**Direct evidence from lipid residue analysis for the routine consumption of millet in Early Medieval Italy**

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## Abstract

Millets have been cultivated in Europe since the Late Neolithic but, beyond recording their presence, little is known about their use and context of consumption. As a C4 plant, the contribution of millet on diet can be readily identified through stable isotope analysis of human bones. Using this approach, however, previous studies have been unable to distinguish direct consumption of the cereal from the consumption of millet fed animals. Historical evidence suggests that the latter was common practice. To address this issue, we present the first direct evidence for millet consumption in Medieval period using organic residue analysis. Lipid were extracted from 45 pottery vessels from the Episcopal centre in Padua, Northern Italy dating from the 6th to 10th centuries AD. Miliacin, a biomarker for broomcorn millet, was present in many of the cooking vessels tested. Based on the co-occurrence of miliacin with other food derived lipids and the vessel typologies, we suggest that millet was a common culinary ingredient during the Early Medieval period in this region. The earliest evidence dates to the 6th c. AD and notably derives from deposits associated with high status occupation of the site, a surprising result given the common association of these crops as low-status or starvation foods in the historic periods. It is likely that millet was a common cereal staple in human diet during this period in North-eastern Italy and that its use was far less restricted than previously thought. More broadly, our study highlights the efficacy of combining organic residue analysis and stable isotope analysis of bone to relate culinary and dietary information of ancient populations.

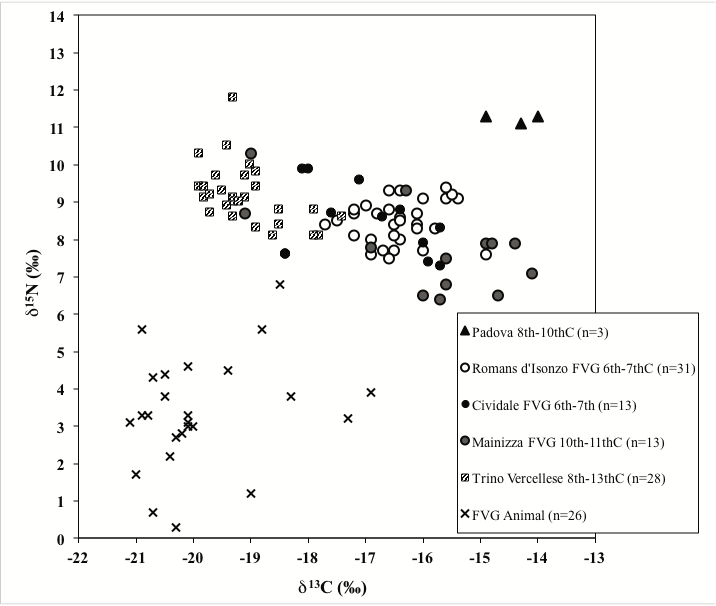
Keywords; Millet, miliacin, organic residue analysis, lipids, ceramic, cooking wares, pottery, early medieval

**Introduction**

The cultivation of millet in Europe has a long history but its significance in ancient economies is far from clear. In Northern Italy, the botanical evidence for the appearance of millets (Broomcorn millet, *Panicum miliaceum* and Foxtail millet, *Setaria italica*) from the Late Neolithic period is debated, however there is clear evidence for widespread cultivation during the Bronze and Iron Ages [(Castiglioni and Rottoli, 2013; Motuzaite-Matuzeviciute et al., 2013)](https://paperpile.com/c/A6xqY5/kx2H+OuDx). Millet has also been identified chemically in alpine sediments dating to the Bronze Age ([Jacob et al., 2008)](https://paperpile.com/c/A6xqY5/P9YN+Jd98). Millet is a C4 plant and its contribution to human diet can also be assessed through stable isotope analysis of human bone collagen since it is relatively enriched in 13C compared to C3 cereal crops such as wheat, barley and oats. Stable isotope evidence broadly supports the botanical evidence, although the evidence is sporadic with only a few studies indicating that millets made a major contribution to prehistoric European human diets (e.g. Lightfoot et al., 2013; Lightfoot et al., 2015; Knipper et al., 2016; Goude et al., 2017), including humans from Bronze Age Northern Italy [(Tafuri et al., 2009; Laffranchi et al., 2016)](https://paperpile.com/c/A6xqY5/V56z). However, it is unclear from this evidence whether millet was directly consumed or became indirectly incorporated into the human tissues through the consumption of the meat and milk of millet-foddered animals.

In the Roman period, there is little evidence that millet was any more than a minor crop. Most historical accounts suggest that apart from animal feed it was deemed suitable only for the poor, although socio-cultural influences would have played a part in their use in the diet [(Spurr, 1983;](https://paperpile.com/c/A6xqY5/N9Zq) Murphy, 2016[)](https://paperpile.com/c/A6xqY5/N9Zq). Archaeobotanical evidence attests to the presence of millet on Roman sites, usually in small proportions in comparison to other major cereal crops (Murphy, 2016) and C4 signals rarely register in the stable isotope values of humans from this period. Only one individual buried in periurban Rome has clearly enriched carbon stable isotopes values indicative of C4 plant (millet) consumption [(Killgrove and Tykot, 2013)](https://paperpile.com/c/A6xqY5/h4JS). However, stable isotope investigations are still quite limited for the Roman period in general and there have been no dietary isotopic studies of Roman and Late Antique diet in Northern Italy. A recent survey of the botanical evidence has shown that millets as well as another C4 crop, sorghum, made a resurgence in the Early Medieval period of Northern Italy as part of a mixed agrarian economy [(Castiglioni and Rottoli, 2013; Rottoli, 2014)](https://paperpile.com/c/A6xqY5/kx2H+ILLn). However, written accounts consider millets and sorghums to be a minor crop, inferior to the major grains, such as spelt that were important in the Roman period. The term “*grano minuto*” is commonly used in historical texts to describe millet (Montanari, 1979), although it is not clear whether this refers to its short growing season, sowed in spring and harvested in August, or its low status as a food for the poor. In areas of Northern Spain, unlike wheat and barley, millets were tax exempt in the Medieval period and so peasants did not need to use part of the harvest to pay rents (Zapata and Ruiz-Alonso, 2013), thus reinforcing the idea that it was grown and consumed by the poor.

The current stable isotope evidence shows widespread consumption of C4 foodstuffs during the Early Medieval period of North East Italy (Fig 1): Padova (Marinato, 2017), Friuli-Venezia Giulia (FVG: Romans d’Isonzo, Cividale and Mainizza, [Iacumin et al., 2014](https://paperpile.com/c/A6xqY5/LjJw)) and Trino Vercellese (Reitsema and Vercellotti, 2012). Given the absence of any C4 wild plants in this area, the observed high δ13C are most easily explained by consumption of millet and/or sorghum directly or through animals foddering on millet. Limited analysis of animal bones, many unidentified, is consistent with the use of millet or sorghum as a fodder, as shown by collagen δ13C values above ca. -18‰ (Fig 1; [Iacumin et al., 2014](https://paperpile.com/c/A6xqY5/LjJw)).



**Figure 1:** Stable carbon and nitrogen isotope data from fauna and adult humans from Northern Italy (6th - 13th centuries) deriving from published sources.

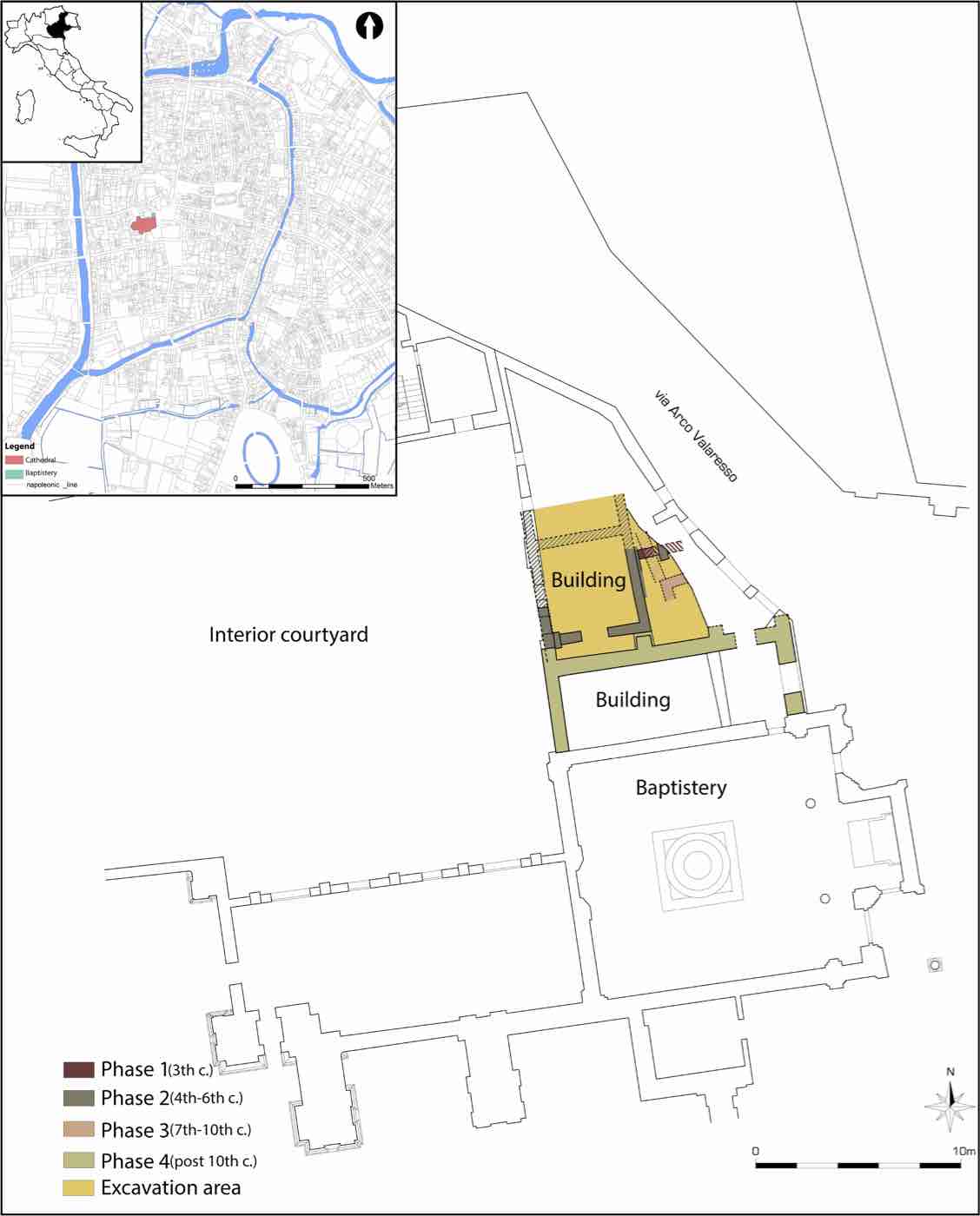
Overall, whilst changes in the production of millets have been well documented there is little evidence regarding their use or the social context of their consumption. Recently, a chemical marker for broomcorn millet (miliacin) has been identified in European and East Asian Bronze Age pottery [(Heron et al., 2016)](https://paperpile.com/c/A6xqY5/Dzg0), providing compelling evidence of its direct consumption at this time. Miliacin (olean-18-en-3β-ol methyl ether) is a pentacyclic triterpene methyl ether (PTME) that is enriched in seeds of *Panicum miliaceum* miliaceum (Bossard et al., 2013). It is readily absorbed in the walls of pottery during cooking and is highly resistant to degradation. This approach allows the crop itself to be directly linked with material culture, i.e. ceramic containers, to potentially understand the mode of use, through association with vessels associated with cooking, storage, serving or even drinking, the context of vessel deposition and the other types of foods millet was combined with. The association of millet with pottery vessels therefore opens up a new opportunity to examine the role of millet in Early Medieval society; both its culinary role and its association with contexts attributable to different sectors of society.

Here, we examine organic residues associated with an assemblage of ceramics dating from Late Antique and Early Medieval Age (6th - 10th century) at the episcopal centre of Padova (Brogiolo et al., 2017). The site offers an opportunity to study the economic changes in the city over this period and particularly with Lombard occupation in the 7th century. The presence of a large number of jars (olla) throughout the sequence provides an ideal target for comparative residue analysis, especially as the forms show minor variation throughout the sequence. The jars are wide bellied and unglazed, and were clearly used for cooking as shown by a boiling line on the interior and sooting on the external surfaces.

## The site and its setting

Excavations of the episcopal centre of Padova between 2011-2012 revealed a rich archaeological sequence dating from Late Antiquity to the Modern Period (Figure 2). The first structure detected is Building 1 (Phase 1), dated to before the 4th century, however this remains unexcavated. Amoung the next series of structures (Phase 2) was a high status building (Building 2) with mosaic floors which was AMS dated by its rudus mortar to the second half of the 4th century (Addis et al., 2017). At the beginning of 7th c. (Phase 3) the building was destroyed by fire, as shown by burning on the mosaic floors and the presence of large pieces of charred wood. This event was most likely perpetrated by the Lombards who occupied the city from 602 AD (Brogiolo et al., 2017). The pottery from the destruction layers (layer 222, inside the building, and 340-344, outside the building) includes many domestic cooking vessels but also amphora and red slipwares from different Mediterranean regions. In the destruction layers, a huge quantity of architectonic material, roof elements and a number of marble fragments were recovered that can be linked to liturgical elements, including a piece of altar table (Vedovetto, 2017). Considering that the destruction of Building 2 is dated to the beginning of 7th c., the archaeological remains within the destruction layer are dated to the use of the building during the 6th c., preceding the destruction.

After this destruction, the site was associated with lower status activities (Phase 3) from the 7th to the 10th centuries. In particular during the 7th c. there is a rapid formation of occupation levels, including rammed earth surfaces (Nicosia et al., 2017) that suggest a more modest domestic context, with some small buildings constructed from stone and earth. At the same time there is a rapid accumulation of domestic waste in postholes that contain archaeological material dated between the 7th and 8th centuries and these are followed by 4 graves (two infants and two adults). One of these burials was deposited in a very deep and cut into a small part of a wall of building 2. These graves appear to be linked to the houses made with stone and earth material. The oldest grave (Tb. 14) is AMS dated to between 770-980 AD. There were no objects in the graves except for a deer antler comb dated to the 7th century in grave 7 (De Marchi, 2017). The area was subsequently intensively occupied, with a quick succession of dwelling surfaces exposed, and traces of frequent reconstruction of the buildings identified. Around the beginning of 10th c., a silty layer was deposited with construction rubble that obliterated the preceding activities. Following this event, a large building was constructed parallel to the northern wall of the Romanesque baptistery containing a number of infant burials (Phase 4). This marks a new important transformation of the area which reassumes its Christian function, maybe as external area of the early medieval baptistery (9th-11th century AD) .



**Figure 2**: Plan of archaeological excavation in the Padua city centre (after Brogiolo et al., 2017; Brogiolo, 2017a).

In terms of the pottery sequence, imported red slip wares were substituted by imitations from the 7th century, including regional glazed pottery and a very high number of locally produced cooking and coarse wares. The decline in imported pottery at this time is also typical of the other cities in this region (Brogiolo, 2011). From the beginning of 8th century, the cooking wares decline in frequency and become more difficult to distinguish, exacerbated by the disturbance and mixing of archaeological layers by later funerary activities.

There is a well preserved archaeobotanical sequence at the site with a range of cereals identified. In all phases *Triticum aestivum/durum* was the most abundant followed by broomcorn millet (*Panicum miliaceum*) and foxtail millet (*Setaria italica*), (Peña-Chocarro and Pérez-Jordà, 2017). The archaeozoological remains testify to the consumption of fish (almost all were identified as freshwater fish, Gabriel, 2017) and terrestrial animals in all periods with an increase of poultry from Late Antiquity to the Early Medieval period (Moreno García, 2017). Of particular interest are the four early medieval graves. Isotope analyses of collagen extracted from the skeletal remains of 3 individuals show that C4 plants made a sizeable direct or indirect contribution to the human diet (Marinato, 2017; Figure 1). The relatively high δ15N values (>10 ‰) observed in the adult skeletons would rule out a high cereal diet, leading to the suggestion that animals foddered on C4 plants as a likely scenario, although a partially marine diet is also plausible. In previous studies where high nitrogen have been observed with a C4 signature, animals were also clearly consuming C4 crops as shown by direct stable isotope evidence (Alexander et al., 2015). Stable isotope evidence from animal bone from Padova, however, is lacking.

## Materials and Methods

### Sample selection

Forty-five samples were selected from 4 contexts from the Baptistery at Padova (Table 1). The majority of these were fragments of earthenware jars (*olla*) but other types of cooking-wares and coarse-wares were also analysed e.g. bowls (*ciotola-coperchio*), cauldrons (*casseruola*) and basins (*catino)* together with large artefacts thought to be portable ovens (covered basins/*catino-coperchio*), a flask (*borraccia*) and a ceramic bottle (*bottiglia*), associated with the manipulation of liquids. The external surface of the ceramic sherds were removed with a drill and a sample was obtained by drilling to a depth of 2–5 mm from the sherd surface using a clean drill bit.

### Lipid extraction

Lipids were solvent extracted from all 45 sherd powders (1 g) by ultrasonication in a mixture of DCM:MeOH (2/1 v/v, 3 x 2 mL) together with an internal standard (10 μg of *n*-Tetratriacontane) to quantify the amount of lipids in the sample. The resulting total lipid extracts (TLEs) were combined and dried under a gentle stream of N2. These were silylated with N,O-bis(trimethylsilyl)trifluoroacetamide (BSTFA) with 1% trimethylchlorosilane (TMCS) at 70 °C for one hour, and dried again under N2. N-hexane was added to the derivatised samples prior to gas chromatography-mass spectrometry (GC-MS). Ten μg of internal standard (*n*-hexatriacontane) was added to each sample prior to immediate analysis by GC-MS to assess lipid recovery.

*Gas chromatography Mass Spectrometry (GC-MS)*

GC-MS was carried out on all samples using an Agilent 7890 A Series chromatograph attached to an Agilent 5975 C Inert XL mass-selective detector with a quadrupole mass analyser (Agilent technologies, Cheadle, Cheshire, UK). All samples were initially screened using a splitless injector maintained at 300 °C. The carrier gas used was helium, and inlet/column head-pressure was constant. The column (DB-5 ms) was coated with 5% phenyl-methylpolysiloxane (30 m x 0.25 mm x 0.25 μm; J&W Scientific, Folsom, CA, USA). The oven temperature was set at 50 °C for 2 min, then raised by 10 °C min-1 until 325 °C was reached, where it was held for 15 min until the end of the run. The GC column was inserted directly into the ion source of the mass spectrometer. The ionisation energy of the mass spectrometer was 70 eV and spectra were obtained in scanning mode between m/z 50 and 800.

The MS was also used in selected ion monitoring (SIM) mode with the oven temperature set at 50 °C for 1 min, then raised by 20 °C min-1 until 280 °C, then raised at 10 °C min-1 until reaching 325 °C, where it was held for 10 min until the end of the run. In SIM mode, a first group of ions (*m/z* 189, *m/z* 204, m/z 231, m/z 425, m/z 440) corresponding to miliacin fragmentation were monitored. After 16 min, a second group of ions (*m/z* 57, *m/z* 71, m/z 85, *m/z* 478, *m/z* 506) were monitored to record the internal standard. An authentic standard of miliacin was injected in each sample run to monitor the retention time and confirm the presence of this compound. Hexane ‘blanks’ were injected regularly throughout the sequence to monitor for any carry-over between analytical runs.

Derivatized extracts (1μL) were also analysed with a cold on-column injector inserted into a DB5-HT column (15m x 0.32mm x 0.1μm; Agilent, UK ) using an Agilent GC with the column effluent split (50:50) between an Agilent 5975 C Inert XL mass-selective detector and an Agilent flame ionization detector (FID). The oven temperature was set at 50°C for 1 min, then raised by 15°C/min to 100°C, then 10°C/min to 375°C and held for 10 mins. The inlet temperature tracked the oven temperature program. The FID was set at a temperature of 350 °C. Helium was used as a carrier gas.

### Gas chromatography combustion isotope ratio mass spectrometry (GC-c-IRMS)

The δ13C value of miliacin was determined in the TLE of one sample (G1) where the compound was particularly abundant (Fig. 3) by GC-c-IRMS system comprising of a Isoprime 100 (Isoprime, Cheadle, UK) linked to a Hewlett Packard 7890B series gas chromatograph (Agilent Technologies, Santa Clara, CA, USA) with an Isoprime GC5 interface (Isoprime, Cheadle, UK), according to previously described protocols [(Lucquin et al., 2016)](https://paperpile.com/c/A6xqY5/jTIO). The results from the analyses are reported in parts per mil (‰) relative to an international standard (V-PDB). Replicate measurements of the sample and a mixture of fatty acid methyl esters (FAMEs) with δ13C values traceable to international standards were used to determine instrument precision (± 0.3‰ SE) and accuracy (± 0.5‰ SE).

**Results and Discussion**

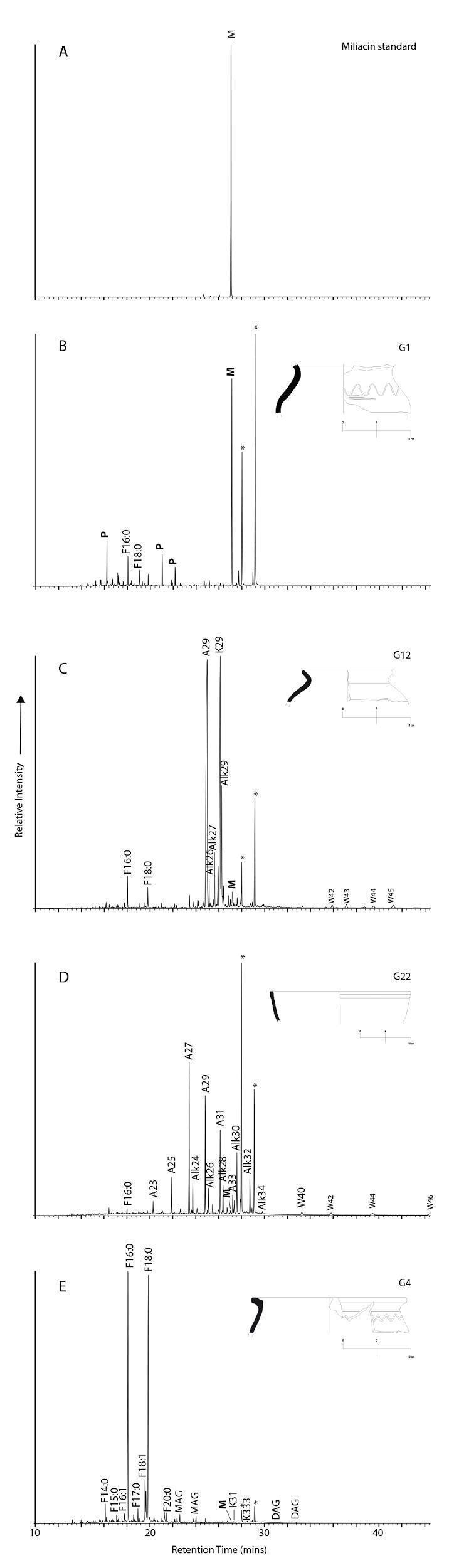
Samples yielding total lipid concentrations of >5μg g-1 or mono-, di- or tiracylglycerides were considered to be interpretable. In total, 23 of the 45 vessels analysed met these criteria (Table 3). The majority of these were from cooking pots (n= 20) but also two bowls and a ceramic basin. The remaining 22 samples revealed only trace amounts of lipids, such as alkanes, fatty acids and sterols which are usually considered not to be easily interpretable or derived from the burial environment [(Evershed, 2008)](https://paperpile.com/c/A6xqY5/B7f4). These vessels included the containers for liquids (a flask and a bottle), the majority of the ceramic basins (possibly used as ovens: Garanzini and Quercia 2016; Olcese, 2003), a basin lid as well as a larger cauldron and the remaining cooking pots. The presence of trace amounts long-chain ketones with 31, 33 and 35 carbon atoms on seven of these artefacts may imply that any food residue was extensively exposed to heat, as these are typically pyrolysis products of commonly occurring C16:0 and C18:0 fatty acids [(Evershed et al., 1995)](https://paperpile.com/c/A6xqY5/ss3c), although precursor free acids were absent. Three further samples contained trace amounts of miliacin (*m/z* 440, 189, 204, 425), despite no other diagnostic lipid compounds or ketones present. Conceivably, these compounds could be derived from the burial environment, especially as the molecule is known to occur in soils and sediments associated with millet cultivation at appreciable concentrations [(Bossard et al., 2013)](https://paperpile.com/c/A6xqY5/Jd98). Although no soil samples were available to test this directly, miliacin was absent from a basin cover /lid from the same layer, which was sampled as a control, as well in other ceramic vessels as noted above which would seem to rule out this scenario.

Of the 23 samples containing appreciable amounts of solvent extractable lipid or mono-, di- and triacylglycerides, miliacin was identified in 19, which includes 90% of the cooking vessels, particularly cooking jars (olla), regardless of their typology (Table 2). In these samples the miliacin was either the only, or clearly the most dominant, PTME, providing strong evidence that broomcorn millet (*Panicum miliaceum*) was processed in these vessels [(Bossard et al., 2013)](https://paperpile.com/c/A6xqY5/Jd98). The association of miliacin and appreciable accumulations of lipids in general with a particular vessels typology (i.e. jars) again indicates that the observed signals are most likely derived from vessel use rather than from transfer from the depositional environment. The identification of millet in the residue of the cooking vessels is in agreement with findings of millet seed at this site, (Peña Chocarro and Pérez-Jordà, 2017) but allows us to unequivocally confirm that this grain was used for human consumption.

Interestingly, in the majority of cases, other lipid molecules were also present in addition to miliacin implying that the millet was either mixed together and/or processed sequentially with a range of other food products (Table 3). Typical examples are shown in Fig. 3. Most frequently miliacin was associated with lipids derived from degraded animal fats (Fig. 3 E), including high abundances of saturated mid-chain length free fatty acids (C14:0, C16:0 and C18:0) and their corresponding mono- and diacylglycerols, as well as mid-chain ketones formed from the condensation of free fatty acids through protracted heating [(Evershed et al., 1995)](https://paperpile.com/c/A6xqY5/ss3c). Millet was also observed with epicuticular plant leaf wax components with a distribution typical of the cabbage family Brassicaceae [(Charters et al., 1997)](https://paperpile.com/c/A6xqY5/HZvg), including nonacosane, nonacosan-15-one, and nonacosan-15-ol (Fig. 3 C). In two vessels miliacin was observed with lipids derived from beeswax and its degradation products [(Regert et al., 2001)](https://paperpile.com/c/A6xqY5/2M1R), including palmitic wax esters with 40-52 carbon atoms, odd-numbered alkanes with 23-33 carbon atoms and even numbered alkanols with 24-34 carbon atoms (Fig. 3 D).

In a single case (G1, Fig. 3 B), miliacin was the most abundant lipid recovered from the ceramic sherd together with trace amounts of free fatty acid. The absolute abundance (ca. 10 μg g-1) of the molecule in this sample was much greater than previously reported (Heron et al. 2016) permitting a stable carbon isotope measurement by GC-C-IRMS. The δ13C value of this compound was -20.5‰ which is in excellent agreement with reported values from miliacin directed isolated from millet grains and extracted from soils [(Courel et al., 2017; Jacob et al., 2008)](https://paperpile.com/c/A6xqY5/ATJa+P9YN) and slightly enriched (ca. 3‰) compared to fatty acids extracted from previously reported prehistoric pottery associated with miliacin [(Heron et al., 2016)](https://paperpile.com/c/A6xqY5/Dzg0). Notably, this compound is more enriched in 13C compared to lipids from C3 plants, which are typically below -30‰ [(Collister et al., 1994)](https://paperpile.com/c/A6xqY5/9y6A), providing further compelling evidence that the compound is derived from broomcorn millet. Given the high absolute and relative abundance of miliacin compared to other lipids we suggest that the vessel was predominantly used to prepare millet, although the exact nature of the preparation (e.g. as a gruel, porridge or even fermented beverage) is not clear and demands further experiments to examine residue formation under these different simulated scenarios. Similarly the differential preservation of miliacin compared to other lipids needs to be explored through experimentation.

In contrast, in all other cases millet seems to have been mixed with other ingredients (animal products, vegetables) rather than been prepared on its own as gruel or porridge. Although we can’t differentiate simultaneous from sequential episodes of pottery use, millet is nonetheless the most consistent food product found in these vessels and as such may have been a staple or base to most culinary endeavours. There is no evidence of barley or wheat biomarkers [(Colonese et al., 2017)](https://paperpile.com/c/A6xqY5/aAYe) in the Padovan pots so these grains may have preferentially been used for bread making, although more work is needed to investigate the differential diagenesis of different cereal biomarkers. Millets are low in gluten and do not leven easily and would therefore seem less suitable for bread making. Whilst there is some evidence that millet was used to make typically unleavened bread in the Roman period (Montanari, 1999; Adamson, 2004; Murphy, 2016), historical sources suggest that in the Late Medieval period millets were more often cooked in soups and porridge, with physician’s texts arguing that the grain was more digestible when prepared with meat in a broth or milk [(Adamson, 2004)](https://paperpile.com/c/A6xqY5/eeJn).



**Figure 3:** **Partial total ion currents of trimethylsilylated total lipid extracts from four Early Medieval cooking (B-E) vessels from Padova compared with a miliacin standard (A)**. \* = internal standards (C34 and C36 alkane), Fx:y = fatty acids with x carbon atoms and y unsaturations , M = miliacin, A = *n*-alkanes with x carbon atoms, Alk = n-alkanols with x carbon atoms, K = ketones with x carbon atoms, W = wax esters with x carbon atoms, MAG = monoacylglycerols, DAG = diacylglycerols, P = plasticizer contaminating peaks.

Although it is obviously difficult to reconcile the paleodietary information from the human bones found in Early Medieval deposits with the evidence from the use of pottery from the same contexts, the organic residue evidence does show that millets were directly consumed during this period. Interestingly, millet is widely associated with cooking vessels throughout the sequence. We observe miliacin on the earliest ceramics relating to the high status of occupation of the site in the 6th century and later cooking vessels associated with the lower status occupation of the area (Table 2). The early use of millet is particularly interesting as the ceramic evidence undoubtedly confirms that it was being directly consumed in the period and whatsmore in a household of considerable standing. This contrasts historical sources, including Columella, where the crop has tended to be associated with the poor, slaves or as an animal feed but even Columella notes that “porridge made with millet or panicum with milk is not to despised even in time of plenty (*Col. II, 9. 19)*”. Its role as a staple crop deemed suitable for human consumption is also likely to extend beyond the early Slavic cultures, as has been suggested [(Reitsema and Kozłowski, 2013)](https://paperpile.com/c/A6xqY5/hF6L) based on the stable isotope evidence.

Of course, we do not know in Padova at least, the degree to which millet was also fed to animals but given the other evidence from the Early Medieval period (Fig. 1) this seems likely and would explain the relatively high carbon and nitrogen values observed during this period. An alternative scenario is that human stable carbon isotope values were influenced by the direct consumption of C4 cereals whereas the nitrogen isotopes reflect the dominant protein source, i.e. animal products. Such as scenario invokes more complex scrambling of dietary macronutrients as has been suggested for Roman populations, where cereals were the major dietary staple [(Craig et al., 2013)](https://paperpile.com/c/A6xqY5/l4wM). Resolving these two scenarios has considerable significance for understanding diet during this period, particularly the contribution of plant and animal products, and may be achieved by examining the isotopic composition of individual amino acids from collagen [(Choy et al., 2010)](https://paperpile.com/c/A6xqY5/cJ3K).

*Conclusions*

Overall, based on the identification of a biomarker for broomcorn millet (miliacin) on a range of cooking pots and with other commonly consumed foods, we argue that the plant was cultivated for more than just a animal fodder, as has been previously supposed. Where an interpretable absorbed lipid residue was present, miliacin was identified in 19 out of 23 cases, whereas of 22 samples with uninterpretable amounts of lipids the compound was identified in just 6 cases. The data are therefore not consistent with absorption of miliacin from the burial environment. From the co-occurrence of miliacin with different food derived lipids, we suggest that millet was a common staple cereal throughout the occupation of the site and mixed with other foods in elaborate culinary practices. The residue data are supported by archaeobotanical findings of charred millet grains indicating that the cereal was used during Late Antique period and through Lombard occupation in the 7th century. More broadly, our study shows how organic residue analysis can be used in concert with human stable isotope to provide detail regarding the context and scale of past food consumption practices.

This study joins a growing body of research that indicates that importance of millets has thus far been underestimated in early historic societies. Whilst we may never precisely know how foods such a millet were valued in the past, organic residue analysis helps define their culinary role from which conclusions regarding their status can begin to be made. Further analysis of earlier Roman cooking pots would make an interesting comparison to the early medieval cooking practices that our study has revealed, especially in relation broader changes in the use of the landscape between these periods. Notably, around Padua, increased millet production may have been associated with less favourable weather conditions and radical transformations in the fluvial network (Brogiolo, 2017b). Future studies linking the production and consumption of different foodstuffs should allow greater elucidation regarding the cultural and environmental drivers for economic change.

### Acknowledgments

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**Supplementary Section**

**Table 1**: Association with the archaeological layer and the pottery chose for the analysis

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Layer** | **Context** | **Date (Century AD)** | **Pottery by layer** | **Jars (Olla)** | **Basin (Catino)** | **Covered/basin(Catino/coperchio)** | **Bowl (ciotola/coperchio)** | **Cauldron (Casseruola)** | **Flask (Borraccia)** | **Bottle (Bottiglia)** |
| 347 | collapse of building 1 | 4th | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 |
| 226 | Destruction of building 2 | 6th-beginning 7th | 3 | 1 | 1 | 0 | 0 | 0 | 1 | 0 |
| 222 | collapsed building 2 following fire (226) | 5th-beginning 7th | 6 | 2 | 0 | 3 | 1 | 0 | 0 | 0 |
| 344 | exterior of collapsed building 2 | 5th-beginning 7th | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 |
| 340 | burnt layer (exterior building 2) | 6th-beginning 7th | 5 | 5 | 0 | 0 | 0 | 0 | 0 | 0 |
| 219 | Re-occupation (low status) above collapsed building 2 | 7th | 17 | 14 | 0 | 2 | 0 | 0 | 0 | 1 |
| 330=335 | Occupation (low status) above 219 | 7th | 4 | 2 | 0 | 0 | 1 | 1 | 0 |  |
| 323=322 | levelling of site 330=335 | 7th -beginning of 8th | 4 | 3 | 0 | 1 | 0 | 0 | 0 | 0 |
| 261 | Waste midden (low status) | 8th-9th | 2 | 1 | 0 | 0 | 1 | 0 | 0 | 0 |
| 270 | Waste midden (low status) | 8th-9th | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| 178 | Occupation prior to construction of building 3 | 9th-beginning 10th | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| **Total** |  |  | 45 | 30 | 2 | 7 | 3 | 1 | 1 | 1 |

**Table 2**: Association with the archaeological layer and the conservation of lipids and the Number of millet seed from archaeobotanical remains (\*= from Peña Chocarro, Peréz-Jordà, 2017, Table 1).

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Layer** | **Context** | **Date (Century AD)** | **Pottery analysed by layer** | **Pottery with lipid** | **Pottery with millet** | **Number of millet seeds\*** |
| 347 | collapse of building 1 | 4th | 1 | 1 | 1 | 0 |
| 226 | Destruction of building 2 | 6th-beginning 7th | 3 | 0 | 0 | 0 |
| 222 | collapsed building 2 following fire (226) | 5th-beginning 7th | 6 | 2 | 2 | not analysed |
| 344 | exterior of collapsed building 2 | 5th-beginning 7th | 1 | 0 | 0 | not analysed |
| 340 | burnt layer (exterior building 2) | 6th-beginning 7th | 5 | 4 | 2 | 55 |
| 219 | Re-occupation (low status) above collapsed building 2 | 7th | 17 | 8 | 7 | 4 |
| 330=335 | Occupation (low status) above 219 | 7th | 4 | 1 | 1 | not analysed |
| 323=322 | levelling of site 330=335 | 7th -beginning of 8th | 4 | 3 | 2 | not analysed |
| 261 | Waste midden (low status) | 8th-9th | 2 | 2 | 2 | not analysed |
| 270 | Waste midden (low status) | 8th-9th | 1 | 1 | 1 | not analysed |
| 178 | Occupation prior to construction of building 3 | 9th-beginning 10th | 1 | 1 | 1 | not analysed |
| **Total** |  |  | 45 | 23 | 19 | 59 |

**Table 3**: FA= *f*atty acids, M = miliacin, A = *n*-alkanes, Alk=n-alkanols, K = long chain ketones, Ch = cholesterol, Sit= Sitosterol, MAG = monacylglycerols, DAG = diacylglycerols, TAG = triacylglycerols, W = wax esters

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **Sample** | **Pottery forme** | **Layer** | **Context** | **Lipid concentration (ug g-1)** | **Lipid Classes dectected** | **Interpretation** | **Intepretable lipid** |
| G1/219\_par5 | Jar | 219: Re-occupation (low status) above collapsed building 2 | poor | 15,2 | FA; MAG; Ch; Alk; M | Millet, Animal fat | x |
| G2/219\_f6 | Jar | 219: Re-occupation (low status) above collapsed building 2 | poor | 4 | FA; DAG; Ch; Alk; K; M | Animal fat, Brassicaceae, Millet | x |
| G6/ 340\_1 | Jar | 340: burnt layer (exterior building 2) | rich | 4,3 | FA; MAG; DAG; Alk; A; K | Animal fat, Brassicaceae | x |
| G8/340\_10 | Jar | 340: burnt layer (exterior building 2) | rich | 15,2 | FA; MAG; DAG; Ch; A; K; M | Animal fat, Brassicaceae, Millet | x |
| G10\_2/219\_12 | Jar | 219: Re-occupation (low status) above collapsed building 2 | poor | 10,7 | FA; MAG; Ch; Alk; K; M | Animal fat, Millet | x |
| G11/ 323\_1 | Jar | 323: levelling of site 330=335 | poor | 3,6 | FA; MAG; DAG; Ch; A; K; M | Animal fat, Brassicaceae, Millet | x |
| G12/ 219\_13 | Jar | 219: Re-occupation (low status) above collapsed building 2 | poor | 6,3 | FA; Alk; W; A; K; M | Animal fat, Brassicaceae, vegetable fat, Millet | x |
| G13/219\_28 | Jar | 219: Re-occupation (low status) above collapsed building 2 | poor | 1,9 | FA; MAG; DAG; Ch; Alk; K; M | Animal fat, Brassicaceae, Millet | x |
| G21/ 219\_5 | Jar | 219: Re-occupation (low status) above collapsed building 2 | poor | 11,4 | FA; MAG; DAG; Ch; Alk; A; K; M | Animal fat, Brassicaceae, Millet | x |
| G22/347\_1 | Basin | 347: collapse of building 1 | rich | 11,5 | FA; Alk; W; A; M | Beeswax, Millet | x |
| G23/222\_15 | Bowl | 222: collapsed building 2 following fire (226) | rich | 44 | FA; Ch; Alk; W; A; M | Animal fat, Millet | x |
| G24/ 219\_2 | Jar | 219: Re-occupation (low status) above collapsed building 2 | poor | 0,7 | FA; MAG; Ch; Alk; A; K | Animal fat, Brassicaceae | x |
| G26/ 330\_1 | Jar | 330: Occupation (low status) above 219 | poor | 11,8 | FA; A; K; M | Animal fat, Millet | x |
| G27/323\_f4 | Jar | 323: levelling of site 330=335 | poor | 0,5 | FA; MAG; Ch; Sit; Alk; A; K; M | Animal and vegetable fat, Millet | x |
| G29/ 340\_3 | Jar | 340: burnt layer (exterior building 2) | rich | 7,2 | FA; MAG; DAG; Ch; Alk; A | Animal fat | x |
| G3/323\_5 | Jar | 323: levelling of site 330=335 | poor | 35,6 | FA; MAG; Alk; A; M | Animal fat, Millet | x |
| G30/ 178\_1 | Jar | 178: Occupation prior to construction of building 3 | poor | 8,8 | FA; MAG; Alk; W; M | Animal fat, Beeswax, Millet | x |
| G32/ 270\_par5 | Jar | 270: Waste midden (low status) | poor | 5,9 | FA; MAG; DAG; A; K; M | Animal fat, Brassicaceae, Millet | x |
| G34/ 222\_3 | Jar | 222: collapsed building 2 following fire (226) | rich | 30,2 | FA; DAG; W; K; M | Animal fat, Millet | x |
| G35/219\_3 | Jar | 219: Re-occupation (low status) above collapsed building 2 | poor | 26,4 | FA; MAG; A; M | Animal and vegetable fat, Millet | x |
| G36/ 261\_7 | Jar | 261: Waste midden (low status) | poor | 6,2 | FA; MAG, DAG; Ch; Alk; W; M | Animal fat, Millet | x |
| G4/340\_4 | Jar | 340: burnt layer (exterior building 2) | rich | 400,7 | FA; MAG; DAG; Ch; Alk; W; A; K; M | Animal fat; Millet | x |
| G42/ 261\_bis | Bowl | 261: Waste midden (low status) | poor | 10 | FA; Ch; W | Animal and vegetable fat | x |
| G5/344\_5 | Covered/basin | 344: exterior of collapsed building 2 | rich | 0,1 | FA (tr) | n/a | n/a |
| G7/222\_f9 | Covered/basin | 222: collapsed building 2 following fire (226) | rich | 0 | FA (tr) | n/a | n/a |
| G9/219\_f3 | Jar | 219: Re-occupation (low status) above collapsed building 2 | poor | 0,8 | FA (tr); K (tr) | n/a | n/a |
| G14/226\_f3 | Jar | 226: Destruction of building 2 | rich | 1,6 | M (tr); FA (tr) | n/a | n/a |
| G15/222\_18 | Covered/basin | 222: collapsed building 2 following fire (226) | rich | 2,6 | FA (tr) | n/a | n/a |
| G16/219\_1 | Jar | 219: Re-occupation (low status) above collapsed building 2 | poor | 2,6 | FA; Ch; Alk; K; M | Animal fat, Millet | n/a |
| G17/219\_f12 | Covered/basin | 219: Re-occupation (low status) above collapsed building 2 | poor | 0 | M (tr); FA (tr) | n/a | n/a |
| G18/ 219\_29 | Jar | 219: Re-occupation (low status) above collapsed building 2 | poor | 0 | FA (tr) | n/a | n/a |
| G19/ 219\_15 | Covered/basin | 219: Re-occupation (low status) above collapsed building 2 | poor | 0,2 | FA (tr) | n/a | n/a |
| G20/ 222\_X | Covered/basin | 222: collapsed building 2 following fire (226) | rich | 0,2 | FA (tr) | n/a | n/a |
| G25/330\_4 | Covered/basin | 330: Occupation (low status) above 219 | poor | 0,3 | FA (tr); K (tr) | n/a | n/a |
| G28/226\_1 | Basin | 226: Destruction of building 2 | rich | 0 | FA (tr) | n/a | n/a |
| G31/340\_par1 | Jar | 340: burnt layer (exterior building 2) | rich | 0,5 | FA (tr); K (tr) | n/a | n/a |
| G33/ 323\_10 | Covered/basin | 323: levelling of site 330=335 | poor | 0,2 | M (tr); FA (tr) | n/a | n/a |
| G37/ 330\_1bis | Cauldron | 330: Occupation (low status) above 219 | poor | 0,1 | FA (tr) | n/a | n/a |
| G38/ 219\_18 | Jar | 219: Re-occupation (low status) above collapsed building 2 | poor | 0,1 | FA (tr) | n/a | n/a |
| G39/330\_3 | Jar | 330: Occupation (low status) above 219 | poor | 0,8 | FA (tr) | n/a | n/a |
| G40/222\_1 | Jar | 222: collapsed building 2 following fire (226) | rich | 2,5 | FA (tr); K (tr) | n/a | n/a |
| G41/219\_41 | Jar | 219: Re-occupation (low status) above collapsed building 2 | poor | 0,9 | FA (tr); K (tr); M (tr) | n/a | n/a |
| G43/219\_45 | Jar | 219: Re-occupation (low status) above collapsed building 2 | poor | 2,8 | FA; Ch; Sit; A ; Alk; K; M | Animal and vegetable fat, Millet | n/a |
| G44/ 226\_19 | Flask | 226: Destruction of building 2 | rich | 0,6 | FA (tr) | n/a | n/a |
| G45/219\_47 | Bottle | 219: Re-occupation (low status) above collapsed building 2 | poor | 0,2 | FA (tr) | n/a | n/a |

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