à l'analyse des pratiques. Méthodes, limites et apports de l'expérimentation. In: Beyries, S. (Ed.), *Expérimentation En Archéologie de La Préhistoire Bulletin de La Société Préhistorique Française. Archives Contemporaines*, Paris, pp. 105–121.
- Townsend, C.C., 1974. *Flora of Iraq: Leguminales*. Ministry of Agriculture of the Republic of Iraq, Baghdad.
- Treitler, J.T., Drissen, T., Stadtmann, R., Zerbe, S., Mantilla-Contreras, J., 2017. Complementing endozoochorous seed dispersal patterns by donkeys and goats in a semi-natural island ecosystem. *BMC Ecol.* 17, 42. <https://doi.org/10.1186/s12898-017-0148-6>.
- Valamoti, S.M., Charles, M., 2005. Distinguishing food from fodder through the study of charred plant remains: an experimental approach to dung-derived chaff. *Veg. Hist. Archaeobot.* 14, 528–533.
- Vallet, R. (Ed.), 2018. Report on the fourth season of excavation at Girdi Qala and Logardan, UMIFRE. CNRS – Institut Français du Proche-Orient, Suleymaniah.
- Vallet, R., 2019. Report on the Fifth Season of Excavations at Girdi Qala and Logardan. Directorate of Antiquities of Suleymaniah, Suleymaniah.
- Vallet, R., Baldi, J.S., Naccaro, H., Rasheed, K., Saber, S.A., Hamarashheed, S.J., 2017. New evidence on Uruk expansion in the Central Mesopotamian Zagros Piedmont. *Paléorient* 43, 61–87.
- Vallet, R., Baldi, J.S., Zingarello, M., Sauvage, M., Naccaro, H., Paladre, C., Padovani, C., Bridey, F., Rasheed, K., Rauf, K., Halkawt, Q., 2019. The emergence of cultural identities and territorial policies in the longue durée: A view from the Zagros Piedmont. *Paléorient* 45, 163–189. <https://doi.org/10.4000/paleorient.751>.
- Vallet, R., 2020. Early Uruk Expansion in Iraqi Kurdistan: New Data from Girdi Qala and Logardan. In: Otto, A., Herles, M., Kaniuth, K. (Eds.), *Proceedings of the 11th International Congress on the Archaeology of the Ancient Near East*. Harrassowitz Verlag, Wiesbaden, pp. 445–462. <https://doi.org/10.2307/j.ctv10tq3zv.41>.
- van Zeist, W., 1999. Third to first millennium BC plant cultivation on the Khabur, North-eastern Syria. *Palaeohistoria* 41 (42), 111–125.
- Van Zeist, W., Vynckier, J., 1984. Palaeobotanical investigations of Tell ed-Dér. In: Meyer, L. de (Ed.), *Tell ed-Dér IV: progress reports (second series)*, Comité belge de recherches en Mésopotamie. Peeters, Leuven, pp. 119–133.
- van Zeist, W., Bottema, S., 1977. Palynological investigations in Western Iran. *Palaeohistoria* 19, 19–85.
- Van Zeist, W., Wright, H.E., 1963. Preliminary Pollen Studies at Lake Zeribar, Zagros Mountains, Southwestern Iran. *Science* 140, 65–67.
- Vaschalde, C., Chabal, L., 2020. La production de combustible pour les fours d'après l'anthracologie et la dendrométrie : exploitation par rotation des taillis de chênes méditerranéens. In: Mauné, S., Bourgaud, R. (Eds.), *Contours (Saint Pargoire, Hérault). Recherches Pluridisciplinaires Sur Un Atelier d'amphores Vinaïres de Gaule Narbonnaise, Monographies d'Archéologie Méditerranéenne. Éditions de l'Association pour le développement de l'archéologie en Languedoc-Roussillon*, Lattes, pp. 227–247.
- Vila, E., 2018. Faunal Remains from Girdi Qala and Logardan. In: Vallet, R. (Ed.), *Report on the Fourth Season of Excavations at Girdi Qala and Logardan. Directorate of Antiquities of Suleymaniah, Suleymaniah*, pp. 31–38.
- Wallace, M., Charles, M., 2013. What goes in does not always come out: The impact of the ruminant digestive system of sheep on plant material, and its importance for the interpretation of dung-derived archaeobotanical assemblages. *Environ. Archaeol.* 18, 18–30. <https://doi.org/10.1179/1461410313Z.00000000022>.
- Wallander, R.T., Olson, B.E., Lacey, J.R., 1995. Spotted knapweed seed viability after passing through sheep and mule deer. *J. Rang Manage* 48, 145–149.
- Walther, D., 2011. The effect of grazing and management measures on the vegetation of a dehesa – an agro-ecosystem formed during centuries by agro-sylvopastoral exploitation. PhD Thesis. Der Universität Regensburg, Kaiserslautern.
- Wang, S., Lu, W., Waly, N., Ma, C., Zhang, Q., Wang, C., 2017. Recovery and germination of seeds after passage through the gut of Kazakh sheep on the north slope of the Tianshan Mountains. *Seed Sci. Res.* 27, 43–49. <https://doi.org/10.1017/S0960258517000022>.
- Wessels, S.C., 2008. The contribution of sheep zoochory to the conservation and restoration of target plant communities in isolated sand ecosystems (phd). Technische Universität, Darmstadt.
- Willcox, G., 2002. Evidence for ancient forest cover and deforestation from charcoal analysis of ten archaeological sites on the Euphrates. In: Thiébaud, S. (Ed.), *Charcoal Analysis: Methodological Approaches, Palaeoecological Results and Wood Uses. BAR International Series. Archaeopress, Oxford*, pp. 141–145.
- Winterhalder, B., Larsen, R., Thomas, R.B., 1974. Dung as an essential resource in a highland Peruvian community. *Hum. Ecol.* 2, 89–104. <https://doi.org/10.1007/BF01558115>.
- Zapata Peña, L., Peña-Chocarro, L., Ibañez-Estévez, J.-J., Gonzáles Urquijo, J.E., 2003. Ethnoarchaeology in the maroccan Jebala (Western Rif): wood and dung as fuel. In: Neumann, K., Butler, A., Kahlheber, S. (Eds.), *Food, Fuel and Fields: Progress in African Archaeobotany, Africa Praehistorica. Heinrich-Barth-Institut, Köln*, pp. 163–175.
- Zingarello, M., 2018. Bronze Age Ceramics from Logardan. In: Vallet, R. (Ed.), *Report on the Fourth Season of Excavations at Girdi Qala and Logardan. Directorate of Antiquities of Kurdistan Regional Government, Suleymaniah*, pp. 137–152.
- Zingarello, M., in press. Between Tigris and Zagros Piedmont. A Material-Cultural Perspective from Logardan in the Early Bronze Age. In: Couturaud, B. (Ed.), *Early Bronze Age in Iraqi Kurdistan. Les Presses de l'Ifpo, Beyrouth*.
- Zohary, M., 1950. *The Flora of Iraq and its Phytogeographical Subdivision*. Government Press, Baghdad.
- Zohary, M., 1973. *Geobotanical Foundations of the Middle East*, 1st ed. Gustav Fischer Verlag, CRC Press, Stuttgart.