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Holocene resource exploitation along the Nile: diet and subsistence strategies of Mesolithic and Neolithic societies at Khor Shambat 1, Sudan

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Abstract

Recent excavations at Khor Shambat, Sudan, yielded well-defined Mesolithic and Neolithic stratigraphy. Here, for the first time, we combine archaeozoological, palaeobotanical, phytolith and dental calculus studies, with lipid residue analysis of *c.* 100 Mesolithic and Neolithic pottery fragments from Khor Shambat and comparative analysis of faunal remains and organic residues, to provide valuable information on changes in adaptation strategies, including hunting and consumption models, from Mesolithic hunter-gatherers to Neolithic herders, exploiting domesticates for meat and milk. These results paint a unique picture of the natural environment and human subsistence in Early to Middle Holocene Central Sudan.

Introduction

Relatively little is known about the diet and subsistence practices of Early and Middle Holocene communities in Central Sudan, with much of the available data coming from osteological assemblages or burial contexts. Sites with preserved stratigraphy, where reliable observations could be made, are rare. One such site is Khor Shambat 1 (KSH1), located in Omdurman on the west bank of the Nile (**Figure 1**). Excavations at KSH1 (funded by the National Science Centre, Poland, grant No. 2015/17/D/HS3/01492) yielded a well-preserved stratigraphy, demonstrating Mesolithic and Neolithic settlement activity, providing a remarkable opportunity to investigate the environmental and cultural changes beginning at the turn of the 7th/8th millennium BC, continuing for more than three thousand years.

With a surface area of approx. 1.5 hectares, the site occupies a small hill at an absolute altitude of 385m ASL. The thickness of cultural layers of silt and sand, offering an abundance of archaeological materials, locally exceeds *ca.* 1.5 ha (**Figure 1**). The full chronological sequence was only preserved in the central part of the site, where traces of Mesolithic settlements with numerous structures and two burials of male adults were visible. These are topped with Neolithic layers, indicating intensive settlement activity, and a vast cemetery (Jórdeczka *et al.* 2020a, b).

Figure 1. Map of the KSH1 site (a) and section of the profile with visible stratigraphy (b) (by P. Wiktorowicz and M. Jórdeczka).

Chronology

The first Early Mesolithic hunters-gatherers appear at KSH1 in the early 7th millennium cal BC (**Figure 2**), with more intense settlement activity appearing in the Middle Mesolithic (late 7th millennium cal BC), followed by episodic horizons associated with the Late Mesolithic (late 6th millennium cal BC). The highly intensive Early Neolithic settlement activity is dated to the second half of the 5th millennium cal BC, although earlier and later elements have been found.

Figure 2. Calibrated dates and two-sigma range for the KSH1 site.

The paleoenvironment

The Mesolithic and Neolithic occupation in KSH1 corresponds to the Early to Mid-Holocene when climate in Sudan was characterised by high rainfall, frequent Nile floods, and seasonal lakes in

deserts east and west of the Nile - allowing the expansion of savannah vegetation and contributing to a rich faunal assemblage. These wet climatic conditions (interrupted by dry periods, e.g. 6200 cal BC) are referred to as the African Humid Period (Gasse 2000; Kuper & Kröpelin 2006, Drake *et al.* 2018).

Early and Mid-Holocene KSH1 was one of several locations along the Nile providing extensive opportunities for hunting, gathering and fishing, and eventually for cattle herding. Open grasslands close to the river would have been exploited by Mesolithic and Neolithic groups, both for food and other resources.

Archaeobotany

The archaeobotanical remains retrieved from Mesolithic and Neolithic contexts at KSH1 (Table S1) revealed the presence of charred fruit stones of *Ziziphus spina-christi* (Figures 3 & S1f), likely a common woody element of the area's vegetation, probably concentrated in the river valley. The plum-like fruits would have been gathered for human consumption and the charred, and often crushed, fruit stones suggest that the plums may have been processed. Found in both Mesolithic and Neolithic wood charcoal assemblages, it was likely an important source of firewood. Charred and silicified fruit stones of edible *Celtis*, likely *Celtis integrifolia* (African hackberry; Figure 3), were found in Neolithic contexts. Regularly present at other archaeological sites, *Celtis* likely formed a significant component of the Holocene vegetation of Central Sudan. The charcoal assemblage also includes *Acacia*, also part of the woody vegetation at/near KSH1, well represented in the Neolithic period, but only sporadically in the Mesolithic. The proximity of the site to the Nile floodplain may account for the presence of the *Acacia seyal* - *A. nilotica* vegetation, typically present on temporarily inundated areas in Central Sudan (cf. Barakat 1995). Also present in the assemblage are *Grewia* sp., *Balanites aegyptiaca* (SI 1).

Figure 3 a. left, charred fruit-stone remains of *Ziziphus* (probably *Ziziphus spina-christi*) from Feature 1, level 110-120cm (Photo: L. Kubiak-Martens) and on the right, the living plant near Al Khiday, White Nile, showing plum-like fruit (Photo: M. Jórdeczka). b. Silicified fruit-stone remains of African hackberry (*Celtis integrifolia*) from Feature 1, level 70-90cm. Photo: L. Kubiak-Martens.

Fauna

The Mesolithic faunal assemblage (Figure 4 and SI 2) is dominated by fish, mostly large catfish (*Siluriformes*) and molluscs. Reptile bones are rare and there are only isolated avian remains (mostly river birds). Mammals (Mammalia) are the most diverse group with 26 species identified. The Bovidae family comprise 70% of the remains (14 species, Figure 4), Suidae are also present, including bushpig (*Potamochoerus larvatus*) and common warthog (*Phacochoerus africanus*), although during the Mesolithic these are present in small numbers (1.3%). Many Mesolithic remains represent territorial and non-migrating species, such as warthog, bushpig, oribi (*Ourebia ourebi*), dik-dik (*Madoqua saltiana*), kob (*Kobus kob*) and klipspringer (*Oreotragus oreotragus*), whose natural biome are areas overgrown with shrubbery and woody savannah. The anatomical distribution of mammal remains indicates that carcasses of small and medium ruminants were transported to the settlement and processed locally. The high degree of fragmentation of bones, representing various carcass parts, suggests specific processing methods, with the aim of maximising use of all edible body parts. Consumption of marrow from long bones was also common practice. The diversity of species, and carcass parts, represented at KSH1 correlates with the sedentary nature of settlement at other Mesolithic sites in the Middle Nile area (Chaix & Honegger 2014; Honegger & Williams 2015). Subsistence strategies at these sites involve intensive and comprehensive exploitation of the local environment, in keeping with the so-called “Broad Spectrum Revolution” (e.g. Clark & Kandell 2013).

Figure 4. Faunal data for Mesolithic and Neolithic periods by NISP, including a Mesolithic harpoon and Neolithic hook.

Animal remains from Neolithic contexts (Figure 4 and SI 2) are dominated by domesticated ruminants, including cattle (*Bos taurus*), sheep (*Ovis aries*) and goat (*Capra hircus*). The number of hunted mammal species is much smaller than in the Mesolithic. Bushpigs were commonly hunted although ruminant species dominate, with a preference for medium-sized antelopes. The osteological assemblage also suggests a change in fishing practices. Catfish continue to dominate although they are more diversified in terms of size, with the Neolithic layers usually containing parts of medium and small-sized individuals, suggesting more shallow water exploitation.

The Neolithic faunal assemblage suggests that beef was far more important than sheep or goat meat. The size of the faunal assemblage precluded full reconstruction of an age-at-death profile but

it seems that only mature animals (above 4 years of age) were slaughtered, suggesting that the cattle and small ruminants were bred mostly for their secondary products, such as milk (Balasse 2003; Gillis *et al.* 2013). All parts of the animals were used and bone shafts were broken to obtain marrow.

Lipid residue results

Lipid analysis and interpretations were performed using well-established protocols described previously (SI 3; Dudd & Evershed 1998; Correa-Ascencio & Evershed 2014).

Figure 5. Mesolithic pottery samples containing lipid residues (photograph by M. Jórdeczka).

Figure 6. Neolithic pottery samples containing lipid residues (photograph by M. Jórdeczka).

Lipid biomarker analysis by GC-MS showed residues to fall into two categories (Table 1). Extracts from thirteen sherds (KSH003, KSH008, KSH1953, KSH1956, KSH1958, KSH1964, KSH1965, KSH1967, KSH1979, KSH1981, KSH1991, KSH1998 and KSH2033 (Figures 5 and 6), include a series of long-chain fatty acids, containing C₂₀ to C₂₆ carbon atoms (Figure 7a), likely originating directly from animal fats, incorporated via routing from the ruminant animal's plant diet (Halmemies-Beauchet-Filleau *et al.* 2014).

The second category comprises lipid profiles which also contain distributions (generally in low abundance) of long-chain fatty acids ($n=10$), ranging from C₂₀ to C₃₀, often dominated by the C₂₆, displaying a strong even-over-odd predominance (Figure 7b, c). The n -alkanoic acids are generally found in higher plants as C₁₆ - C₃₆ homologues, with a strong even-over-odd predominance and, of these, the C₂₂, C₂₄, C₂₆, C₂₈ and C₃₀ fatty acids originating from epicuticular (plant) waxes are indicative of a higher plant source (Eglinton & Hamilton 1967). However, they are not diagnostic to families of plants and are only a general indicator of plant processing.

Figure 7. Partial gas chromatograms of trimethylsilylated FAMES showing a. typical degraded animal fat lipid profile KSH1964, b,c typical plant lipid profiles (KSH2035, Neolithic and KSH2028, Mesolithic). Red circles, n -alkanoic acids (fatty acids, FA); IS, internal standard, C₃₄ n -tetratriacontane. Number denotes carbon chain length.

Table 1. Lab number, phase, sample no, site location, vessel form, decoration, lipid concentration ($\mu\text{g g}^{-1}$), $\delta^{13}\text{C}$ and $\Delta^{13}\text{C}$ values and attributions of KSH1 potsherds.

Laboratory Number	Phase	Sample no.	Depth/location	Vessel form	Decoration	Lipid concentration			Attribution	
						($\mu\text{g g}^{-1}$)	$\delta^{13}\text{C}_{16:0}$	$\delta^{13}\text{C}_{18:0}$		$\Delta^{13}\text{C}$
KSH002	Neolithic	9	Trench 2, layer 1 (0-10 cm)	Not known	LB Impressed ware-dotted zigzag	113.9	-20.2	-22.3	-2.1	Ruminant adipose
KSH003	Neolithic	14	Trench 2, layer 3 (20-30 cm)	Not known	LC (RSI) Impressed ware-lines of dots and vees	285.4	-20.1	-18.7	1.4	Non ruminant/plant
KSH005	Neolithic	17	Trench 2, layer 4 (30-40 cm)	Not known	IV.D (INS3) Incised ware-horizontal lines	26.0	-23.7	-24.9	-1.3	Ruminant adipose
KSH008	Neolithic	6	Trench 1, layer 1 (0-10 cm)	Not known	Undecorated (Plain ware)	146.7	-24.4	-26.4	-2.0	Ruminant adipose
KSH1953	Neolithic	38	Trench 5	Not known	LB dotted zigzag	22.2	-14.1	-15.7	-1.6	Ruminant adipose
KSH1956	Neolithic	132	Trench 5, layer 1	Simple closed form	undecorated	24.0	-20.7	-18.7	1.9	Non ruminant/plant
KSH1958	Neolithic	149	Trench 2, layer 4	Not known	Black top	196.0	-23.5	-26.1	-2.6	Ruminant adipose
KSH1959	Neolithic	195	Trench 5, layer 3	Simple closed form	LB dotted zigzag	6.4	-21.5	-25.3	-3.8	Ruminant dairy
KSH1962	Neolithic	250	Surface	Not known	IV.D semicircular panels of incised line	32.8	-19.2	-21.6	-2.4	Ruminant adipose
KSH1964	Neolithic	308	Trench 5	Not known	LB dotted zigzag	43.1	-24.8	-27.5	-2.6	Ruminant adipose
KSH1965	Neolithic	342	Trench 1, surface	Not known	LB dotted zigzag	173.9	-23.9	-26.3	-2.3	Ruminant adipose
KSH1967	Neolithic	390	Trench 2, layer 3	Not known	LB dotted zigzag	17.7	-19.6	-19.4	0.2	Ruminant/non-ruminant adipose
KSH1968	Neolithic	448	Trench 7, 80-100 cm	Not known	IV.D semicircular panels of incised line	49.1	-20.3	-22.5	-2.2	Ruminant adipose
KSH1977	Neolithic	765	Trench 6, m.162, 60-80 cm	Not known	LB dotted zigzag	92.0	-21.4	-23.6	-2.2	Ruminant adipose
KSH1979	Neolithic	853	Prof. E, m.164, 130-140 cm	Not known	undecorated	13.7	-25.3	-27.8	-2.5	Ruminant adipose
KSH1981	Mesolithic	909	Trench 7, 100-110 cm	Not known	IIJ3 dotted wavy-line	14.2	-19.8	-18.5	1.3	Non ruminant/plant
KSH1983	Neolithic	1031	Trench 5, layer 3	Not known	LB dotted zigzag	7.0	-15.9	-14.2	1.8	Non ruminant/plant
KSH1991	Neolithic	1174	Trench 7, 60-80 cm	Simple closed form	IV.D semicircular panels of incised line	205.5	-23.0	-23.5	-0.5	Ruminant/non-ruminant adipose
KSH1994	Neolithic	1185	Grave 28, prof. E	Not known	IV.D semicircular panels of incised line	16.4	-24.2	-23.2	1.1	Non ruminant/plant
KSH1998	Neolithic	1505	Trench 2, layer 3	Not known	LA plain zigzag	42.1	-19.1	-21.6	-2.5	Ruminant adipose
KSH1999	Mesolithic	1513	Trench 5, 40-60 cm, secondary deposit	Not known	IIJ3 dotted wavy-line	15.2	-24.6	-23.2	1.4	Non ruminant/plant
KSH2009	Neolithic	1578	Trench 2, layer 2	Not known	LA plain zigzag	11.3	-22.3	-21.6	0.6	Non ruminant/plant
KSH2011	Mesolithic	1580	Trench 2, layer 2	Simple open form	IIJ3 dotted wavy-line	6.0	-24.4	-20.9	3.4	Non ruminant/plant
KSH2020	Mesolithic	2548	Trench 6, 140 cm	Not known	IIJ3 dotted wavy-line	33.7	-19.0	-18.5	0.5	Non ruminant/plant
KSH2021	Mesolithic	2551	Trench 6, 130 cm, close to grave 28	Simple closed form	IIJ3 dotted wavy-line	37.5	-18.8	-20.5	-1.7	Ruminant adipose
KSH2025	Mesolithic	2560	Trench 6, 140-145 cm	Simple closed form	IIJ3 dotted wavy-line	16.1	-22.3	-21.6	0.6	Non ruminant/plant
KSH2026	Mesolithic	2561	Trench 6, 120-130 cm	Simple open form	IIJ3 dotted wavy-line	10.2	-21.4	-20.9	0.5	Non ruminant/plant
KSH2028	Mesolithic	2569	Trench 6, 130-145 cm	Not known	IIJ3 dotted wavy-line	42.4	-22.9	-22.4	0.5	Non ruminant/plant
KSH2033	Mesolithic	2594	Trench 6, feature 16	Not known	IB.Bw wavy line	106.2	-18.8	-18.3	0.5	Non ruminant/plant
KSH2035	Mesolithic	2598	Trench 9, m. 215-220, Profile E	Unknown; perforation for handling under the rim	LB dotted zigzag	133.8	7	-	-	Plant
KSH2173	Neolithic	140	Trench 4, 20-40 cm	Simple closed form	undecorated	10.6	-16.0	-17.8	-1.8	Ruminant adipose

Animal product lipid profiles

Thirty samples underwent gas chromatography–combustion–isotope ratio mass spectrometry (GC-C-IRMS) analyses (Table 1 and Figure 8) to determine the $\delta^{13}\text{C}$ values of the major fatty acids, $\text{C}_{16:0}$ and $\text{C}_{18:0}$, and ascertain the source of the lipids extracted (Dunne *et al.* 2012). Lipid residue results show that KSH1959 (Neolithic), plots in the dairy region with a $\Delta^{13}\text{C}$ value of -3.8‰ (Figure 8). Vessels KSH002, KSH005, KSH008, KSH1953, KSH1958, KSH1962, KSH1964, KSH1965, KSH1968, KSH1977, KSH1979, KSH1998, KSH2021 and KSH2173 (Figures 5 and 6) plot within the ruminant carcass region with $\Delta^{13}\text{C}$ values of $-2.1, -1.3, -2.0, -1.6, -2.6, -2.4, -2.6, -2.3, -2.2, -2.2, -2.5, -2.5, -1.7$ and -1.8‰ (Figure 8), respectively, confirming they were used to process carcass products from domesticated cattle, sheep or goat. Of these, one, KSH2021 (Figure 5, no. 6) is of Mesolithic origin, the remainder ($n=14$) are Neolithic. Two Neolithic vessels, KSH1967 and KSH1991, plot between the ruminant and non-ruminant regions with $\Delta^{13}\text{C}$ values of 0.2 and -0.5‰ (Figure 8).

Potsherds KSH003, KSH1956, KSH1981, KSH1983, KSH1994, KSH1999, KSH2009, KSH2011, KSH2020, KSH2025, KSH2026, KSH2028 and KSH2033 (Figures 5 and 6) plot in the non-ruminant/plant region with $\Delta^{13}\text{C}$ values of $1.4, 1.9, 1.3, 1.8, 1.1, 1.4, 0.6, 3.4, 0.5, 0.6, 0.5, 0.5,$ and 0.5‰ , respectively. Of the Mesolithic potsherds, 8 (89%) plot within the non-ruminant/plant region, whereas 5 (24%) of the Neolithic sherds plot within the non-ruminant/plant region (Figure 8).

The $\delta^{13}\text{C}_{16:0}$ values of the fatty acids (Table 1) extracted from the potsherds range from -25.3 to -14.1‰ (-11.2‰ difference) and the $\delta^{13}\text{C}_{18:0}$ values range from -27.8 to -14.2‰ (-13.6‰ difference). These values are comparable to those from the Nile site of Kadero (Dunne *et al.* 2017) where they clustered within two distinct groups, suggesting the Kadero animals producing the fats consumed diets comprising mainly C_3 or C_4 plants. This is not the case at KSH1, suggesting KSH1 animals subsisted on a broad range of forages, from primarily C_3 through to C_4 . Interestingly, the $\delta^{13}\text{C}_{16:0}$ values from the Mesolithic period have a more C_3 influence than the Neolithic, suggesting wetter conditions.

Figure 8. Graphs showing: $\Delta^{13}\text{C}$ ($\delta^{13}\text{C}_{18:0} - \delta^{13}\text{C}_{16:0}$) values from the a. Mesolithic and b. Neolithic at KSH1. Ranges shown here represent the mean \pm 1 s.d. of the $\Delta^{13}\text{C}$ values for a global database comprising modern reference animal fats from the UK, Africa and elsewhere (Dudd and Evershed 1998; Dunne *et al.* 2012).

Freshwater fish biomarkers

In common with other riverside Holocene sites in Sudan, fish remains, mostly catfish, were present in the Mesolithic and Neolithic. These were generally very large in the Mesolithic (≥ 200 cm), reducing in size during the Neolithic, from medium (≥ 30 cm) to small sized (≤ 30 cm). This change may reflect alternative fishing methods such as a transition from harpooning to net fishing or the use of hook and line tackle and, possibly, alternative processing methods. For instance, small fish cannot easily be roasted over fires and are difficult to sun dry but could have been salted (Maritan *et al.* 2018) or are very easy to cook in vessels. Consequently, FAMES from both phases were analysed by GC-MS in SIM mode to check for the presence of freshwater biomarkers, such as *o*-alkylphenyl) alkanolic acids (APAAs) and vicinal dihydroxy acid (DHYAs), which would denote the processing of shellfish/crustaceans, fish, waterfowl and aquatic mammals (see Cramp and Evershed 2014). Significantly, no aquatic biomarkers were detectable in the analysed potsherds, suggesting that fish were likely grilled on open fires rather than boiled in pots, although some aquatic input to the vessels cannot be discounted.

Plant processing

Several lipid profiles from the Mesolithic and Neolithic contain a series of even-numbered long-chain fatty acids, in distributions and concentrations typical of plant processing (Dunne *et al.* 2016), although there are no *n*-alkanes present. However, one sherd from the Mesolithic (KSH2028, non-ruminant, Figure 8) and Neolithic (KSH1977, ruminant, Figure 8) each contain long-chain fatty acids (C_{24} , C_{26} and C_{28}) in greater abundance than the C_{16} and C_{18} fatty acids, suggesting the vessels were used to process mainly plants with the addition of small amounts of animal meat. However, care must be taken in their interpretation as fatty acids which derive from plant processing can contribute more depleted $\delta^{13}C$ values to the overall fatty acid signature of the $C_{16:0}$ and $C_{18:0}$ fatty acids.

Vessel KSH2035 (Figure 5, no. 5), plotting in the non-ruminant/plant region, yielded a similar lipid profile (Figure 7), save that it contained low concentrations of C_{16} and C_{18} fatty acids, with the C_{16} being too low to measure isotopically. The $\delta^{13}C$ values of the C_{18} , C_{20} , C_{22} , C_{24} , C_{26} and C_{28} were -21.3, -21.8, -27.63, -28.6, -29.0 and -28.8 ‰, respectively (Figure 7), suggesting, as noted above, a depletion in plant $\delta^{13}C$ values, which appear strongly C_3 , in contrast to the $C_{18:0}$ and $C_{20:0}$ fatty acids. This vessel was likely dedicated to plant processing. These $\delta^{13}C$ values fall within the known

$\delta^{13}\text{C}$ values for C_3 plant lipids, which range from -32 to -20 ‰ for C_3 plants (Boutton 1991), suggesting the plants being cooked in the vessels were C_3 . A further four Mesolithic vessels (KSH1999, KSH2011, KSH2020, KSH2021 and KSH2025, Figure 5) and two Neolithic vessels (KSH1962 and KSH1968, Figure 6, numbers 4 and 7) include minor abundances of long-chain fatty acids, again indicative of the addition of plants to meat, possibly to make stews. Mesolithic sherds with indications of plant processing originate from non-ruminant (hunted) animals, likely warthog, bushpig or small reptiles, whilst the Neolithic sherds with plant lipids contain ruminant products from domesticates.

This combination of LCFAs and $\delta^{13}\text{C}$ values in KSH2035 (Figure 5, no 5) strongly suggests the processing of predominantly C_3 plant material (Dunne *et al.* 2016), likely fruits, leafy plants and/or wild grasses, possibly mixed with animal products, confirming the importance of plant resources across the Mesolithic and Neolithic. Likely plant candidates processed in the vessels are *Zizyphus spina-christi*, and *Celtis integrifolia*, both C_3 plants, which dominate the archaeobotanical assemblage at KSH1. Charred and crushed *Zizyphus* fruit stones suggest that the plums were processed, similarly to other Early and Middle Holocene sites in Central and Northern Sudan, and in Southern Egypt (Majid 1989; Kubiak-Martens 2011; Beldados 2017), possibly to extract seed oil or, as *Zizyphus* is known for its medicinal properties, as a decoction (Saied *et al.* 2008). The identification of *Celtis integrifolia* at Mesolithic Khartoum Hospital, Garif town, Abu Darbien, Zakyab and Umm Direwiya and the later sites of Kadero I and Esh Shaheinab (Arkell 1949; Krzyżaniak 1978; Majid 1989) confirms their importance in Holocene diet in Sudan.

Results from phytolith analyses (SI 4, including Figure S2a-g) of sediment, grinding stones and macrolithic stone tools indicated the phytoliths derived from monocotyledonous plants and varied grasses (around 80% or more of counted morphotypes). Grasses belonged mostly to the Panicoideae subfamily, particularly abundant were diagnostic morphotypes deriving from the floral parts of these plants. Spheroid echinates from the leaves of the Arecaceae family (palms) were noted in many samples and have occasionally been recorded in Mesolithic and Neolithic burial contexts in central Sudan (Out *et al.* 2016). These may have been brought to the site unintentionally alongside the dominant grass assemblages, although their presence in settlement areas and association with ground stone artifacts could be related to matting and basketry, as well as to a varied range of domestic items, such as brooms, brushes and sieves, possibly linked to grain

cleaning activities (Portillo & Albert 2014). Archaeobotanical evidence from Mesolithic and Neolithic sites in Sudan suggests the exploitation of a wide range of wild taxa, including native panicoids such as *Sorghum* sp., *Panicum* sp., and *Setaria* sp. (Krzyżaniak 1991; Kubiak-Martens 2011; Out *et al.* 2016; Fuller & González Carretero 2018; Fuller & Stevens 2018).

Phytolith analysis was carried out on dental calculus from one Mesolithic and three Neolithic graves (SI 4). These results indicate the consumption of grasses, including panicoids, also found in the ground stone assemblages, in addition to edible wild fruits. However, the phytolith and vegetable fibres could equally derive from non-dietary activities such as raw material processing, oral hygiene (Radini *et al.* 2017) or ritual activities.

Comparative analysis – Faunal remains and organic residues

Comparison of two independent datasets on animal exploitation strategies, the pottery lipid residues and faunal remains, can provide greater insight into the nature of faunal exploitation at KSH1 (SI 5 & Dunne *et al.* 2019).

Figure 9. Proportion estimates for different animal resources based on sampling the raw integer counts of lipid profiles and faunal counts from a Dirichlet distribution, and using a prior estimate that 75% of domestic ruminant remains were used for dairying. The four resource exploitations are: A-Aquatic; B-Ruminant adipose; C-Non-ruminant adipose; D-Dairy.

Figure 9 illustrates how all four animal resources are differentially represented in the faunal data and lipid profiles. The distributions associated with the faunal remains (solid blue and yellow lines) are typically very tight due to the large sample size. This compares to the lipid residues (dashed blue and yellow lines), which have a much broader distribution due to small sample sizes. The absence of aquatic biomarkers in the pottery (Figure 9A) is striking, especially considering the large number of fish bones at KSH1, and seems to be indicative of fish processing across large parts of Holocene North Africa i.e. that they were not being boiled in pots and were likely being air dried, or grilled instead. Because there is a non-zero probability of there being aquatic biomarkers in the pots, the Dirichlet sampling produces a distribution around zero, which is why the dashed lines in Figure 9A tail off from zero. Non-ruminant adipose fats (Figure 9C) also appear to be differentially processed. During both the Neolithic (yellow line) and Mesolithic (blue lines), non-ruminant adipose resources appear to have been selectively processed in pots as they represent around 30% of all lipid attributes during the Neolithic and up to 70% during the Mesolithic, even

though non-ruminants represent only 5-10% of all faunal remains.

Figure 9B shows there is some overlap in the estimated ruminant adipose, especially during the Mesolithic (blue solid and dashed lines). During the Neolithic, the ruminant adipose fats are better represented in the pots than in the faunal remains (yellow solid and dashed lines). However, this may be due to our assumed estimate of the proportion of domestic ruminants being bred for milk. If we accept that most domestic ruminants were kept for secondary products (i.e. 75%) then **Figure 9D** shows little overlap between the estimates from the lipid profiles and faunal remains, suggesting that dairy products are not being processed in pots. Alternatively, if we assume that the lipid profiles are an accurate proxy for the amount of dairying taking place at KSH1 and that, in fact, most domesticates were bred for meat, we can change the prior estimate of faunal remains that represent dairy, say to 25%, and get a much better fit between the lipid profiles and faunal remains (**Figure 10B**). This is illustrated in **Figure 10**, which clearly shows an improved overlap in both resources during the Mesolithic and Neolithic (note that the faunal estimates for dairy animals during the Mesolithic is very tightly constrained around zero as we have large faunal samples and no domestic ruminant animals, whilst the estimates of dairy fats in pottery is distributed around zero due to the small sample sizes and non-zero probability).

Figure 10. Proportion estimates for ruminant adipose (A) and dairy (B) exploitation based on sampling the raw integer counts of lipid profiles and faunal counts from a Dirichlet distribution, and using a prior estimate that 25% of domestic ruminant remains were used for dairying.

Vessel types and use

A total of 39 Early and Middle Mesolithic sherds were analysed, with 10 sherds (26%) yielding lipids (**Table 1 and Figure 5**). Pots were made of clay tempered with an admixture of fine and medium sand. Single vessels were made of clay with admixtures of medium and coarse quartzite sand and mica. The walls were medium-thick (7-8mm) or thick (9-12mm and more). Most ($n=31$) were decorated with dotted wavy lines (DWL) with the remainder comprising wavy lines (6), basket-like impressions (1) and impressed ware (1). Eight of the lipid-yielding sherds (**Table 1**) were decorated with DWL (alternately pivoting stamp), whereas the remaining two were decorated with a wavy line (KSH2033, **Figure 5, no 10**) and dotted zigzag (KSH2035, **Figure 5, no 5**). Wall thickness of vessels ranged from 8 to 11mm and successfully reconstructed forms included slightly restricted vessels with diameters of *c.* 16-20 cm and open bowls, from 20-25 cm in diameter. Both vessel types were used to process non-ruminant adipose, whereas the Mesolithic vessel (KSH2021,

Figure 5, no 6) used to process ruminant products was of restricted form (16cm in diameter) and decorated with a dotted wavy line.

Recovery from Neolithic pottery ($n=60$) was greater at 35 % ($n=21$, Table 1). These were made of Nile silt with an admixture of fine quartz sand, occasionally covered with red slip on the outside. Vessels are thin-walled (4-6mm), slightly thicker (7-8mm) or exceptionally thick (10-12mm). Lipid profiles were identified in both restricted vessels and open bowls, diameters ranged from 17 to 25cm. Neolithic pottery is more diversely decorated and includes both fine 'tableware' with surfaces covered with red ochre (including black topped Figure 6, no 3, red polished Figure 6, no 9, and decoration of semi-circular incised panels Figure 6, no's 4, 7 and 11) and much coarser vessels, or 'kitchenware'. These include undecorated (brown burnished, Figure 6, no 2) vessels, together with impressed patterns, either rocker-stamped (dotted zigzag Figure 6, no's 1, 5, 6 and 10, continuous zigzag Figure 6, no's 8, 12 and 13, triangles and dotted lines) or decorated with alternately pivoting stamps.

Lipids were found in four undecorated vessels, eleven rocker stamp decoration (8 dotted zigzag, 2 plain zigzag and 1 triangles and dots), one black top vessel and five incised ware vessels. There does not appear to be any relationship between vessel decoration and commodities processed although lipids were not found in vessels decorated with alternately pivoting stamps (APS) in the form of parallel dotted lines, or on pottery decorated with rows of triangles or dots, typical for Central Sudan. The eight vessels decorated with APS (triangles and vees, gray burnished) did not contain lipids, suggesting they were used for storing water or other liquids or, possibly, low lipid-yielding foods. The vessel used to process dairy products was of dotted zigzag type.

Discussion

Interestingly, there is a clear difference between the products processed in the vessels during the Mesolithic and Neolithic. Mesolithic vessels were predominantly used to process non-ruminant animal products, albeit at low concentrations, with a small number possibly used for processing meat and plants together, likely common warthog and bushpig, found in the faunal assemblage, although some aquatic input cannot be discounted. One Mesolithic vessel was used to process ruminant carcass products, likely from hunting of wild ruminants such as Salt's dik-dik, Common bush duiker and Greater kudu, as domesticates were not present at this time.

During the Neolithic, lipid residue results are dominated by the processing of ruminant carcass products, domesticated cattle, sheep or goat, confirmed by the presence of *c.* 67% livestock faunal remains, although this is significantly lower than at other Early Neolithic sites, such as Kadero (4600-3800 BC; [Krzyżaniak 1991](#)). However, Kadero is located a little further from the Nile - around 6.5 km. Other sites closer to the Nile, such as Nofalab, have, like KSH, faunal assemblages comprising large amounts of fish and similar compositions of mammals. [Gautier & Van Neer \(2011:407\)](#) suggest that people on the left bank may have relied less on cattle, because good grazing land was found on the alluvial plain on the right bank, where domesticates comprised 81% of faunal remains. However, the presence of 5 vessels (24%) used for non-ruminant processing indicates that some exploitation of non-ruminant wild game still occurred. This is in contrast to other sites in Sudan (such as Kadero) where faunal assemblages suggest a near complete reliance on livestock. However, it should be noted that lipid residue results from Kadero confirm that *c.* 33% of vessels were used for non-ruminant processing, suggesting that hunting also still played an important role ([Dunne et al. 2017](#)).

One lipid residue plots within the dairy range, suggesting possible low-level exploitation of secondary products, such as milk, butter and cheese, in contrast to Kadero where nearly half of vessels (47%) were used to process dairy products. This contrasts with the KSH1 faunal assemblage which indicates the cattle and small ruminants were bred for their secondary products, such as milk. However, if we assume the lipid residues are an accurate proxy for how much dairying was being practiced, then the revised estimate of 25% used in the comparative analysis provides a good fit between the faunal representation and lipid profiles ([Figure 10](#)), offering a novel way of estimating the proportion of deadstock that were used for dairying. Low incidences of dairy lipids in pots may have other explanations, for example, some of the milk obtained from the domesticates may have been drunk fresh from the animal with only a portion being processed in pots to make products such as butter and cheese. Dairy products may also have been processed in vessels made from organic materials, such as wood or bark, which do not survive archaeologically, or egg shell containers, an example of which is found in Neolithic grave 15 ([Jórdeczka et al. 2020b:154-156](#)).

These seemingly different subsistence strategies are interesting considering both are Early Neolithic sites, situated in similar positions (north of the convergence of the Blue Nile and the White Nile), although some 15 km apart. Such differences suggest these settled groups were

flexible and resourceful, adapting their subsistence practices to maximise resource availability in an increasingly unpredictable environment.

The presence of lipids denoting plant processing, the LCFA $\delta^{13}\text{C}$ values, together with the phytolith evidence from groundstones, confirms the importance of plants in both Mesolithic and Neolithic diets, likely with an important input of grasses from the Panicoideae subfamily and fruits from *Ziziphus spina-christi* and *Celtis integrifolia*.

Conclusion

The well-preserved stratigraphy at the Early and Middle Holocene site of Khor Shambat provided a valuable opportunity to investigate three thousand years of environmental and cultural change in Central Sudan, beginning in the 7th millennium BC. Here, for the first time, we combine archeozoological, paleobotanical, phytolith and dental calculus studies, together with lipid residue analysis and comparative analysis of the faunal remains and organic residues, to provide a holistic overview of changes in adaptation strategies, including hunting and consumption models, from Mesolithic hunter-gathering to Neolithic herding, with implications for the understanding of this transition in the broader region. Lipid and faunal data show a clear change from hunting small to medium sized game in the Mesolithic to the exploitation of domesticates, both for their carcass and dairy products, in the Neolithic. Selective hunting of bushpigs and medium-sized antelopes continues, albeit at a lower level than in the Mesolithic. Plant resources were clearly important during both the Mesolithic and Neolithic, being processed in pots, either as fruit or for their seed oil, sometimes mixed with animal products. In summary, these results paint a unique picture of the natural environment, and human subsistence, during the African Humid Period, in Early to Middle Holocene Central Sudan.

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Author contributions

The project was designed by JD, KM and MJ, and the paper was written by JD and MJ, with contributions from KM, MC, SD-R, KH, LK-M, MM-H, MO, MP, IS-T, PB and ND. JD, MO, MP, MC, IS-T, LK-M, MM-H and KH performed analytical work and data analysis.

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