What the Pig Ate: A Microbotanical Study of Pig Dental Calculus from 10th-3rd Millennium BC Northern Mesopotamia

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Abstract:

One of the main questions that zooarchaeologists have attempted to answer in their studies of ancient agropastoral economies relates to animal diet. Starch granules and phytoliths, which derive from the plant foods consumed over the course of an animal's life, become imbedded in dental calculus and thus offer direct clues about diet. In this paper, we investigate pig diet with an eye toward understanding husbandry strategies in northern Mesopotamia, the region in which pigs were first domesticated, from the Epipaleolithic through the Early Bronze Age. Our data reveal that pigs consumed an assortment of plant foods, including grasses, wild tubers, acorns, and domestic cereals. Although poor preservation plagued the identification of plant microremains at Epipaleolithic (10th millennium cal. BC) Hallan Çemi, the identification of a diet based on tubers and grasses matches models of wild boar diet. Pigs at 6th millennium Domuztepe, 5th millennium Ziyadeh, and 4th millennium Hacinebi consumed cereals, particularly oats (*Avena* sp.) and barley (*Hordeum* sp.), as well as wild plant food resources. Several of the cereal starch granules showed evidence of cooking, indicating that pigs had access to household refuse beginning at least in the late Neolithic. Moreover, calculus from morphologically wild specimens also contained cooked cereal grains. This points to a close relationship between wild boar populations and human settlements in the Neolithic and beyond. Preservation was poor for 3rd millennium sites in the study, including Atij, Raqa'i, Ziyadeh, and Leilan, but the available data suggest that pigs ate oats, barley and other Triticeae (the tribe that includes wheat, barley, and goatgrass), and other grasses. This may represent foddering practices in the Early Bronze Age.

1.0 Introduction

The reconstruction of ancient animal management practices from archaeologically-recovered assemblages of bones and teeth is a major topic of zooarchaeological research (e.g., Crabtree, 1990; Halstead, 1996; Mengoni Goñalons, 2007; deFrance, 2009; Arbuckle, 2012; Stiner, et al., 2014). While animal diet is one of the most critical aspects of animal husbandry, reconstructing it archaeologically remains difficult. Diet is particularly interesting with respect to pigs, which are omnivorous and can thrive on a variety of foods. For this reason, numerous researchers have attempted to reconstruct pig diets in the ancient past (Wilkie, et al., 2006; Mainland, et al., 2007; Vanpoucke, et al., 2009; Lösch, et al., 2006; Masseti, 2006; Hamilton, et al., 2009).

Ethnographic evidence suggests that pig diets vary considerably under different husbandry regimes, the latter of which range from allowing pigs to forage their own food to provisioning pigs with agricultural and household waste (Hide, 2003; Albarella, et al., 2011; Halstead, 2011). Under intensive husbandry regimes, pigs are provisioned with food, often household refuse ("slop"). Under more extensive regimes, they are allowed to forage their own food, often rooting for tubers and nuts, such as acorns.

In this paper, we analyze plant microremains (i.e., starch granules and phytoliths) obtained from the dental calculus of archaeologically recovered pigs' teeth in order to reconstruct their diets at six sites in northern Mesopotamia from the Epipaleolithic through the Early Bronze Age. Northern Mesopotamia is the region that stretches across modern-day southern Turkey, Syria, and northern Iraq (Figure 1) and

was the location in which pigs were first domesticated. Our diachronic analysis of pig diets aims to understand how ancient husbandry and feeding practices evolved over time from the period immediately before domestication until the rise of the first cities in the region.

2.0 Pig Husbandry in Northern Mesopotamia

Pigs and their progenitors, wild boar (*Sus scrofa*), have a long history with humans in northern Mesopotamia. Epipaleolithic hunter-gatherers preyed upon wild boar. This predatory relationship intensified over time, and evidence from Cyprus suggests that people brought pigs and other animals to the island by boat in the 10th millennium cal. BC (Vigne, et al., 2009). Domestication, by which we mean the accumulation of morphological traits in response to human management, began in the 9th millennium cal. BC (Ervynck, et al., 2001; Zeder, 2011; Peters, et al., 2013). The precise manner in which pig domestication occurred is unclear, but it appears to have been a long process in which certain populations slowly adapted to human niches after the advent of plant agriculture (cf. Larson and Fuller, 2013). The initial husbandry strategies appear to have been extensive, in the sense described in the Introduction. Ervynck *et al.* (2001) who examined the pig remains from Çayönü, argue that extensive husbandry practices led to a slow process of pig domestication.

In the millennia following the Neolithic, pigs were crucial, if often secondary, components of the animal economies of northern Mesopotamia and typically make up 10-20% of the faunal remains recovered from archaeological sites (Vila, 1998). Complex societies emerged in the 4th millennium cal. BC, and full-fledged urban societies appeared in the middle of the 3rd millennium (Ur, 2010; Stein, 2012). How did pig husbandry change in these periods?

Ongoing research is attempting to answer this question to document the changes in pig management practices in northern Mesopotamia from the Neolithic through the Early Bronze Age, a period defined by the development of complex societies and urbanism (Price, Forthcoming). Understanding pig diets is an important component of this research. As discussed in the Introduction, the pig feeding regimes vary markedly between extensive and intensive husbandry systems, and thus determining what the pigs ate in ancient northern Mesopotamian settlements will help us identify husbandry practices more generally.

3.0 Dietary Reconstruction through Dental Calculus

Dental calculus is mineralized plaque that accumulates on the surface of a tooth at the base of a living plaque deposit. It forms dense accumulations on the buccal surfaces of molars (molars are not constantly growing) close to salivary glands, especially in the context of a high-starch diet and a lack of dental hygiene (Hillson, 1996). Because it is a mineralized deposit, it survives well in archaeological contexts (Lieverse, 1999).

Starch granules and phytoliths preserve within calculus deposits in both human and animal teeth (Lalueza Fox and Pérez-Pérez, 1994; Middleton and Rovner, 1994; Scott Cummings and Magennis, 1997). These microremains are incorporated into plaque and, eventually, calculus via the food an animal consumes and are thus direct indicators of the plant foods in an animal's diet. In the past two decades, archaeologists have successfully reconstructed ancient diets in a diverse number of contexts, including those of Neanderthals (Henry, et al., 2011), 18th century farm animals (Middleton and Rovner, 1994), 10th through 6th millennium Andeans (Piperno and Dillehay, 2008), 3rd millennium BC agriculturalists in the Khabur River valley (Henry and Piperno, 2008), and Pleistocene fauna (Asevedo, et al., 2012). It is important to note that pig and human dental calculus differ in crystalline makeup – the former comprising primarily calcite and the latter comprising primarily hydroxyapatite (Weaver, 1964). However, microfossils are still incorporated into this crystalline matrix.

It is important to recognize that dental calculus accumulates naturally over the course of an animal's life, though the rate of accumulation is variable and contingent on a number of factors. As a result, it is impossible to determine when within the lifetime of an animal a specific plant microremain was ingested. Starch granules and phytoliths in dental calculus represent a palimpsest of feeding events, or in the case of pigs, rooting. Dental calculus may be uncommon in archaeological and modern pigs due

to their young age of slaughter (Anthony, 1946), but it is not unheard of in archaeological contexts (Middleton and Rovner, 1994; Albarella, et al., 2006).

Based on the sites examined in this study, which we detail in the next section, we pose several questions. First, what were the diets of Epipaleolithic wild boars, which may have been attracted to human settlements such as Hallan Çemi, but were otherwise not managed? Did the diets of wild boar change over time in response to increased human population density? Second, what were the diets of early domestic pigs at sites such as Domuztepe? Third, how did the diets of domestic pig change during the emergence of complex societies in the 4th and 3rd millennia at sites such as Hacinebi, Atij, Ziyadeh, Raqa'i, and Leilan?

4.0 Faunal Collections Analyzed and Their Paleoenvironmental Contexts:

We collected and analyzed samples of dental calculus obtained from pig teeth from several sites spanning the 10th through 3rd millennia cal. BC in northern Mesopotamia. We visited the following institutions: the Smithsonian Institution (Hallan Çemi, Raqa'i, Atij, Ziyadeh, Umm Qseir), the Oriental Institute at the University of Chicago (Hacinebi), the Kahramanmaraş Archaeological Museum in Turkey (Domuztepe), and Harvard University (Leilan).

4.1 Hallan Çemi

Hallan Çemi is an Epipaleolithic (ca. 10000-9000 cal. BC) site in the Taurus foothills of what is today southeastern Turkey. The local paleoenvironment included oak and pistachio forests. The archaeobotanical samples included wild pistachio, lentils, bitter vetch, and almonds. Sea clubrush was also present, indicating proximity to wetlands (Rosenberg, et al., 1995; Savard, et al., 2006).

4.2 Domuztepe

Domuztepe is a Late Neolithic and Halaf (6th mill. cal. BC) settlement in southeastern Turkey. Paleobotanical and geoarchaeological data indicate that at the time of occupation the environment consisted of wetlands laced with streams (Kansa, et al., 2009; Gearey, et al., 2011). The primary agricultural products included wheat, barley, lentils, peas, and flax which were supplemented with gathered foods such as pistachios, figs, and almonds (Kansa, et al., 2009).

4.3 Umm Qseir

Umm Qseir is an Ubaid (5th mill. cal. BC) site located on the Khabur in northern Syria. Charcoal data indicate past exploitation of riparian and steppic environments, but the archaeobotanical data indicate irrigation was likely practiced to grow wheat, barley, bitter vetch, peas, and chickpeas (McCorriston, 1992, 1998).

4.4 Tell Mashnaqa

Tell Mashnaqa is an Ubaid site located approximately 20 km downstream from Umm Qseir (Thuesen, 1991, 1994, 2000). Although no paleobotanical data have been published, we can assume that the occupants of Tell Mashnaqa had access to similar riparian, steppic, and farmed resources.

4.5 Tell Ziyadeh

Tell Ziyadeh is an Ubaid/Late Chalcolithic (5th mill. BC) and early 3rd millennium site located across the Khabur River from Umm Qseir. Environmentally, Ziyadeh and Umm Qseir are identical (McCorriston, 1992). Archaeobotanical evidence suggests that agricultural production at Ziyadeh centered on wheat and legumes in the 5th millennium and barley and steppic plants in the early 3rd millennium (McCorriston, 1992).

4.6 Hacinebi Tepe

Hacinebi Tepe is a 3.3 ha site on the eastern bank of the Euphrates River in Taurus foothills of southeastern Turkey. The primary occupation dates to the Late Chalcolithic (4th mill. BC) (Stein, et al.,

1996a; Stein, 1999). The immediate local environment includes riparian woodlands with steppic zones a short distance away. Archaeobotanical evidence indicates that barley was the primary agricultural product supplemented by wheat, lentils, peas, grapes, and flax production (Miller in Stein and Misir, 1994; Stein, et al., 1996a; Stein, et al., 1996b).

4.7 Tell Atij

Atij is a Ninevite V (early 3rd mill. BC) site located on the eastern bank of the Khabur River, nearby Umm Qseir, Raqa'i, and Ziyadeh. The local environment during the 3rd millennium supported riparian forests as well as oak parklands. The presence of dry-farming weeds in the paleobotanical record suggests that the residents of Atij did not depend on irrigation for agricultural production, which focused on barley (McCorriston, 1998).

4.8 Tell Raqa'i

Raqa'i is another Ninevite V (early 3rd mill. BC) site located on the eastern bank of the Khabur River. Raqa'i's ancient environment mirrors that of Atij (van Zeist, 2003). Henry and Piperno (2008) carried out analysis of starch granules found in human dental calculus from Raqa'i. Their results demonstrate that the occupants consumed a wide variety of plant food resources including barley and oats.

4.9 Tell Leilan

Leilan is located in the Khabur Basin. Occupations span the Ubaid through the 2nd millennium BC, but samples in this study all date to the 3rd millennium (Weiss, 1997). The site's catchment includes woodland, riparian, and steppic zones (Deckers and Pessin, 2010). Agricultural production focused on cereals – primarily wheat and barley – but also included chickpeas, field peas, grass peas, lentils, bitter vetch, figs, flax and grapes.

5.0 Methods

5.1 Selection of Dental Calculus

The teeth included in this study were also used for dental microwear analysis, and the results of that study will be published elsewhere (Price, Forthcoming). Because the polyvinyl siloxane molds for that analysis sometimes remove dental calculus, we obtained permission to study the removed calculus. For the pig teeth from Hacinebi, Leilan, and Domuztepe, we obtained additional permission to remove small amounts of dental calculus directly from the tooth with a sterilized dental pick. In these cases, samples were selected on the basis of presence or absence of dental calculus. The selected teeth exhibited great variability in the amount of dental calculus present. When possible, excess dental calculus was left for future studies, however many samples contained so little calculus that it was necessary to take all of it. The dental calculus was gently removed to avoid damage to the surface of the tooth (following Henry and Piperno, 2008).

5.2 Dissolution of Dental Calculus

The dental calculus samples were brushed and washed with distilled water to remove any adhered soil or other particulates and placed in 15ml plastic centrifuge tubes. 8ml of 10% solution of HCl were added to the tubes, which were allowed to sit for 12-24 hours depending on the amount of dental calculus that remained to be dissolved (Middleton and Rovner, 1994; Henry and Piperno, 2008).

Despite the 12 hour HCl dissolution, a small number of samples required further processing with heavy liquid to separate the plant microremains from any large inorganic matter trapped in the dental calculus. These samples were processed using a heavy liquid separation protocol for dual extraction of starch and phytoliths that Judith Field of the University of Sydney developed following Lisa Kealhofer (Santa Clara University, n.d.). This procedure is used by Li Liu and Sheahan Bestel at the Stanford Archaeology Center (n.d.) and is hereafter referred to as the Liu-Bestel protocol. Heavy liquid separation requires that the samples be added to sodium polytungstate (SPT) mixed to a specific gravity of 2.35. Starch has a specific gravity of 1.35, and the specific gravity of phytoliths ranges from 1.5 to 2.3 (Carol

Lentfer in Torrence, 2006: 161), so following the centrifuging process, the starch granules, phytoliths, and less dense material should rise to the top of the tube leaving the heavier sediment at the bottom. While this does give a “cleaner” slide, there is a risk of losing microremains when transferring the sample among tubes and slides.

5.3 Contamination Control

Microbotanical research often falls prey to issues of contamination (see Crowther, et al., 2014), and several measures were put in place to avoid the potential of contamination. Calculus samples were processed in the Archaeology Multi-User Lab (AMUL) at Harvard University. The AMUL’s facilities are not dedicated to botanical analysis alone – all stages of petrographic analysis are conducted in the lab, which raises the risks of contamination. In order to limit the possibility of contamination of the archaeological materials, all surfaces where slide preparations occurred were cleaned with hydrogen peroxide to remove any organic materials. All processes were carried out while wearing powder-free gloves.

Though it would have been ideal to have access to soil samples from each site and washes off the surfaces of each tooth to have for control samples, we were unable to access such materials from all sites except Leilan. As such, control samples (a total of 5) were taken from the working surface following cleaning (Sample 1), an empty centrifuge tube that contained Hacinebi tooth 47 (Sample 2), and three samples of sediment adhered to three different pig teeth/mandibles from Leilan (Samples 3-5). Control samples 1 and 2 yielded no microbotanical remains, while control samples 3-5 yielded few phytoliths. The presence of phytoliths in the sediment samples is not all surprising, and we recognize that there may be a danger of these microremains contaminating our samples.

5.4 Microscopy

All samples were analyzed using a Zeiss Axio Scope.A1 microscope. Scanning was carried out under polarized light at a magnification of 200x in order to quickly identify starch granules and phytoliths. Starch granules demonstrate birefringence under polarized light and exhibit an extinction cross, however there are other objects that exhibit an extinction cross and/or birefringence under polarized light (e.g., spherulites, bordered pits, bubbles, and various minerals). Once starch granules were identified, three separate photos were taken: one under polarized light, one under bright-field light, and one under the differential interference contrast (DIC) filter – all at a magnification of 400x. Polarized light was used for rapid, positive identification of starch granules and phytoliths, while bright-field and DIC were used to further distinguish morphological features of the starch granules and phytoliths. Comparative images of modern plant taxa predicted to be most analogous to archaeological starch granules and phytoliths were also used in order to aid in identification and classification.

5.5 Comparative Collections and Nomenclature

All archaeological microremains analyzed in this study were compared to images of known modern reference samples. Given the variety of starch granule and phytolith forms, it was necessary to standardize the descriptions of the microremains. As a result, all descriptions are based in either the International Code for Starch Nomenclature (ICSN, 2011) or the International Code for Phytolith Nomenclature (Madella, et al., 2005). Starch granules were also assessed for damage, which can be indicative of cooking (gelatinization) or mechanical processing (Babot, 2003; Henry, et al., 2009).

6.0 Results

The full results of the analysis can be found in Table 1. We summarize the results below.

6.1 Hallan Çemi

The two Hallan Çemi samples produced few phytoliths and only one starch granule. The poor preservation and small sample size do not provide a complete picture of Epipaleolithic wild boar diet. However, the results, while admittedly paltry, match our initial expectations. The only starch granule

(Figure 2) found in the Hallan Çemi sample is likely from a tuber. Meanwhile, the phytoliths suggest the consumption of grasses. Both of these foods are common in the diets of modern-day wild boars (Groot Bruinderink, et al., 1994; Schley and Roper, 2003; Gimenez-Anaya, et al., 2008).

6.2 Domuztepe

The 14 Domuztepe samples produced the most microremains, with only one tooth, specimen #67, yielding no preserved starch granules or phytoliths. The data from Domuztepe indicates that pigs ate processed (ground and cooked) oat and barley (*Avena* sp. and *Hordeum* sp. respectively), other grasses (members of Triticeae), and two likely acorn starch granules (*Quercus* sp.) (see Figure 3). The presence of cooked cereals strongly indicates that pigs consumed domestic refuse. The presence of barley (*Hordeum* sp.) and members of the Triticeae tribe parallels the macrobotanical remains (Kansa, et al., 2009). *Avena* sp. and *Quercus* sp., on the other hand, are unknown in the Domuztepe macrobotanical assemblage, a fact that points to the potential of microremain assemblage to complement that of the macrobotanical one.

Because the Domuztepe assemblage contained both domestic pigs and wild boars (Kansa, et al., 2009), we used metrical information to identify individual specimens as domestic or wild (Table 1). In some cases, however, metrical data were not obtained because the tooth was fragmented. In other cases, the metrical data did permit identification.

Interestingly, while one of the three morphologically wild specimens reflect a diet based on acorns and grasses, as expected, two included barley and oat starch granules, several of which appear to have been processed and cooked. This unexpected result suggests that wild boar may have been attracted to Domuztepe or that the inhabitants of the site captured and incorporated wild boar into domestic sounders. The morphologically domestic specimens show similar patterns as the wild ones. Four domestic specimens show evidence of cereals processed and cooked by humans. These pigs may have been provisioned with household refuse (“slop”) or they may have subsisted, in part, by scavenging waste. The other domestic pig specimens yielded no/unidentified starch granules and grass phytoliths.

6.3 Umm Qseir

Neither starch nor phytoliths were present in the sample. This is likely due to poor preservation, possible sampling error, and/or attrition during heavy liquid separation.

6.4 Tell Mashnaqa

Like Umm Qseir, no starch or phytoliths were present in the Mashnaqa sample.

6.5 Tell Ziyadeh

Two of the three Tell Ziyadeh samples yielded starch granules (Figure 2) – one from each the 5th and 3rd millennium. Much like Domuztepe, it appears that pigs fed on a variety of grass seeds that either humans provided or pigs raided from agricultural fields or stores.

The single 3rd millennium specimen reflects that this pig consumed unidentified small-grained grasses. The 5th millennium pig likely consumed oats (*Avena* sp.). Like the situation at Domuztepe, the presence of oat starch granules is interesting given the absence of this grain in the archaeobotanical assemblage (McCorriston, 1998; McCorriston and Weisberg, 2002).

6.6 Hacinebi Tepe

In general, the rate of microremain preservation from the Hacinebi samples was poor. Two starch granules and one phytolith were recovered. Only one starch granule was classifiable (Figure 2). This single granule is a damaged – potentially through cooking – barley (*Hordeum* sp.) starch granule. Consequently, it is possible that at Hacinebi pigs’ diets included human refuse or pigs scavenged in nearby barley fields. The archaeobotanical remains from Hacinebi consisted primarily of barley, according to Naomi Miller’s analysis (Miller in Stein and Misir, 1994; Stein, et al., 1996a; Stein, et al.,

1996b). Miller interprets the predominance of barley as reflecting the deposition of sheep and goat dung onsite. Our data suggest that, in addition to the caprines, pigs also had access to barley.

6.7 Atij

The samples from Atij did not yield many microremains. Only one multicellular phytolith with echinate borders was found.

6.8 Raqa'i

Generally, microremain preservation in the pig dental calculus at Raqa'i was poor. Only one of the three samples yielded few microremains. The starch granule morphology is consistent with oat (*Avena* sp.) (Figure 2) – much like Domuztepe and Ziyadeh. Previous research on human dental calculus from Raqa'i carried out by Henry and Piperno (2008) demonstrated that humans consumed a wide variety of plant foods including barley (*Hordeum* sp.), oats (*Avena* sp.), and other grasses.

6.9 Tell Leilan

Microremain preservation from the Tell Leilan samples was similarly poor. Only ten phytoliths were found in three of the samples.

7.0 Discussion

The plant microremain data obtained from the dental calculus of pigs and wild boar from 10th-3rd millennium BC sites reveal diets primarily based on domestic cereals and supplemented by wild foods. These data, while plagued by poor preservation and the inherent ambiguity of starch granule morphology, allow us to draw several conclusions in response to the questions posed at the beginning of this paper.

7.1 Preservation and Recovery of Starch Granules from Dental Calculus

Table 1 shows that the majority of specimens from which dental calculus specimens were collected were upper or lower third molars. The preponderance of samples from these teeth is due to the fact that they contained the thickest calculus deposits. We suspect that the proximity of the third molars to salivary glands and the fact that it is in the back of the mouth, where food particles can become trapped, contribute to this pattern.

One of the most intriguing finds of this paper is the idiosyncratic nature of microremain preservation. Domuztepe was far and away the most productive assemblage in terms of number of preserved starch granules and phytoliths, number of microremains identified to taxon, and the proportion of specimens with preserved starch granules. Chronological variables and environmental conditions do not immediately explain this trend. The curation of these assemblages may also have little effect on the survival plant microremains, as all of the assemblages are stored in plastic bags at temperatures well below the temperature at which the starch granules could gelatinize. It is also possible that exposure to a specific chemical during the life history of the samples may have damaged or gelatinized starch granules beyond recognition (Henry, 2014). Polyvinyl siloxane impressions were made to examine the surface microwear of the pigs' teeth, but it is unknown what effect this chemical may have on starch granule structure.

One would expect later period sites in similar environmental contexts, such as Leilan and Hacinebi, to show much higher rates of preservation – this was not the case. In fact, the preservation of starch granules at 10th millennium Hallan Çemi was better than that of 3rd millennium Leilan. The preservation of starch granules and phytoliths in dental calculus may have to do with highly specific (“micro-environmental”) features of the burial environment.

7.2 Wild Boar Diets

The Hallan Çemi dataset fell short of providing clear answers to our initial questions; there were too few samples and the preservation of plant microremains was too poor to obtain a complete picture of the diets of wild boar hunted by Epipaleolithic populations. However, the data that we did obtain indicate

diets based on grasses and tubers. Rooting for subsurface plant food is one of the main activities of wild boar, and thus the presence of tubers in the diet is unsurprising (Groot Bruinderink, et al., 1994; Schley and Roper, 2003; Gimenez-Anaya, et al., 2008). The morphologically wild specimens from Domuztepe suggest a different dietary profile. Although one specimen showed evidence of acorn and wild grass consumption, the other two wild specimens consumed processed/cooked food, as did their domestic conspecifics.

The fact that at least some morphologically wild boar were eating the same foods as domestic pigs raises several questions about the relationship between humans and wild animals. Wild boar were likely attracted to human settlements by agricultural fields and waste, as they are today (e.g., Schley and Roper, 2003; Schley, et al., 2008). Another possibility is that wild boar and hybrids were incorporated into domestic sounders as a way to increase livestock numbers. Such capture-and-incorporation attempts are known ethnographically (e.g., Boyd, 1985: 123; Albarella, et al., 2011: Table 1), and a recent paper by Fiona Marshall and colleagues (2014) has argued that the introgression of wild genotypes and phenotypes into domestic stock was far more common in the past than previously realized. The similarity of morphologically wild boar diets to those of domestic pigs at the Late Neolithic site of Domuztepe adds tentative support to this hypothesis. It suggests that wild boar (and likely other species as well) continued to adapt to and exploit human niches in the millennia after domestication.

7.3 Diets of Domestic Pigs at Domuztepe

The domestic pigs at Domuztepe ate oats and barley, as well as a variety of other grasses that could not be identified. The fact that many of the cereal starch granules show evidence of exposure to heat and/or mechanical processing suggests that these pigs ate household refuse. This suggests that pigs were kept close to the settlement, rather than being herded under the care of a swineherd, a situation which is attested to in southern Mesopotamian texts from the 3rd and 2nd millennia BC (Englund, 1995; Van Koppen, 2006: 184). What is unclear is whether these pigs were allowed to forage in and around the settlement or whether they were kept in pens, and this question forms one of the main topics of ongoing research (Price, Forthcoming).

7.4 Diets of Domestic Pigs during the Emergence of Complex Society

Although preservation of starch granules and phytoliths was poor and sample sizes were small for all sites other than Domuztepe, the data point to the feeding of pigs with fodder or agricultural/household waste at the 5th-3rd millennium BC sites of Ziyadeh, Hacinebi, Atij, Raqa'i, and Leilan. Pigs continued to eat a diet based on barley and oats, some of which shows signs of grinding and other forms of processing. A diet that included cereal fodder is supported by textual evidence from 3rd and 2nd millennium texts from both northern and southern Mesopotamia that indicate that farmers fed their pigs barely, dates, reeds, wheat, and barely mash from beer processing (Owen, 2006: 78-80; Van Koppen, 2006).

8.0 Conclusion

The idiosyncratic nature of plant microremain preservation limits the extent to which we can answer all of the questions posed at the beginning of this paper. However, we have presented evidence that pig diets possibly shifted to the consumption of processed and cooked domestic cereals at an early date (6th millennium) at the site of Domuztepe and that contemporaneous wild boar populations maintained similar diets. There does not appear to have been a dietary shift for pigs in the period of complex society formation, which might suggest that these large-scale sociopolitical practices had minimal effects on pig husbandry, although that remains a topic of further research.

While the total number of studies conducted on animal dental calculus from archaeological contexts is still quite small, we hope to demonstrate that this is a useful medium through which ancient human-animal interactions may be illuminated. Plant microremains provide a direct reflection of the plant diets of humans and animals, and we have demonstrated the utility of the analysis of starch granules and phytoliths remains for future research into ancient animal husbandry. Though we did not recover many starch granules, our results demonstrate that merging archaeobotanical and zooarchaeological data, and

the collaboration between practitioners in these sub-disciplines, provides useful insight into past agricultural economies.

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Figure 1. Map of northern Mesopotamian sites included in this study.

Figure 2. Polarized and Brightfield Images of Diagnostic Starch Granules from Various Sites. 1a and 1b) Starch granule from Hallan Çemi. The ovoid shape and eccentric hilum and extinction cross suggest that this is a root or tuber. 2a and 2b) Starch granule from Hacinebi. The vaguely oval shape and presence of multiple beta granules (smaller starch granules) suggest that this granule is a member of Triticeae, likely *Hordeum* sp. This granule has lost much of its fluorescence due to damage – possibly cooking of some sort. 3a and 3b) Starch granule from Ziyadeh. Though it is heavily damaged –which is indicative of processing – the granule’s polygonal shape and probable centric hilum suggest that this is *Avena* sp. 4a and 4b) Starch granules from Raqa’i. The granule’s polygonal shape, centric hilum suggest that this is *Avena* sp. However, the granules are cracked at the hilum and the extinction crosses are indistinct – both of which are indicative of processing.

Figure 3. Polarized and Brightfield Images of Diagnostic Starch Granules from Domuztepe. 6a and 6b) Starch granule from specimen #43. The granule is polygonal in shape with a centric hilum and extinction cross. The size and morphology of this granule indicate that it is likely *Avena* sp. 6c and 6d) Starch granule from specimen #43. The granule is bell-shaped with a centric hilum and extinction cross. The size and morphology of this granule indicate that this granule likely comes from a wild tuber. 6e and 6f) Starch granule from specimen #43. The granule is ovoid with a small, natural fissure at the hilum; the hilum and extinction cross are eccentric. This morphology and size are consistent with members of the genus *Quercus*. 7a and 7b) Starch granule from specimen #36. This granule is heavily damaged – potentially by boiling. However, the vaguely oval shape and the size of the granule indicate that it is likely Triticeae – possibly *Hordeum*. 8a and 8b) Starch granule from specimen #114. The vaguely oval shape, centric hilum and distinction cross, and presence of distinct lamellae suggest that this granule is a member of Triticeae, likely *Hordeum* sp. The extinction cross of this granule is somewhat faded and indistinct which suggests that this granule was processed or damaged. 8c and 8d) Starch granule from specimen #114. The granule is polygonal with a centric hilum and extinction cross and a longitudinal fissure that runs through the hilum of the granule. The size and morphology of this granule suggest that it is likely *Avena* sp. 9a and 9b) Starch granule from specimen #10. The granule is ovoid with a small with several natural fissures at the hilum; the hilum and extinction cross are eccentric. This morphology and size are consistent with members of the genus *Quercus*. 10a and 10b) Starch granules from specimen #36. The granules are round but both exhibit facets where the two granules make contact. Both have centric hila with small fissures and centric extinction crosses. The size and morphology of these granules is consistent with *Avena* sp. 11a and 11b) Starch granule from specimen #79. The granule is circular with a centric hilum and indistinct extinction cross, which suggests the granule has been processed. The size and morphology are consistent with members of Triticeae and other small-grained grasses.

Table 1. Summary of results for starch granules and phytoliths recovered from pig dental calculus, ordered chronologically. The column “Sample” includes site name and arbitrary ID number used for this analysis. Additional relevant contextual information is included in the parentheses. In the “Tooth” column, the type and number of tooth is indicated following standard notation (e.g., “M³” means “upper third molar”). Wild or domestic status is based off the metrics WA (Breadth of Anterior), WP (Breadth of Proximal), and Length of each tooth (measurements are in mm). Asterisk (*) indicates that the sample was not processed with heavy liquid.

Figure 1

Figure 2

Figure 3

Table 1

Summary of Results

Sample	Tooth	Status	WA	WP	Length	# Starches	# Phytoliths	Identified Microfossils
Hallan Çemi 41	M ₃	Wild	17.7		39.6	0	1	
Hallan Çemi 42	M ₃	Wild	18.4		41.3	1	1	One possible tuber starch; Bulliform phytolith
Domuztepe 10	M ₁	Wild	11.0	11.2		1	1	Possible oak (<i>Quercus</i> sp.) acorn starch. Phytoliths likely originate from grass.
Domuztepe 17-18	M ² (17) M ³ (18)	Domestic?	17.0 18.4	16.5	32.5	Many	0	Large cluster of small starch granules – likely from a grass.
Domuztepe 24	M ₃	Domestic	15.0		34.0	Many	0	Mass of gelatinized starch granules.
Domuztepe 29	M ³	Domestic	18.6		32.5	2	1	Two likely grass starch granules. Phytoliths likely originate from grass.
Domuztepe 36	M ³	Domestic	17.7		29.9	7	0	Two damaged (possibly grinding?) <i>Avena</i> sp. starch granules, one gelatinized Triticeae granule.
Domuztepe 43	M ³	ND				8	0	Three damaged (possibly grinding?) <i>Avena</i> sp. starch granules, compound granules – likely tuber starch granules, and one potential <i>Quercus</i> sp. granule.
Domuztepe 47	M ₃	Domestic	15.3		33.5	0	2	Phytoliths likely originate from grass.
Domuztepe 67	M ₃	Domestic?	15.7		36.4	0	0	-
Domuztepe 68	M ³	Domestic?	19.0		31.6	3	0	Three damaged (possibly grinding?) <i>Avena</i> sp. starch granules.
Domuztepe 72	M ₃	ND				17	0	All small granules – likely grasses.
Domuztepe 79	M ₃	Domestic	14.4		32.1	1	12	One damaged Triticeae granule; several grass stem phytoliths.
Domuztepe 93	M ₂	Wild?		14.6		2	0	Two damaged (possibly grinding?) <i>Avena</i> sp. starch granules.
Domuztepe 114	M ³	Wild			32.3	5	0	Two (likely <i>Hordeum</i> sp.) damaged granules, and one damaged <i>Avena</i> sp. granule.
Umm Qseir 12	M ³	Domestic	17.3		27.0	0	0	
Mashnaqa 5-7	M ₁ (5) M ₂ (6) M ₃ (7)	ND ND ND				0	0	

Ziyadeh 4 (Post-Ubaid)	M ₃	Domestic	15.0			0	0	
Ziyadeh 17 (Ubaid)	M ₂	Domestic?	13.2	14.0		3	0	One damaged starch granule – possibly <i>Avena</i> sp., though this is difficult to determine.
*Hacinebi Tepe 46 (Phase LCB2 local)	M ²	Domestic	15.9	16.0		1	0	Heavily damaged Triticeae (likely <i>Hordeum</i> sp.).
*Hacinebi Tepe 47 (Phase LCB2 local)	M ₃	Domestic	13.7		30.2	0	0	
*Hacinebi Tepe 81 (Phase LCB2 local)	M ₃	Domestic	13.6		33.7	0	0	
*Hacinebi Tepe 82 (Phase LCB2 local)	M ₃	Domestic	13.5		26.0	0	0	
*Hacinebi 102 (Phase LCB2 Uruk)	M ¹	Domestic	12.1	12.3		1	1	Small non-diagnostic starch granule; likely grass lemma phytoliths.
Ziyadeh 16 (Early 3rd Mill.)	M ³	Domestic	15.8			4	1	Four small unidentifiable granules.
Atij 3-4	M ₂ (3) M ₃ (4)	Domestic Domestic	9.9 11.9		28.0	0	0	
Atij 5	M ¹	Domestic	11.6	12.1		0	0	
Atij 18	M ₃	Domestic			29.5	0	0	
Atij 44	M ₃	Domestic	14.5		31.4	0	1	Unidentified plate of phytoliths.
Raqa'i 4	M ₃	Domestic	13.9		31.6	0	0	
Raqa'i 8	M ₂	Domestic	10.6	11.5		2	1	Two damaged (possibly grinding?) <i>Avena</i> sp. starch granules. One echinate short cell phytolith – likely a grass stem.
Raqa'i 22-24	M ¹ M ² M ³	Domestic Domestic Domestic	 16.0 16.3	13.0 15.3		0	0	
*Leilan 169 (Phase 3B/C, Upper Town)	M ³	ND				0	0	
*Leilan 8 (Phase 3D, Upper Town)	M ³	Domestic	16.5		27.8	0	0	
*Leilan 65 (Phase 3D, Upper Town)	M ³	Domestic	16.9		31.1	0	4	Dendritic long cell phytoliths.
*Leilan 109 (Phase	M ₁	Domestic	9.0	9.8		0	4	Likely grass lemma phytoliths.

2B, Lower Town)								
*Leilan 120 (Phase 2B, Lower Town)	M ²	Domestic	14.9	14.4		0	0	
*Leilan 137 (Phase 2B, Lower Town)	M ₁	Domestic	9.6	10.0		0	2	Likely grass phytoliths.
*Leilan 168 (Phase 2B, Upper Town)	M ₃	ND				1	0	Too damaged to identify.
*	Indicates sample was not processed with heavy liquid.							