Animal dung from arid environments and archaeobotanical methodologies for its analysis: An example from animal burials of the Predynastic elite cemetery HK6 at Hierakonpolis, Egypt

Elena Marinova[1], Philippa Ryan[2], Wim Van Neer[1,3], Renée Friedman[4]

[1]Center for Archaeological Sciences, University of Leuven, Celestijnenlaan 200E, bus 2408, B-3001 Leuven, Belgium, [2]Department of Conservation and Scientific Research, British Museum, London WC1B 3DG, UK, [3]Royal Belgian Institute of Natural Sciences, Vautierstraat 29, B-1000 Brussels, Belgium, [4]Department of Ancient Egypt and Sudan, British Museum, London WC1B 3DG, UK

Bioarchaeological studies of animal dung from arid environments provide valuable information on various aspects of life in ancient societies relating to land use and environmental change, and from the Neolithic onwards to the animal husbandry and the use of animals as markers of status and wealth. In this study we present the archaeobotanical analysis of animal gut contents from burials in the elite Predynastic cemetery HK6 at Hierakonpolis, Upper Egypt. The study involved analysis of plant macrofossils, phytoliths and pollen applied on samples from two elephants, a hartebeest, an aurochs and five domestic cattle. The study showed that most probably the elephants were given fodder containing emmer spikelets (dehusking by-products) before the animals death. Most of the other animals were also foddered with cereal chaff, but were mainly allowed to browse and graze in the settlement area and near the Nile. The diet of some contained only wild growing plants. The variety of plant remains identified in the stomach contents indicates that the food plants for the animals were obtained from three possible habitats near the site: the river banks, the low desert and the cultivated/anthropogenically modified areas.

Keywords: Plant macrofossils, Phytoliths, Fodder, Animal feeding, Bioarchaeology, Predynastic Egypt

Introduction

Dung remains from arid or desert environments show in some cases excellent preservation of plant remains. They can provide information on past environment and subsistence that can rarely be obtained from other sources in such environments where proxy data are generally scarce (Scott 2005). Pure desiccation does not occur in all cases: material is often preserved in a state transitional between desiccation and mineralisation (Linseele *et al*. 2010, 2013). The mineralised state makes the analyses difficult and reduces the range of information that can be obtained. However, careful sampling and sub-sampling in order to select better preserved material can increase the potential of successful analysis. Animal dung deposits from cave and shelter sites can provide valuable paleoenvironmental and paleoeconomic evidence (see di Lernia 2001; Delhon *et al*. 2008, Mercuri 2008; Linseele *et al*. 2010) especially when accompanied by good stratigraphic and chronological control. Animal dung contributing to settlement deposits in desert environments has a greater chance of being preserved intact and in a recognisable state; it can provide information on the supply of fodder and functional zoning at the sites as well as the use of dung as building materials and fuel (see Cappers 2006; van der Veen and Tabinor 2007; Ghosh *et al.* 2008; Mercuri 2008; Marinova *et al*. 2012).

Animal burials in cemeteries of the Egyptian Predynastic period (ca. 4000–3000 BC) traditionally have yielded domestic animals (sheep, goat, cattle and dogs), which were interred alone or in association with human bodies (Flores 2003, 2004). The elite cemetery HK6 at Hierakonpolis, Upper Egypt, from which the materials presented in this paper are

Correspondence to: Elena Marinova, Center for Archaeological Sciences, University of Leuven, Celestijnenlaan 200E, bus 2408, B-3001 Leuven, Belgium. Email: Elena.Marinova@bio.kuleuven.be

DOI 10.1179/1461410313Z.00000000020

derived, includes not only the usual domestic species, but uniquely also a range of wild and exotic species including baboon (*Papio anubis*), jungle cat (*Felis chaus*), wild cat (*Felis silvestris*), leopard (*Panthera pardus*), wild donkey (*Equus africanus*), hippopotamus (*Hippopotamus amphibius*), elephant (*Loxodonta africana*), hartebeest (*Alcelaphus buselaphus*), aurochs or wild cattle (*Bos primigenius*) and crocodile (*Crocodylus niloticus*). Some of these wild animals have healed fractures, indicating that they lived at least 4–6 weeks in captivity before their deaths (Van Neer *et al*. 2004; Friedman *et al*. 2011). Owing to the excellent preservation of the abdominal content of the herbivores buried in this cemetery (elephant, hartebeest, aurochs and domestic cattle) and the possibility of identifying the plant remains included in it, the diet of these sacrificed animals can be documented. The plant materials in the gut contents were analysed using different methods (macrobotanical analysis, phytolith and pollen analysis) in order to test their potential and to propose an optimal protocol for further studies in this specific context. Further aims of the study were to reconstruct the diet of the buried animals and compare the respective diets of the domestic and wild captured animals in order to gain knowledge on the feeding practices and the conditions under which they were kept by their high status owners at this major site of Predynastic Egypt.

Environmental Settings

Hierakonpolis (25°06′N, 32°46′E) is located in Upper Egypt (Fig. 1), on the west bank of the Nile, between the modern towns of Esna and Edfu. The site is situated in the zone of subtropical arid deserts characterised as very arid. Hierakonpolis owes its climate to the fact that it is far from the sea and sits at low altitudes (ca. 80–100 m asl). The latter is the reason of the absence of orographic rain. Further, the area has a high temperature, low relative humidity, high evaporation and very low rainfall: 1.4–5.3 mm per year (Cambertlin 2009). The modern vegetation in the area belongs to two main vegetation zones: the flood plain, today occupied mainly by cultivated lands, and the arid desert habitat with its typical sparse vegetation mainly concentrated in the wadi beds (Fahmy *et al*. 2012).

Archaeological Settings

The history of Hierakonpolis begins at around 5000 BC. From limited occupation during the Badarian period (ca. 4500–4000 BC), the site grew to become one of the largest Predynastic settlements in Upper Egypt, reaching its maximum size in the early Naqada II period (ca. 3700 BC), with habitation remains, cult establishments, food and pottery production installations and cemeteries stretching for ca. 3 km along the edge of the low desert, for 2 km up the central wadi that bisects the site, and for an indeterminate distance into the flood plain (overviews in Adams 1995; Friedman 2011). Commensurate with the site's size and complexity, an elite class developed, which established an exclusive cemetery for its burials. Called HK6, it is from this cemetery that the material discussed in this study is derived.

The elite cemetery at HK6 is located in the central wadi, on a flat terrace some 2 km west of the cultivation edge. Covering an area of about 7000 m^2, less than 15% of it has been excavated. At its centre was a series of wood-built funerary temples which take the form of pillared halls. Flanking this precinct, the elite constructed their sizeable and well-equipped tombs and marked them with elaborate wooden superstructures and enclosure walls, but as a further display of their power and wealth, the elite also surrounded their tombs with subsidiary graves containing an array of human and animal associates (Friedman 2008). The cemetery is unique for the quantity of animal burials it contains, the diversity of the species present and the mixture of these species within the tombs (Van Neer *et al*. 2004). The majority of the material in this study comes from animal burials associated with the complex surrounding the large and rich tomb called Tomb 16 (Fig. 1B), which was established in the Naqada IC-IIA period (c. 3700 BC) (Friedman *et al*. 2011). In addition, the gut content of an elephant (Tomb 24) associated with another funerary complex dated to the Naqada IIB period (c. 3650 BC) (Friedman 2004) was also analysed.

Materials and Methods

The studied Burials: Field Conditions, Sampling and Dating

The samples analysed for this study originate from the intestinal tract of nine buried animals, both domestic and wild: two elephants (Tombs 24 and 33), a hartebeest (Tomb 46), an aurochs (Tomb 19) and five domestic cattle (Tombs 36, 43, 49) (Fig. 1 and Table 1). The analysed materials consist of desiccated plant remains, which were partly damaged by digestion and later fossilisation. In general, they are considered to reflect the food eaten in the last days of the animals' lives. Seeds/fruits, chaff, stems in smaller or bigger fragments, as well as fragments of tissues were visible as more or less compacted organic matter (Fig. 2). Generally, the plant remains were less compacted and more recognisable in the samples from the elephants, owing to their non-ruminant digestion. This is also illustrated by the variation in the concentrations of identifiable plant remains (Table 1). Some of the plant materials were mineralised due to the temporary presence of water enriched with minerals and

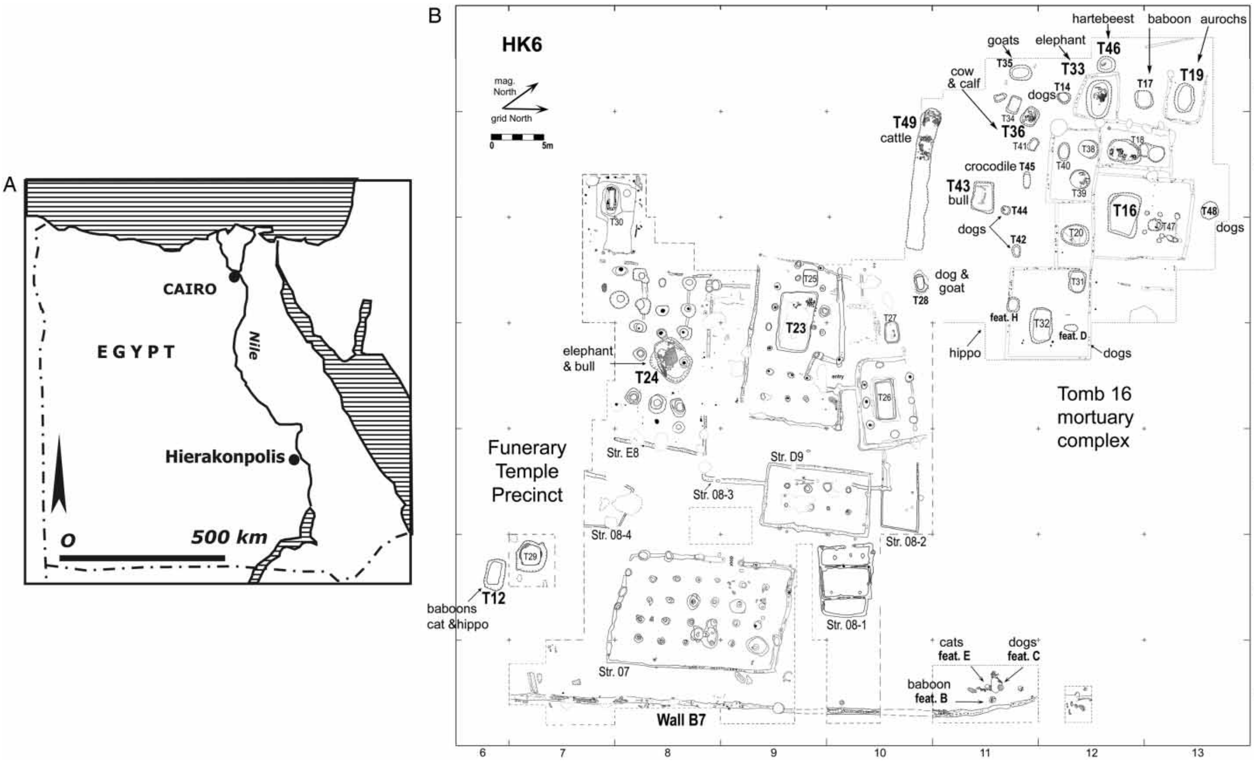

Figure 1 Map of Egypt indicating the location of Hierakonpolis (A) and plan of the relevant excavated areas of the HK6 cemetery, showing the location of the tombs of the studied animals (B).

consequent re-drying at some point in the past. Owing to the mineralisation most of the structures were no longer recognisable in the completely mineralised plant remains.

At their burial, the unbutchered animals were often placed on mats lining the bottom of the graves and then covered with mats and sometimes textile before the grave was filled with sediment, and then probably capped with natural stone slabs. The decay that occurs in such an environment is illustrated in the case of the herbivores by the presence of a yellow-greenish discoloration of the soil in the abdominal area.

The major difficulty for analysis and interpretation of the material from these tombs is the fact that all of them have suffered from disturbance caused by robbing events over the millennia (Adams 2000; Van Neer *et al.* 2004). As a result, few animals are still in full articulation and faunal and botanical material has been scattered and mixed. However, the majority of the gut contents discussed in this paper were found *in situ* within the animal, leaving no doubt about the integrity of the sample. This was clearly the case for the elephant from Tomb 33, a young male individual (10–11 years of age), of which the lower half of the body was still more or less in articulation at the bottom of his large tomb. Within the rib cage and the abdominal area large quantities of botanical matter were recovered as well as other ingested material, such as two catfish bones, flint debris, stones and partially digested potsherds (Marinova and Van Neer 2009; Friedman *et al.* 2011). This suggests that the animal had been feeding on or near settlement refuse. A bone fragment of the elephant was AMS dated to 4850 ± 40 BP (Beta 252910) or 3700–3630 and 3570–3530 cal BC (2 sigma), the earlier probability range being roughly in agreement with the ceramic dating of the Tomb 16 complex to Naqada IC-IIA (cf. Hendrickx 2006).

The elephant from Tomb 24 was also a young male (Van Neer and Linseele 2003; Friedman 2004), however, its skeleton was more heavily disturbed and the amount of intestinal content that could be retrieved for analysis was small.

The gut content of the aurochs from Tomb 19 produced an AMS date of 4850 ± 60 BP (Beta 142094) or 3720–3520 cal BC (2 sigma), similar to the elephant in Tomb 33. Located directly adjacent to the elephant's grave, Tomb 46 contained the remains of a human adult male and a pregnant female hartebeest (Van Neer 2011).

In addition to these wild herbivores, domestic cattle also yielded intestinal content. Samples were available from a bull buried in Tomb 43 and a cow with a calf from Tomb 36, all of which are tentatively attributed to the Naqada IC-IIA period according to associated archaeological finds (Friedman *et al.* 2011).

Two further samples were analysed from cattle (sub adult females) found in Tomb 49, a large trench-like

Table 1 Results of the macrobotanical analysis (absolute counts)

	Analysed dry									Analysed in solution	
Animal	Elephant	Elephant	Aurochs	Hartebeest	Bull	Cow	Calf	Cow	Cow	Elephant	Cow
Tomb	T33	T24	T19	T46	T43	T36	T36	T49/3	T49/4	T33	T36
Matting present	+	+	+		+					+	
Sample volume (in ml)	1300	45	72	117	16.5	800	170	240	200	600	800
Volume studied (in ml)	80	45	12	57	16.5	40	60	20	20	40	10
Total nr. identifiable plant remains	1903	330	61	78	18	261	166	30	17	207	9
Concentration identification of plant remains in 10 ml	284.6	65.6	36	20.8	2.8	26.1	16.8	3.1	1.8	25	2.9
Botanical remains											
Crops											
Hordeum vulgare (rachis fragment)		6				11	14				2
Triticum dicoccum (spikelet nearly whole)	14										
T. dicoccum (spikelet damaged, some chaff)	159	34									
T. dicoccum (spikelet fork, without chaff)	435	119	1	41	12	212	85		4	15	5
T. dicoccum (chaff fragment)	97	65		12		26	8			3	1
Triticum sp (pericarp fragment)	3									8	
Wild growing											
Acacia sp. (leaf)	36	6								14	
Acacia sp. (thorn)	1128	76								166	
Aizoon sp. (seed)					1				2		
Ceruana pratensis (inflorescence)	4										
Chenopodium sp. (seed)				1	1				3		
Cyperaceae (epidermis fragments)	13		57					16			
Cyperaceae (nutlet)	2										
Fimbristylis (fruit)			1		4			5			1
Hyosciamus cf. *muticus* (seed)				2							
Portulaca oleracea (seed)				8							
Rumex sp. (seed)	4		1							1	
Setaria (fruit)	5		1				1		3		
Tamarix sp. (charred wood)	2						1				
Fabaceae (small seeded)	1	2		1					2		
Panicoideae (small fruit)				1		1					
Poaceae (stem fragment)		22		12		11	57	9	3		
Indet (seed/fruit)	3		6	24	1			1			
Indet (charred wood)	3		4	2			2		1		
Indet *(wood fragment)*	541	250			9					41	20
Dicotyledoneae (leaf epidermis)	9									2	
herbaceous stem fragment	387	77	289	104							
Zoological remains											
Elephant skin fragment	+	+									
Insect (fly larve)		+									
Fish scale							+				
Animal bone fragment	+	+		+						+	
Animal hair	+					+	+				+
Other remains											
Mineralised material		+		+	+	+	+				

tomb from which a total of 12 individuals were recorded. The animals were arranged in two rows with their backs against the sides of the trench and their legs towards the centre. Pottery within the grave suggests a dating in the early Naqada II period (Droux 2011).

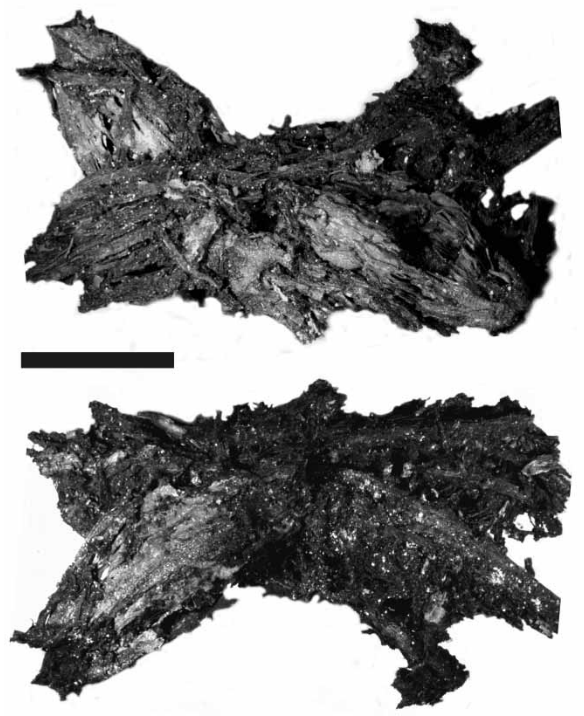

Figure 2 Two views of a gut content fragment of the Tomb 33 elephant. Scale 5 mm.

Laboratory Analyses

For the macrobotanical analyses subsamples were taken of 10–80 cm^3; for the phytolith analysis 3 cm^3; and for pollen subsamples of 3 cm^3.

Plant Macrofossil Analysis

The plant macrofossils were extracted by breaking the subsamples into fragments of ca. 2–3 cm diameter and taking out the visible and identifiable plant macrofossils with a fine brush under a binocular microscope. For this no additional treatment was applied. Of each sample, a certain volume (10–80 ml) was taken for investigation depending on the volume of the whole sample. Among the small fragments, those containing plant remains with visible and well-pronounced structures were isolated and observed at higher magnification (Fig. 3) under a reflected light microscope and scanning electron microscope. This allowed identification mainly of epidermal fragments, *Triticum* pericarps and wood.

Two samples (one each from Tomb 33 and Tomb 36) were hydrated with a 0.5% solution of sodium phosphate (Na_3PO_4) according to the methodology of Bryant and Dean (2006) in order to test its potential for the study of desiccated gut contents. A volume of the sample was placed in a vessel and covered with the solution. After four days this was decanted into a separate container and replaced by an alcohol/water mixture. Identification of the compounds was accomplished under a binocular microscope. To investigate compounds like epidermis or plant tissue fragments, these were placed on a microscope slide, covered with glycerine and a cover slip and studied under magnification of ×40 to ×1000.

Phytolith Analysis

Phytoliths are formed when soluble silica Si $(OH)_4$ is taken up by plants from the groundwater and deposited within and between certain plant cells (Piperno 2006). Under certain environmental conditions, such as combination of water availability and aridity, areas of epidermal tissue can become silicified and these conjoined phytoliths are known as 'silica skeletons' (Rosen 1992). Silica skeletons comprising several cells, especially from grass husk (the seed bracts), can more frequently differentiate genera than single cell analysis; therefore, mainly the multi-cell phytoliths will be discussed in the results (Fig. 3C). Phytoliths were extracted from abdominal content subsamples through the removal of non-silica elements, such as carbonates and organics, in a series of laboratory procedures following methods outlined by Rosen (2005). Extracted phytoliths were analysed at ×400 magnification using a light transmitting microscope and approximately 300 phytoliths were counted per slide. In the results, relative abundances (percentages) from single and multi-cell categories are calculated separately.

Pollen Analysis

For this study four subsamples were prepared for pollen analysis in order to test the potential of the method for further investigations of the animal gut contents at Hierakonpolis. The samples originate from the elephant in Tomb 33 and one sample each from the cow and the calf in Tomb 36. The samples were prepared using standard treatment techniques including heating in a 10% KOH solution for 10 minutes, sieving (300 μm) and subsequently acetolysis. The resulting residues were mounted in glycerine and analysed under a microscope.

Results

Plant Macrofossil Analysis

The results of the macrofossil study are presented in Table 1. Concentrations of identifiable plant remains varied among the different animals even of the same species (e.g. both elephants). This suggests that while the different fodder types and digestion physiologies of the herbivores played a role in the preservation of the plant macrofossils, other factors such as pre-burial treatment and post-deposition conditions are also of significance.

The comparison of the subsamples from Tomb 33 and Tomb 36, which were studied dry without treatment and again wetted with a 0.5% solution of sodium phosphate, shows that the wet samples

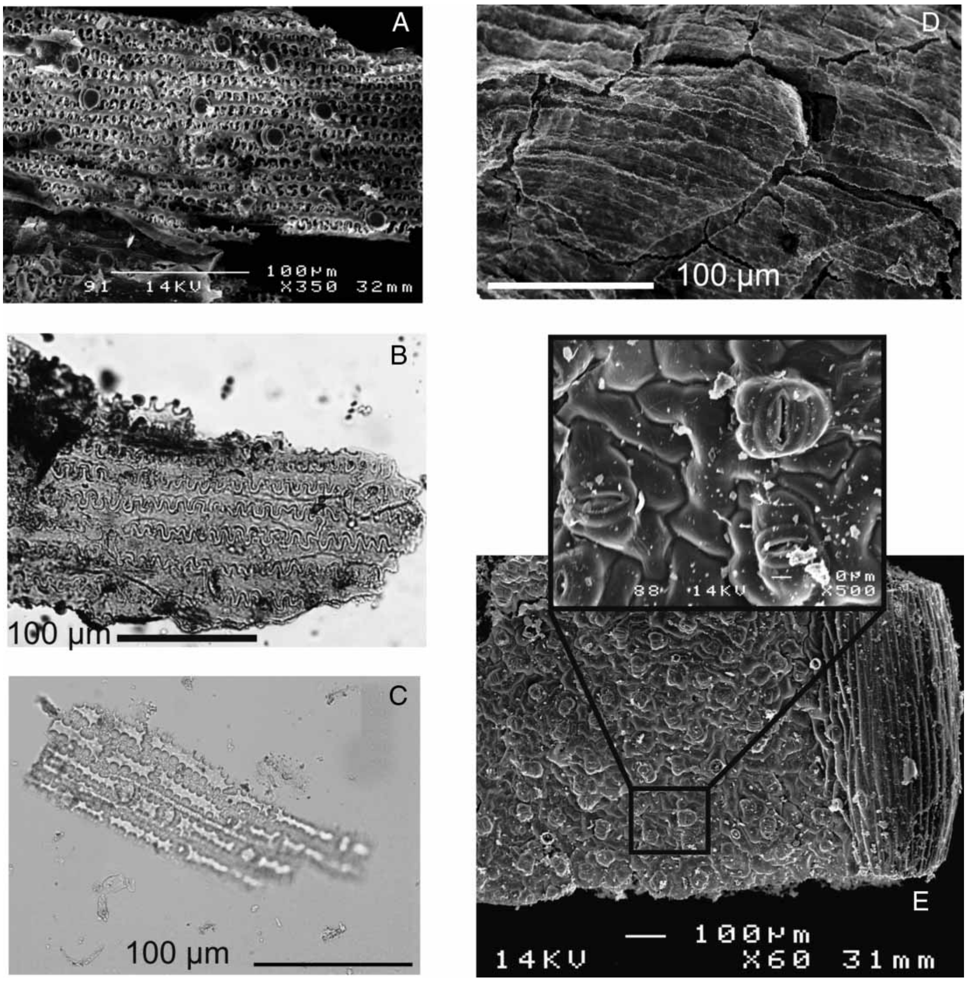

Figure 3 Microscopic plant remains. (A) Cereal chaff fragment under scanning electron microscope (SEM) (B) cereal chaff fragment under transmitted light microscope (C) *Triticum* multicell phytoliths (D) cf. *Triticum* – pericarp under SEM (E) indet. leaf epidermis.

provide few more identifiable plant remains or additional taxa. In fact, the greater part of the plant material was destroyed in the solution and very few plant remains were preserved. In this respect this study confirms the experience of Clapham and Rowley-Conwy (2007) with desiccated material from settlement layers in Lower Nubia, where the desiccated plant remains were severely damaged by contact with water. However, the few additionally identified plant remains from the re-hydrated samples yielded useful information (e.g. cereal grain pericarp fragments and leaves of *Acacia*). It is likely that the 4-day treatment with a solution of sodium phosphate was too long for this brittle material and that with shorter treatments better results could be achieved. This, however, requires further investigation.

The dominant plant macroremains in the samples studied from the gut contents of the elephants from Tombs 33 and 24 consist of young tree twigs and thorns. Some of the thicker twigs allowed observation of the wood anatomy and showed the typical morphological characteristics of *Acacia*. The thorns also suggest this tree and it is likely that the finer twigs, with similar thorns, also belong to *Acacia* (Fig. 4A and B). Leaf fragments of *Acacia* (Fig. 4C) were also found. The other main constituents were chaff (Fig. 4D–F) and the remains of spikelets of emmer wheat (*Triticum dicoccum*; Fig. 4D–F). The last meals of the two elephants exhibit clear similarities, with twigs of *Acacia* and emmer chaff present in both. It is interesting to note, however, that the Tomb 33 elephant also yielded almost whole spikelets of emmer with chaff partly attached. In two subsamples from Tomb 33 several fragments of *Triticum* pericarp were found (Fig. 3D), also hinting at the presence of *Triticum* grains. These finds indicate that post-threshing by-products of emmer were most probably given as fodder to the animals.

The last meals of the domestic cow and calf from Tomb 36 have as their main component cereal chaff (emmer and barley). On the other hand, the diets of cows no. 3 and no. 4 from Tomb 49 and the aurochs from Tomb 19 were based almost completely on wild plants (one spikelet of *Triticum* was found in the

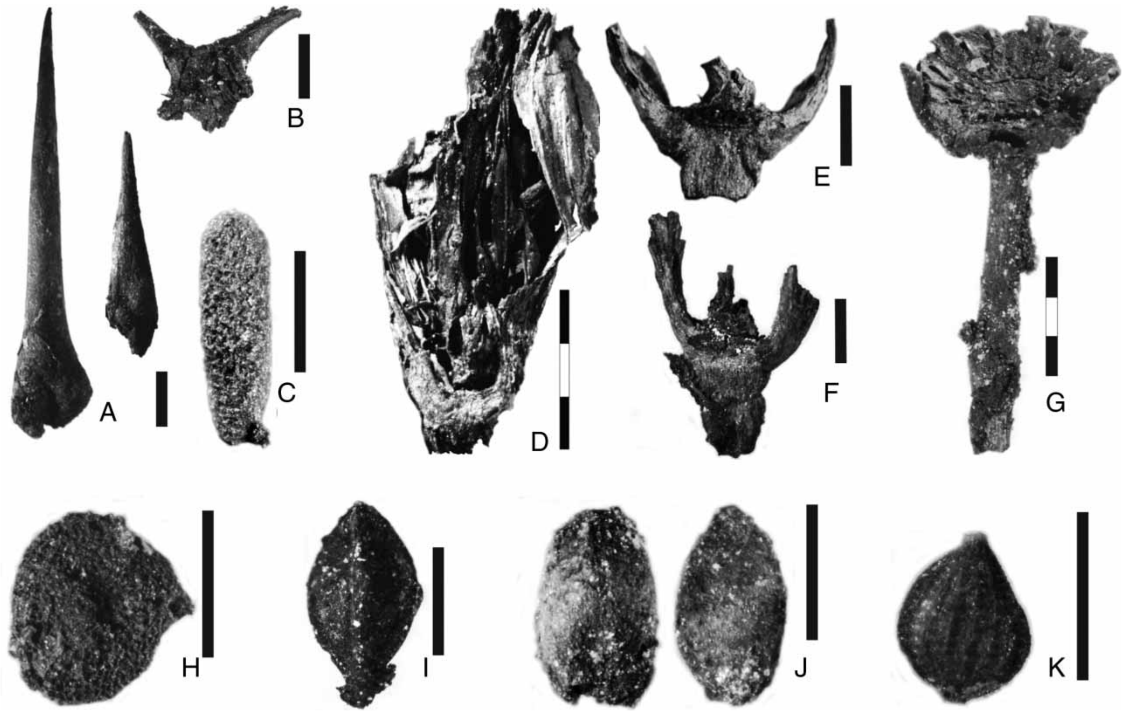

Figure 4 Plant macrofossils found in the gut content of the animals. (A, B) Acacia (*Acacia* sp.) thorns, Tomb 33 elephant; (C) Acacia leaf, Tomb 33 elephant; (D) emmer (*Triticum dicoccum*) whole spikelet, Tomb 33 elephant; (E, F) emmer glume bases, Tomb 33 elephant; (G) *Ceruana pratensis* inflorescence, Tomb 33 elephant; (H) *Hyoscyamus* cf. *muticus* seed, Tomb 46 hartebeest; (I) *Rumex* sp., seed, Tomb 19 aurochs; (J) *Setaria* sp., grain, Tomb 19 aurochs; (K) *Fimbristylis bisumbellata*, fruit, Tomb 19 aurochs.

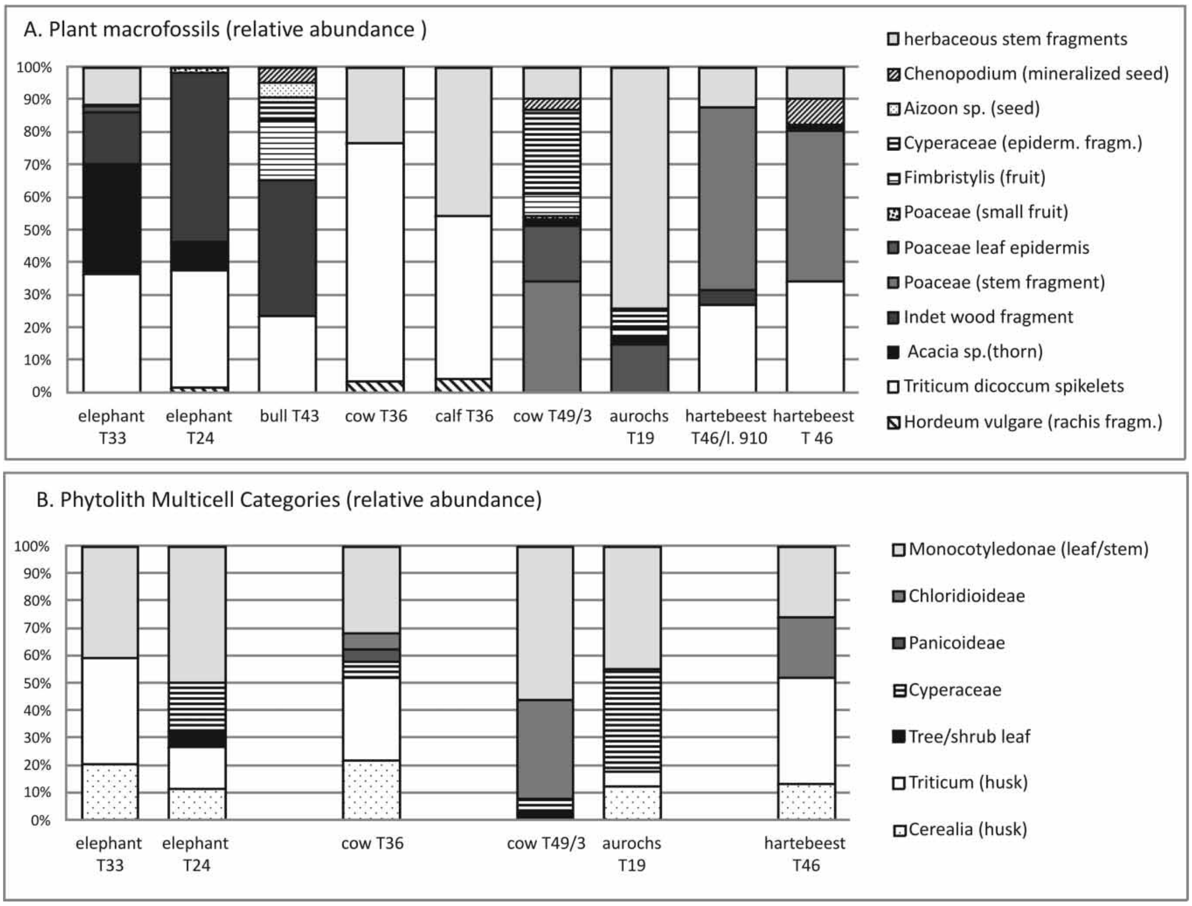

Figure 5 Comparison between the proportions of the main categories of findings from the macrobotanical and phytolith analyses (raw data for plant macrofossils are given in Table 1).

aurochs, four in cow no. 4). The bull from Tomb 43 and the hartebeest from Tomb 46 show to some extent an intermediate situation with emmer as well as several wild growing plants being present (Fig. 5).

Phytolith Analysis

The gut contents from all but one of the animals (cow no. 3 from Tomb 49) contained *Triticum* sp. (wheat) husk silica skeleton phytoliths (Table 2). The elephant from Tomb 33 had the highest relative abundance of wheat husk silica skeletons, the aurochs from Tomb 19 the lowest, and cow no. 3 from Tomb 49 none at all. The gut contents of the elephant from Tomb 24, the cow from Tomb 36, the auroch from Tomb 19 and cow no. 3 from Tomb 49 contained phytoliths from Cyperaceae (sedges), which grow in wetland areas including those along river banks. Sedge phytoliths were not clearly identified in other samples but may nevertheless be part of the unidentified monocot leaf/stem category. The subsample from the elephant of Tomb 33, which included matting, contained tree or shrub 'platey' phytoliths, but these were not present in the other two samples from this animal and may therefore derive from the matting or from surrounding sediments. The sample from the elephant found in Tomb 24 also contained 'platey' phytoliths, which may have a similar provenance, as well as multi-cell polyhedral morphologies from tree or shrub leaves. The gut contents sample of the cow from Tomb 36 also contained wild C4 grasses including bilobe forms, which are found generally in panicoid grasses, and saddle forms, which are generally found in chloridoid grasses but also in *Phragmites* (common reed). Particularly large proportions of a saddle producing wild grass were present in the cow from Tomb 49 and the hartebeest from Tomb 46. *Phragmites* multicells are usually clearly identifiable and these were not found in any of the analysed samples with the possible exception of the cow from Tomb 36.

Pollen Analysis

Pollen preservation was attested in only two of the four subsamples, both of them coming from the gut content of the elephant from Tomb 33. The samples contained up to 90% pollen of the Cerealia-type and very few others belonging to Poaceae, Chenopodiaceae, Asteraceae and Cyperaceae (in total 300 pollen grains were counted). The samples were prepared only for testing pollen preservation so no exotic marker was added and therefore it was not possible to estimate pollen concentrations. Besides pollen, non-pollen palynomorphs were also found. In both samples fungal spores of the *Sordaria*-type usually associated with dung and few of the *Chaetomium*-type, which usually grows on decaying plant matter (see van Geel *et al*. 2003), were found.

Discussion

Integration of the Archaeobotanical Evidence

The applied analyses (macrobotany, phytoliths and pollen) are complementary and show a detailed picture of the last meals of the studied animals. The presence of rather high amounts of Cerealia-type pollen in the samples from Tomb 33 indicates the presence of the inflorescences or chaff of cereals (see Bottema 1992). This accords well with the dominance of emmer chaff in the macrofossil and phytolith records. When examining the general composition of the sampled gut contents as inferred from the plant macrofossils and the phytoliths (Fig. 5), it appears that both methods provide a comparable picture of the diet of the studied animals when it comes to the role played by cereal chaff, wild grasses and sedges. However, the plant macrofossil record provides a more diverse and detailed picture of the fodder, as it reveals the diagnostic remains of several taxa, such as *Juncus, Ceruana pratensis* and *Acacia*, which do not leave a clear phytolith record. Phytolith analysis has, on the other hand, the advantage of giving information on the plant components of the fodder in cases where the available study material is limited in volume, strongly compacted or fragmented. This is illustrated especially in the samples from the aurochs of Tomb 19 and cow no. 3 of Tomb 49, in which the plant macrofossils did not contain much more than herbaceous stem fragments and a few Cyperaceae epidermis remains. The very low number of identifiable plant macroremains may be due to more than just poor preservation. Considering the results of the phytolith analysis, it is more likely related to the diet of those animals, which seems to have been dominated by softer, leafy plant parts.

The identification of the different leafy and epidermal fragments preserved in dung samples is time consuming and its precision depends heavily on the quality of the available reference material (e.g. Kühn and Hadorn 2004; Linseele *et al*. 2010); however, this approach is very useful for tracing strongly fragmented plant parts, like leafs and stems (Kühn *et al*. 2013), which cannot be recognised using other methods. For example, the identification of epidermal tissues could be used as an alternative or as a complement to phytolith analysis for identifying trees or taxa that do not produce diagnostic phytoliths or are not detectable by phytolith analysis. Thus, when studying herbivore dung remains, the combination of phytolith analysis and identifications of epidermal/tissue structures in the macrobotanical samples together can provide a more complete picture of the plant material included in the diet of the herbivores that produced the dung.

Table 2 Results of the phytolith analysis

Sample origin Animal	T33 – lower body Elephant	T33 – pelvic region Elephant	T33 gut contents + matting Elephant	T24 Elephant	T 36 Cow	T 19 Aurochs	T49/3 Cow	T46 Hartebeest
Phytolith density within sediments (weight %)	12	10	8	8	13	39	8	10
Single-cell phytoliths n/per gram sediment (total)	674350	1097425	505827	365217	539856	1220444	372230	383687
Single-cell phytoliths (relative abundance %)								
Elongate smooth LC*	0	0	0	20.8	3.5	7.5	8.8	3.9
Elongate sinuate LC*	0	0	0	1.7	0.9	0	3.5	0
Elongate echinate LC	3.8	6.2	5.3	5.0	12.2	4.3	5.3	2
Elongate dendritic*	75	78.4	58.5	22.5	47.0	9.7	0	54.9
Rod smooth LC	0	0	0	2.5	0	5.4	0	0
Elongate psilate asymmetrical LC	0	2.1	0	0.8	0	29.0	5.3	0
Trapezidform crenate*	0	0.0	0	0	0.9	0	0	0
Papillae*	2.5	1.0	4.3	0	0	0	0	0
Stomata	0	0	0	0	0	0	0	0
Prickle	0	0	0	9.2	4.3	10.8	0	0
Hair	1.3	4.1	0	2.5	0.9	5.4	0	0
Bulliform	2.5	2.1	0	1.7	0	16.1	0	3.9
Keystone bulliform*	0	0	0	0	0	0	45.6	0.0
Bilobe SC*	0	0	0	0	5.2	0	0	0.0
Saddle SC*	0	0	0	0	6.1	0	21.1	27.5
Rondel SC*	15	6.2	22.3	21.7	17.4	6.5	7	6
Cross SC*	0	0	0	0	1.7	0	0	0
Cyperaceae cones	0	0	0	0	0	1.1	1.8	0
Globular echinate (palm)	0	0	0	0.8	0	0	0.0	0
Platey[d]	0	0	4.3	9.2	0	0	1.8	2.0
Ellipsoid psilate[d]	0	0	5.3	1.7	0.0	4.3	0	0
Multi-cell phytolits, *n*/per gram sediment (total)	429898	316782	317487	158261	333303	524922	163259	173035
Multi-cell phytoliths (relative abundance %)								
Unident Monocot L/St	11.8	17.9	37.3	44.2	21.1	45	44	26.1
Silica skeleton elongate smooth L/St*	0	0	0	0	4.2	0	0	0
Silica skeleton elongate sinuate L/St*	11.8	7.1	3.4	0	0	0	0	0
Silica skeleton elongate with rondels L/St*	19.6	0	0	5.8	5.6	0	0	0
cf. Cereal stem*	0	0	0	0	1.4	0	0	0
Silica skeleton with bilobes L/St* Panicoideae	0	0	0	0	4.2	0	0	0
Silica skeleton with saddles L/St* Chloridoideae	0	0	0	0	5.6	0	36	21.7
Phragmites sp. L/St*	0	0	0	0	1.4	0	0	0
Silica skeleton – bulliforms	0	0	0	0	0	0	12	0
Silica skeleton cf. Cyperaceae	0	0	0	7.7	0	10	8	0
Silica skeleton Cyperaceae L/St	0	0	0	9.6	5.6	27.5	0	0
Silica skeleton indet husk cf. Pooideae*	33.3	25	20.3	11.5	21.1	12.5	0	13
Triticum sp. husk*	23.5	50	39	15.4	29.6	5	0	39.1
Polyhedron multicell[d]	0	0	0	5.8	0	0	0	0

The percentage values are calculated separately for single-cell and multi-cell phytoliths.
*Poaceae; d, Dicotyledonae; LC, long cell; SC, short cell; L/St, leaf/stem.

Evidence for Feeding of Domestic and Wild Animals

The identified plant material gives information on the diet of the animals in the last few days of their lives. Botanical remains that can clearly be identified as fodder are the remains of cereal crops, mainly representing refuse from processing for human consumption. It is unclear if the wild growing plants were also supplied by human agency or if they instead reflect grazing or browsing activity. Certainly in the case of the wild animal species, the question needs to be asked whether they were foddered or allowed to feed in suitable areas. Considering the elephants, it may have been better in terms of logistics to keep them close to places where they could find and take up food by themselves.

Young elephants of the size found at HK6 would have needed about 50 kg of food each day (Kleiman *et al*. 2003). A stabling area in proximity to a settlement area where threshing refuse was also available and *Acacia* trees were growing could well fit those requirements. Such a location may be found in the wadi settlement at Locality HK11C where recent study of the artefactual, faunal and botanical remains suggests this area may have been established specifically to service the elite and their mortuary cults (Baba 2011; Fahmy *et al*. 2012). However, given an elephant's daily feeding requirements it seems unlikely that a sufficient stand of *Acacia* trees could be maintained for long. Moreover, given the elephants' association with the elite and the labour and resources available to them, it would make sense for large quantities of suitable forage to be brought to them, at least in part made up from settlement refuse as suggested by the numerous flints, partly digested potsherds and two fish bones recovered from within the rib cage of the Tomb 33 elephant. The vertebra of a clariid catfish and a pectoral spine from a *Synodontis* catfish are most probably the left-overs from human consumption, which were dumped as refuse along with the less-tasty items and subsequently became mixed with the elephant's food.

One of the dominant food items in the elephants' gut contents is emmer, represented mainly by chaff fragments indicating that the animals were fed at least partly on the remains of crop processing. This is also shown by the phytolith analysis (Fig. 3C). Owing to the digestion physiology of the elephants, there are also spikelets with great parts of the chaff attached on them (Figs. 2 and 4D). The observation of the desiccated plant material under reflected light microscope, however, allowed the detection of fragments of wheat pericarp (Fig. 3D), showing that grains were also included in the last meal of the elephants, albeit in low quantities (eight fragments in 40-ml rehydrated sample, Table 1). The general lack of phytoliths from cereal straw (stems) is interesting since this suggests the animals were not simply being fed general crop-processing waste, which usually consists of a mixture of chaff and straw (Hillman 1984). Of course, it is possible that the usual practice observed elsewhere of mixing the straw with the chaff was not applied and that the straw was used for other purposes, so that mainly the dehusking remains were used as fodder for the animals buried in HK6.

Evidence for foddering is also available in both samples from the hartebeest (Fig. 5), in which at least one-third of the plant macroremains and half of the phytoliths originate from emmer wheat. It seems that barley was of much less nutritional value for the animals. Barley rachis fragments were found in the gut contents of the cow and calf from Tomb 36 and one of the subsamples from the elephant of Tomb 24. Barley phytoliths were not positively identified, but it is possible that some may be represented in the unidentified grass husk category. The presence of barley rachis chaff does not necessarily lead to barley phytoliths as these plant parts do not have diagnostic phytoliths (diagnostic barley phytoliths instead derive particularly from barley lemma and paleas). The study of the trash mound at locality HK11C, the result of the long-term accumulation of refuse from the Predynastic settlement (Fahmy *et al*. 2012), indicates that the chaff of barley was less abundant at Hierakonpolis than that of emmer. Study of ingested and offered foods in the human burials in the contemporaneous non-elite cemetery at HK43 further confirms the greater frequency of emmer over barley (Fahmy 2001, 2003). Hence, it seems the picture observed in the animal gut contents reflects the greater importance of emmer at the site in general during the Predynastic period.

Fodder and Land Use

The gut contents of the studied animals, with the exception of the cow and calf from Tomb 36, yielded a variety of wild growing plants. Their proportion in the diet of the animals varies greatly (Fig. 5). The analysed gut contents of cow no. 3 from Tomb 49 and the aurochs from Tomb 19 consisted almost entirely of wild taxa. They indicate grazing in the ruderal areas near the site or along the river banks and wet areas where sedges and other wetland species grow. The meaning of the finds of inflorescences of *Ceruana pratensis* (Fig. 4G) in association with the elephants from Tomb 33 (this paper) and Tomb 24 (Fahmy *et al*. 2008a) is unclear. The animals may have been feeding on the herbaceous stems of this weedy species that grows along the Nile's banks and large irrigation canals. However, since previous studies at HK6 have shown that *Ceruana* was used in matting, garlands and in the architectural structures that stood above the graves (Fahmy *et al.* 2008a; Friedman 2008), it is not excluded that the finds identified in the analysed sample are contaminants from these sources. The gut content of the Tomb 24 elephant (Fahmy in Van Neer and Linseele 2003) suggests that this animal consumed rushes (*Juncus* sp.), which grew along the Nile banks and in wetlands; however, matting to line the graves was also frequently made of this material. No evidence of these rushes was observed in the gut content of the Tomb 33 elephant, but there were a few remains typical of the sedge family (Cyperaceae), which would have come from the same humid, river-side environment as *Ceruana pratensis*. However, as indicated above, the presence of sedges in samples from animals buried with matting needs to be interpreted with caution.

Summarizing, it can be said that the last meals of the studied animals contained not only the remains of crops (like emmer chaff), but also plants coming from different habitats outside the cultivated areas. All possible plant habitats documented within and near the site by previous botanical studies (Fahmy *et al.* 2008b, 2012) were exploited for the purpose of feeding the wild and domestic herbivores buried at HK6. These food plants originated from the weedy or ruderal flora of the site, from the vegetation of the wadis and finally from the wet habitats near the Nile. The amount of ruderal and weedy plants like *Aizoon* sp., *Chenopodium* sp., *Hyoscyamus* sp., *Portulaca oleracea*, *Rumex* sp. and *Setaria* sp. is relatively high considering the volumes of gut content studied and the fragility of these plant remains. The seeds of some of those plants may have come from the Nile banks and may have been eaten by the animals together with wetland representatives such as *Ceruana pratensis*, *Fimbristylis bisumbellata*, *Juncus* and unidentified members of the family Cyperaceae. The presence of *Acacia* twigs, thorns and leaves, *Tamarix* wood and unidentified tree/shrub leafs indicates the exploitation of the woody vegetation developed on and near the site. However, it is difficult to precisely separate these habitats as the ecological range of most of the plants includes both natural and modified areas like river banks and cultivated/ruderal zones (Table 3).

A Special Meal before Death?

The graves of the animals at HK6 vary considerably in their construction and furnishings. This was not simply to accommodate the size and number of the occupants, but rather seems to reflect the perceived value of the animals to their owner due perhaps to their rarity and/or exotic origins, or their symbolic meaning as representatives of the power immanent in natural forces or attributed to specific species. The size and elaboration of the tombs of the elephants, which included large quantities of matting and textile as well as above-ground architecture, coupled with the near contemporaneous iconographic record (Friedman 2004) strongly suggests that these animals were highly valued and may therefore have received particular attention while in captivity.

The relatively high concentrations of emmer spikelets (on average 76 items per 10 ml of gut content) in the stomach contents of the elephant from Tomb 33 is significant in this regard. Considering the large amounts of food it required, it is very unlikely that emmer wheat was its main staple throughout its time in captivity. This cereal crop was grown mainly for human consumption and was a major component of the diet at Hierakonpolis (see Fahmy 2001, 2003 and Fahmy *et al.* 2008b). Therefore, it seems more plausible to see foddering which included emmer grains as part of the meal given to the animal near the end of its life. For the other species in which emmer chaff predominates, such as the hartebeest in Tomb 46 or the calf and cow from Tomb 36, we assume that those remains represent the standard fodder of emmer processing remains (dehusking).

Another plant that could be part of a special practice associated with the burial ritual is *Hyoscyamus* cf. *muticus* (Fig. 4H), which has been identified in the gut content of the aurochs in Tomb 19. The plants from this genus contain hallucinogenic alkaloids and are known to have been used in ancient funerary rituals in the Eastern Mediterranean and Europe (Rätsch 2005). However, the small number of seeds (two remains) in the studied sample does not allow us to confirm or reject this hypothesis. Representatives of the genus *Hyoscyamus* are elements of the natural vegetation and considering that the gut content of the aurochs contained little emmer chaff, but mainly various wild growing plants, it is equally possible that the seeds became part of the diet through grazing. Studies on modern fodder plants used in southern Egypt (Belal *et al.* 2009) have revealed the presence of small amounts of *Hyoscyamus muticus* and shown the high nutritive value of the plant, especially during the winter. Since it is common practice among the Bedouins to collect plants like *Hyoscyamus muticus* and feed them to their goats (Belal *et al.* 2009), it is quite plausible that the plant was given as a fodder to the aurochs as well.

Further Aspects of the Funerary Ritual and Later Disturbances of the Graves

Almost all of the graves excavated thus far at HK6 show evidence of plundering which probably began

Table 3 Main plant habitats indicated by the plant macrofossils

Animals	Plant macroremains	Habitats			
		Desert	Riparian habitats	Ruderal	Crop fields
Elephant	*Acacia* sp. (leafs and thorns)	X	X		
Elephant, cattle	*Tamarix* sp. (charred wood)	X	X		
Hartebeest	*Hyosciamus* cf. *muticus* (seed)	X		X	
Cattle	*Aizoon* sp. (seed)	X		X	
Hartebeest	*Portulaca oleracea* (seed)		X	X	
Elephant	*Ceruana pratensis* (inflorescence)		X		
Cattle	*Fimbristylis* (fruit)		X		
Elephant, cattle	Cyperaceae (nutlet)		X		X
Hartebeest, cattle	*Chenopodium* sp. (seed)		X	X	X
Elephant, cattle	*Rumex* sp. (seed)		X	X	X
Elephant, cattle	*Setaria* (fruit)		X	X	X
Elephant, cattle	*Hordeum vulgare* (rachis)				X
Elephant, cattle, hartebeest	*Triticum dicoccum* (spikelet)				X

already in Early Dynastic times if not earlier, with further activity in the late 19th century AD as demonstrated by coins, pipes and tobacco papers found in and around some tombs (Adams 2000). During the microscopic analysis of the gut contents a few observations were made that may be related to these past disturbances, but may also provide insights into aspects of the funerary ritual and logistics.

In three instances remains have been found of organisms that seem to have infested the animals as they had just begun to decay. The pollen samples in the dung from the elephant in Tomb 33 contained spores of fungi that typically develop on excrements. It is hypothesized that this happened when the gut contents of the elephant were exposed after the grave was robbed, since infestation would have been impossible when the animal was covered by 2 m of soil. On the other hand, these findings may also indicate that the animals were not interred directly upon death. Considering the difficulty of transporting a whole and unbutchered carcass, it is presumed that the animals were sacrificed during the burial rites for their elite owner near their tombs, yet this does not necessarily mean they were placed in their graves or covered with sediment immediately. In addition to whatever role the display of the sacrificed animals may have played in the funerary rites, the number of animals involved – 39 individuals in 14 different tombs can with good confidence be associated with the Tomb 16 complex – it would have taken some time to prepare and position them in their graves and then cover them over. While it is impossible to determine whether all of the animals were killed at the same time, the contiguous architecture above the tombs of the human occupants and those of the elephant, hartebeest and aurochs (Tombs 33, 46 and 19) strongly suggests that their deaths occurred as part of a single event (Friedman *et al.* 2011). Thus, it is quite possible that the dead animals could easily have been exposed to insect infestation prior to full interment.

Such a scenario is also suggested by the skin of a fly larva found in the sample from the Tomb 24 elephant. Since flies do not lay their eggs on dry animal tissue, this find indicates that the decomposing corpse was exposed either because full burial had not yet taken place or the less likely possibility that the tomb was plundered very shortly afterwards.

On the other hand, the gut sample from the aurochs in Tomb 19 produced an exuvium of a larva strongly resembling that seen in *Anthrenus*, a genus of dermestid beetles that contains species that typically feed on dry animal matter such as skin and hide (Günther *et al.* 2000). This infestation may well have occurred as a result of exposure following plundering activities over the millennia.

Conclusions

This study showed very good correspondence among the results of plant macrofossil, pollen and phytolith analyses when applied to ancient dung remains from arid environments. In general the applied methods proved to be complementary to each other and in combination allowed detailed reconstruction of the plant diet of the animals in question, providing further information on the feeding practices, available pasture, land use and taphonomy.

The elephants were provided with fodder of green *Acacia* twigs and the dehusking remains of emmer as main components. Most of the herbivores from the studied burials had also been fed with cereal processing remains, mainly of emmer, a crop meant for human consumption. Most probably some of the cattle and hartebeest were also allowed to graze and browse on ruderal places near the settlement or in wetland environments like the banks of the river Nile.

The variety of plant remains identified in the stomach contents so far indicates that the diet of the animals was obtained from the three eco-zones existing near the site: the river and its shores, the low desert and the cultivated fields.

Acknowledgements

The authors thank Marlies Vleugels for her help with the sorting and identification of the material and Wouter Dekoninck for the identification of the insect remains. The contribution of Wim Van Neer to this paper presents research results of the Interuniversity Attraction Poles Programme – Belgian Science Policy. The excavations in the HK6 cemetery at Hierakonpolis were made possible by grants from the National Geographic Society and the generosity of the Friends of Nekhen. The authors also thank Veerle Linseele and the reviewers Delwen Samuel and Anna Maria Mercuri for valuable comments and suggestions, which helped to greatly improve the current paper.

References

Adams, B. 1995. *Ancient Nekhen: Garstang in the City of Nekhen* (ESA No. 3). Whitstable: SIA Publishing.

Adams, B. 2000. *Excavations in the Locality 6 Cemetery at Hierakonpolis 1979–1985* (British Archaeological Reports International Series 903). Oxford: Archaeopress.

Baba, M. 2011. Up against the walls at HK11C. *Nekhen News* **23**, 22–4.

Belal, A., Briggs, J., Sharp, J. and Springuel, I. 2009. *Bedouins by the Lake: Environment, Change and Sustainability in Southern Egypt*. Cairo: The American University of Cairo Press.

Bottema, S. 1992. Prehistoric cereal gathering and farming in the Near East: the pollen evidence. *Review of Palaeobotany and Palynology* **73**(1–4), 21–33.

Bryant, V. M. and Dean, G. W. 2006. Archaeological coprolite science: the legacy of Eric O. Callen (1912–1970). *Palaeogeography, Palaeoclimatology, Palaeoecology* **237**, 51–66.

Cambertlin, P. 2009. Nile Basin climates, pp. 307–34 in Dumont, H. (ed.), *The Nile. Origin, Environments, Limnology and Human Use* (Monographiae Biologicae 89). Berlin: Springer.

Cappers, R. T. G. 2006. The reconstruction of agricultural practices in Ancient Egypt: an ethnoarchaeological approach. *Paleohistoria* **47/48**, 429–46.

Clapham, A. J. and Rowley-Conwy, P. A. 2007. New discoveries at Qasr Ibrim, Lower Nubia, pp. 157–64 in Cappers, R. (ed.), *Fields of Change - Progress in African Archaeobotany* (Groningen Archaeological Studies 5). Groningen: Barkhuis.

Delhon, C., Martin, L., Argant, J. and Thiébault, S. 2008. Shepherds and plants in the Alps: Multi-proxy archaeobotanical analysis of neolithic dung from "La Grande Rivoire" (Isère, France). *Journal of Archaeological Science* **35**, 2937–52.

di Lernia, S. 2001. Dismantling dung: delayed use of food resources among early Holocene foragers of the Libyan Sahara. *Journal of Anthropological Archaeology* **20**, 408–41.

Droux, X. 2011. Where's the beef? The surprise of Tomb 49. *Nekhen News* **23**, 16–7.

Fahmy, A. G. 2001. Plant remains in gut contents of Ancient Egyptian Predynastic mummies (3750–3300 BC). *OnLine Journal of Biological Sciences* **1**, 772–4.

Fahmy, A. G. 2003. Palaeo-ethnobotanical studies of the Egyptian Predynastic cemeteries: new dimensions and contributions, pp. 95–106 in Neumann, K., Butler, A. and Kahlheber, S. (eds.), *Food, Fuel and Fields: Progress in African Archaeobotany* (Africa Praehistorica 15). Köln: Heinrich-Barth-Institut.

Fahmy, A. G., Friedman, R. F. and Fadl, M. 2008a. Archaeobotanical studies at Hierakonpolis Locality HK6: The Pre and Early Dynastic elite cemetery. *Archeo-Nil* **18**, 169–83.

Fahmy, A. G., Khodary, S., Fadl, M. and El-Garf, I. 2008b. Plant macroremains from an Elite cemetery at Predynastic Hierakonpolis, Upper Egypt. *International Journal of Botany* **42**, 205–12.

Fahmy, A. G., Friedman, R. F. and Fadl, M. 2012. Economy and ecology of Predynastic Hierakonpolis, Egypt: archaeobotanical evidence from a trash mound at HK11 C, pp. 91–118 in Fahmy, A. G., Kahlheber, S. and D'Andrea, A. C. (eds.), *Windows on the African Past. Current Approaches to African Archaeobotany* (Reports in African Archaeology vol. 3). Frankfurt am Main: Africa Magna Verlag.

Flores, D. V. 2003. *Funerary Sacrifice of Animals in the Egyptian Predynastic Period* (British Archaeological Reports International Series 1153). Oxford: Archaeopress.

Flores, D. V. 2004. Funerary sacrifice of animals in the Egyptian Predynastic Period, pp. 731–64 in Hendrickx, S., Friedman, R. F., Cialowicz, K. M. and Chlodnicki, M. (eds.), *Egypt at its Origins I. Studies in Memory of Barbara Adams.* Leuven: Peeters Publishers.

Friedman, R. F. 2004. Elephants at Hierakonpolis, pp. 131–68 in Hendrickx, S., Friedman, R. F., Cialowicz, K. M. and Chlodnicki, M. (eds.), *Egypt at its Origins I. Studies in Memory of Barbara Adams.* Leuven: Peeters Publishers.

Friedman, R. F. 2008. The cemeteries of Hierakonpolis. *Archéo-Nil* **18**, 8–29.

Friedman, R. F. 2011. 'Hierakonpolis', pp. 33–44 in Teeter, E. (ed.), *Before the Pyramids. The Origins of Egyptian Civilization.* Chicago: Oriental Institute Publications.

Friedman, R. F., Van Neer, W. and Linseele, V. 2011. The elite Predynastic cemetery at Hierakonpolis: 2009–2010 update, pp. 157–97 in Friedman, R. F. and Fiske, P. E. (eds.), *Egypt at Its Origins III.* Leuven: Peeters Publishers.

Ghosh, R., Gupta, S., Bera, S., Jiang, H.-E., Li, X. and Li, C.-S. 2008. Ovi-caprid dung as an indicator of paleovegetation and paleoclimate in northwestern China. *Quaternary Research* **70**, 149–57.

Günther, K., Hannemann, H.-J., Hieke, F., Königsmann, E. and Schumann, H. 2000. *Urania Tierreich. Insecten*. Berlin: Urania.

Hendrickx, S. 2006. Predynastic–Early Dynastic chronology, pp. 55–93 and 487–488 in Hornung, E., Krauss, R. and Warburton, D. A. (eds.), *Ancient Egyptian Chronology* (Handbook of Oriental Studies. Section 1, The Near and Middle East, 83). Leiden: Brill.

Hillman, G. 1984. Crop husbandry practices from charred remains in crops, pp. 123–62 in Mercer, R. (ed.), *Farming Practice in British Prehistory.* Edinburgh: Edinburgh University.

Kleiman, D., Geist, G. and McDade, C. M. 2003. *Grzimek's Animal Life Encyclopedia: Mammals IV*, vol. 16. Farmington Hills, MI: Gale.

Kühn, M. and Hadorn, P. 2004. Pflanzliche Makro- und Mikroreste aus Dung von Wiederkäuern, pp. 227–350 in Jacomet, S., Leuzinger, U. and Schibler, J. (eds.), *Die Jungsteinzeitliche Seeufersiedlung Arbon – Bleiche 3* (Umwelt und Wirtschaft. Archälogie im Thurgau 12). Thurgau: Departement für Erziehung unde Kultur des Kantons Thurgau.

Kühn, M., Maier, U., Herbig, C., Ismail-Meyer, K., Le Bailly, M. and Wick, L. 2013. Methods for the examination of cattle, sheep and goat dung in prehistoric wetland settlements with the examples of the sites Alleshausen-Täschenwiesen and Alleshausen-Grundwiesen (around 2900 cal. BC) at Lake Federsee, South West Germany. *Environmental Archaeology* **18**(1), 43–57.

Linseele, V., Marinova, E., Van Neer, W. and Vermeersch, P. M. 2010. Sites with Holocene dung deposits in the Eastern Desert of Egypt: Visited by herders? *Journal of Arid Environments* **74**, 818–28.

Linseele, V., Riemer, H., Baeten, J., De Vos, D., Marinova, E. and Ottoni, C. 2013. Species identification of archaeological dung remains. A summary of possible methods. *Environmental Archaeology* **18**(1), 5–17.

Marinova, E. and Van Neer, W. 2009. An elephant's last meal. *Nekhen News* **21**, 10–1.

Marinova, E., De Meyer, M., van Loon, G. and Willems, H. 2012. Plant economy and land use in the Middle Egypt during the late Antique/early Islamic period – archaeobotanical analysis of mud bricks and mud plasters from the area of Dayr al Barsha, pp. 120–36 in Fahmy, A. G., Kahlheber, S. and D'Andrea, A. C. (eds.), *Windows on the African Past. Current Approaches to African Archaeobotany* (Reports in African Archaeology vol. 3). Frankfurt am Main: Africa Magna Verlag.

Mercuri, A. M. 2008. Human influence, plant landscape, evolution and climate inferences from the archaeobotanical records of the Wadi Teshuinat area (Libyan Sahara). *Journal of Arid Environments* **72**, 1950–67.

Piperno, D. R. 2006. *Phytoliths: A Comprehensive Guide for Archaeologists and Paleoecologists.* Lanham: Altamira Press.

Rätsch, C. 2005. *The Encyclopedia of Psychoactive Plants: Ethnopharmacology and Its Applications*. Rochester: Park Street Press.

Rosen, A. 1992. Preliminary identification of silica skeletons from Near Eastern archaeological sites: an anatomical approach, pp. 129–48 in Rapp, G. and Mullholland, S. (eds.), *Phytolith Systematics*. New York: Plenum Press.

Rosen, A. 2005. Phytolith indicators of plant and land use at Çatalhöyük, pp. 203–121 in Hodder, I. (ed.), *Inhabiting Çatalhöyük, Reports from the 1995–99 Seasons*. Cambridge: McDonald Institute.

Scott, L. 2005. The Holocene of middle altitude arid areas, pp. 396–405 in Mackay, A., Battarbee, R., Birks, J. and Oldfield, F. (eds.), *Global Change in the Holocene*. London: Hodder Arnold.

van der Veen, M. and Tabinor, H. 2007. Ford, fodder and fuel at Mons Porphyrites: the botanical evidence, pp. 84–142 in Peacock, D. and Maxfield, J. (eds.), *The Roman Imperial Quarries Survey and Excavations at Mons Porphyrites 1994–1998. Volume 2 The Excavations*. London: Egypt Explorations Society.

van Geel, B., Buurman, J., Brinkkemper, O., Schelvis, J., Aptroot, A., van Reenen, G. and Hakbijl, T. 2003. Environmental reconstruction of a Roman Period settlement site in Uitgeest (The Netherlands), with special reference to coprophilous fungi. *Journal of Archaeological Science* **30**, 873–83.

Van Neer, W. 2011. Two more wild animals from the elite cemetery at Hierakonpolis. *Nekhen News* **23**, 10–1.

Van Neer, W. and Linseele, V. 2003. A second elephant at HK6. *Nekhen News* **15**, 11–2.

Van Neer, W., Linseele, V. and Friedman, R. F. 2004. Animal burials and food offerings at the Elite Cemetery HK6 of Hierakonpolis, pp. 67–130 in Hendrickx, S., Friedman, R. F., Cialowicz, K. M. and Chlodnicki, M. (eds.), *Egypt at its Origins. Studies in Memory of Barbara Adams* (Orientalia Lovaniensia Analecta 138). Leuven: Peeters.