

Earliest evidence for cheese making in the sixth millennium BC in northern Europe

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The introduction of dairying was a critical step in early agriculture, with milk products being rapidly adopted as a major component of the diets of prehistoric farmers and pottery-using late hunter-gatherers^{1–5}. The processing of milk, particularly the production of cheese, would have been a critical development because it not only allowed the preservation of milk products in a non-perishable and transportable form, but also it made milk a more digestible commodity for early prehistoric farmers^{6–10}. The finding of abundant milk residues in pottery vessels from seventh millennium sites from north-western Anatolia provided the earliest evidence of milk processing, although the exact practice could not be explicitly defined¹. Notably, the discovery of potsherds pierced with small holes appear at early Neolithic sites in temperate Europe in the sixth millennium BC and have been interpreted typologically as ‘cheese-strainers’¹⁰, although a direct association with milk processing has not yet been demonstrated. Organic residues preserved in pottery vessels have provided direct evidence for early milk use in the Neolithic period in the Near East and south-eastern Europe, north Africa, Denmark and the British Isles, based on the $\delta^{13}\text{C}$ and $\Delta^{13}\text{C}$ values of the major fatty acids in milk^{1–4}. Here we apply the same approach to investigate the function of sieves/strainer vessels, providing direct chemical evidence for their use in milk processing. The presence of abundant milk fat in these specialized vessels, comparable in form to modern cheese strainers¹¹, provides compelling evidence for the vessels having been used to separate fat-rich milk curds from the lactose-containing whey. This new evidence emphasizes the importance of pottery vessels in processing dairy products, particularly in the manufacture of reduced-lactose milk products among lactose-intolerant prehistoric farming communities^{6,7}.

The emergence of dairying was a major innovation in prehistoric societies, enabling the supply of nutritious food without the slaughtering of precious livestock¹⁰. The processing of milk, particularly the production of cheese, would have been an important development; however, the origins of cheese making are currently unknown. Iconographic and written evidence from the mid-third-millennium BC weakly documents the history of cheese making^{12,13}; although its origins probably lie much earlier in prehistory.

The production of cheese is a technically complex process. It involves the coagulation of milk, either enzymatically or by acid treatment, yielding the semi-solid curds (a combination of the major milk nutrients—protein, mainly casein, and milk fat) and then removal of the water-soluble lactose by straining off the liquid whey. Today, the straining process is commonly achieved using a coarse textile, ‘cheese-cloth’, or plastic or metal sieves as the curds are sufficiently coarse to be strained effectively through^{11,14}.

Although straining of the curds through textile or even wicker containers would have been possible in prehistoric times, fragments of pottery pierced with small holes (2–3 mm in diameter, Fig. 1) recovered

from central European Linear Pottery (*Linearbandkeramik*) culture sites have attracted considerable attention. Critically, the Linear Pottery culture represents the first communities using cultivated plants and domestic animals in interior central Europe. By typological comparison with modern and ethnographic perforated vessels¹¹ (Supplementary Fig. 1), these sieve vessels have been interpreted as ‘cheese-strainers’^{10,15}. Indeed, the coexistence of such vessels with archaeozoological evidence for domestic ruminants led to the proposal of the emergence of milk exploitation at the beginnings of animal domestication, at least a millennium earlier than Sherratt’s secondary products revolution hypothesis predicted¹². However, other suggestions have been made concerning the use of sieve vessels, for example as flame covers, honey strainers or for beer making^{16–18}. Preliminary investigations of similar

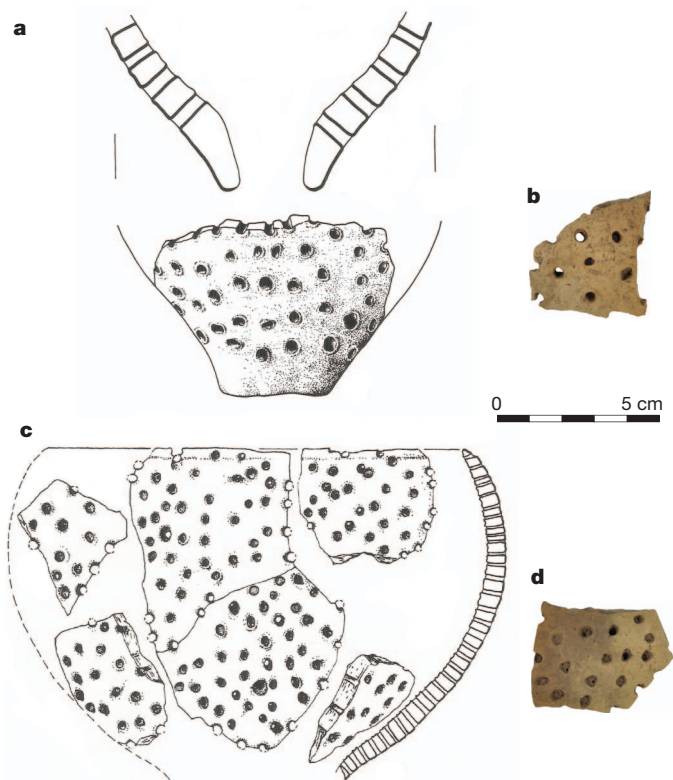


Figure 1 | Drawings of representative reconstructed sieve vessels and photographs of specific sieve fragments from the region of Kuyavia submitted to lipid residue analyses. **a, b**, KUY0750, from Brześć Kujawski site 3. **c, d**, KUY0757 from Smólsk site 4. The typology of the sieve vessels is comparable to those used by modern-day cheese producers (Supplementary Fig. 1). Drawings used with permission from ref. 20.

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Table 1 | List of sherds selected for lipid residue analyses

	Early phase	Classic phase	Late phase	Unknown	Total
Sieves from the region of Kuyavia					
Ludwinowo 6	-	2 (2)	-	-	2 (2)
Ludwinowo 7	-	19 (12)	16 (8)	2 (1)	37 (21)
Brześć Kujawski 3	-	2 (2)	-	-	2 (2)
Brześć Kujawski 4	-	-	2 (2)	-	2 (2)
Miechowice 4	1 (1)	2 (2)	-	-	3 (3)
Smółsk 4	-	-	2 (2)	-	2 (2)
Wolica Nowa 1	-	1 (1)	-	-	1 (1)
Stare Nakonowo 2	-	1 (1)	-	-	1 (1)
Non-perforated vessels from Ludwinowo 7					
Cooking pots	6	19	19	-	44
Bowls	1	2	4	-	7
Flasks	2	6	7	-	15

Each non-perforated sherd corresponds to a single vessel. For the sieves, the total number of individual sieves is indicated in parenthesis. Early phase, 5,400/5,300–5,200 cal. bc; classic phase, 5,200–5000 cal. bc and late phase, 5,100/5,000–4,900/4,800 cal. bc^{20,21}.

strainer vessels from third millennium Haparan sites in Asia showed the presence of fatty acids, although this data alone is insufficient to ascribe an association with dairy product processing¹⁹. The development of lipid biomarker and stable isotope proxies that allow identification of lipid sources from absorbed organic residues in pottery vessels, offers a direct means of testing ideas related to specialized uses of vessels, the antiquity of dairying and related processing activities^{1–4}.

Here we investigate the function of Linear Pottery sieves using chromatographic (gas-chromatography), spectrometric (gas chromatography–mass spectrometry, GC–MS) and isotopic (GC–combustion–isotope ratio MS, GC–C–IRMS) analyses of organic residues in archaeological potsherds from settlements in the region of Kuyavia, Poland. Furthermore, we compare the contents of these vessels with other types of pottery to assess whether specialization existed in the use of vessels. Lipid residue analyses focused on 50 fragments of sieves from 34 vessels recovered from Linear Pottery settlements along the lower Vistula river (including Brześć Kujawski 3 and 4, Miechowice 4, Smółsk 4, Wolica Nowa 1, Stare Nakonowo 2, and Ludwinowo 6 and 7; Supplementary Fig. 2) and, for comparison, coarse ware potsherds from the

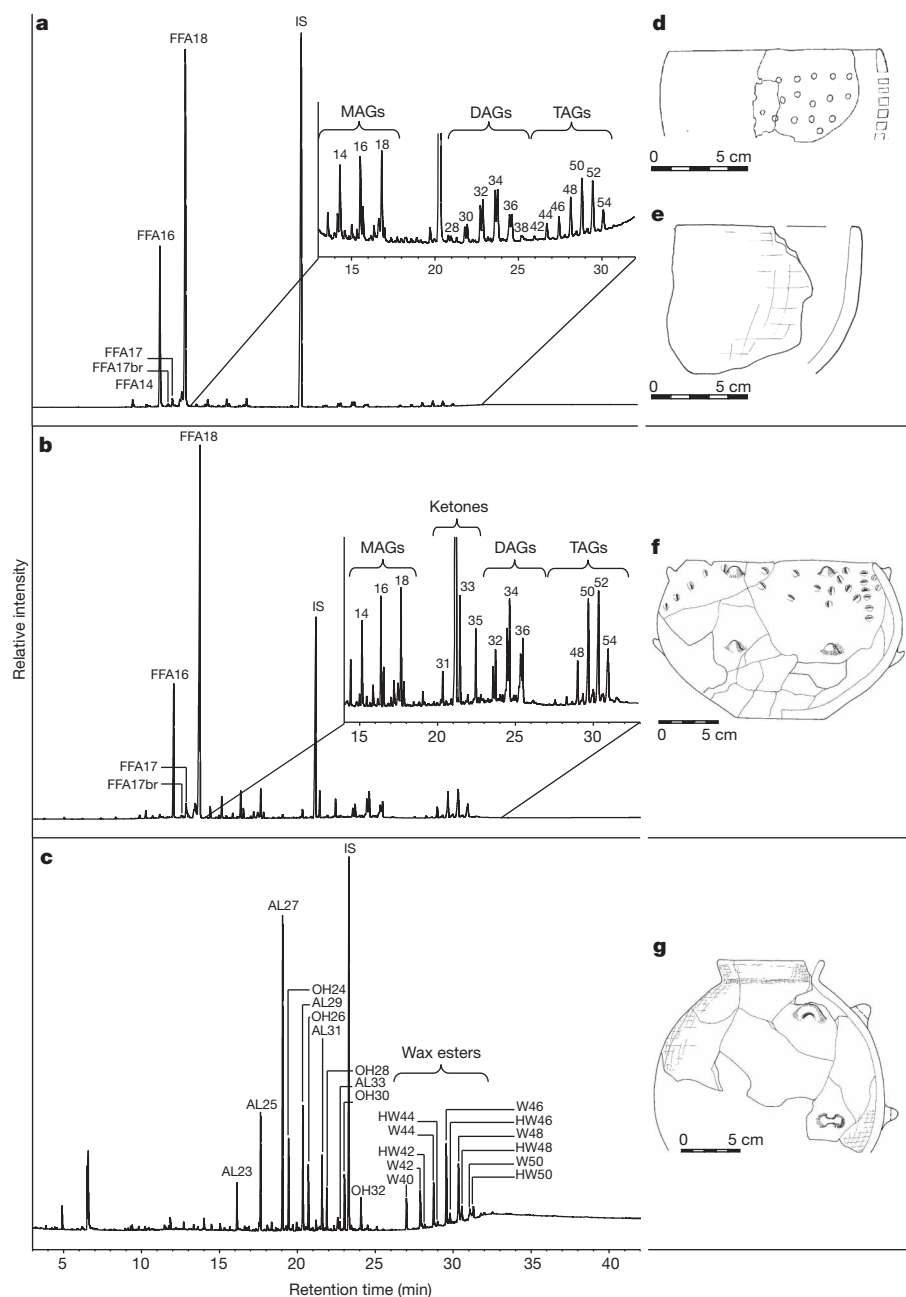


Figure 2 | Partial gas chromatograms of total lipid extracts from typical pottery from Ludwinowo 7 (Poland). **a**, Sieve and bowl: degraded animal fat with a wide distribution of triacylglycerols (sieve LDW0769). **b**, Cooking pot: degraded animal fat with a narrow distribution of triacylglycerols (LDW1039). **c**, Collared flask, beeswax (LDW1070) and associated shapes: **d**, Sieve LDW0769; **e**, bowl LDW1059; **f**, cooking pot LDW1039; **g**, collared flask LDW1074. AL, alkanes; DAG, diacylglycerols; FFA *n*, fatty acids with *n* carbon atoms and no double bonds; br, branched; HW, wax hydroxymonoesters; K, mid-chain ketones with 31, 33 and 35 carbon atoms; IS, internal standard (*n*-tetratriacontane); MAG, monoacylglycerols; OL, alcohols; TAG, triacylglycerols; with M, acyl carbon number; and W, wax monoesters.

three major vessel types from Ludwinowo 7 ('cooking' pots or *kümpfe*, $n = 44$; bowls, $n = 7$; and collared flasks, $n = 15$; Supplementary Tables 1 and 2) dating from the early (5,400/5,300–5,200 calibrated calendar years BC (cal. BC)), classic (5,200–5,000 cal. BC) and late (5,100/5,000–4,900/4,800 cal. BC) phases of the Linear Pottery in Kuyavia^{20,21} (Table 1 and Fig. 2d–g).

Lipids were extracted using well-established protocols^{1,4,22}. A high proportion of the sieve sherds, around 40%, contained lipid residues, with concentration up to $875 \mu\text{g g}^{-1}$ (mean $166 \mu\text{g g}^{-1}$, for the sherds containing lipids), consistent with observations from food processing vessels from other European archaeological sites^{22,23}. Likewise, lipid residues were extracted from around 59%, 29% and 33% of the cooking pots, bowls and collared flasks, respectively, with concentrations up to 2 mg g^{-1} (means for sherds with residues: 225, 13 and $15 \mu\text{g g}^{-1}$, respectively); the high concentrations of lipids in cooking pots suggests their extensive use in cooking fat-rich animal foodstuffs.

Most total lipid extracts were dominated by $\text{C}_{16:0}$ and $\text{C}_{18:0}$ fatty acids, accompanied by odd-number and branched-chain fatty acids ($\text{C}_{17:0}$ and $\text{C}_{17:0\text{br}}$) which are biomarkers of bacterial populations found in the rumen of milk-producing species as well as ruminant animal fats²⁴ (Fig. 2a, b). Triacylglycerols (TAGs) and their degradation products (diacylglycerols (DAGs) and monoacylglycerols (MAGs))²⁵ were observed in around 90% of the animal fats, indicating the high level of preservation of residues. As fresh dairy and adipose fats are characterized by wide and narrow distributions of TAGs, respectively²², the

contrasting distributions in sieves (C_{46} to C_{54}) and cooking pots (C_{42} to C_{54}) suggest specialization in the use of the two vessel types (Fig. 3a, b). This was confirmed through the determination of the $\delta^{13}\text{C}$ values of the individual *n*-alkanoic acids, palmitic ($\text{C}_{16:0}$) and stearic ($\text{C}_{18:0}$) acids. The use of the $\Delta^{13}\text{C}$ ($= \delta^{13}\text{C}_{18:0} - \delta^{13}\text{C}_{16:0}$) proxy removes the exogenous factors linked to the environment, thereby highlighting the metabolic and biosynthetic characteristics of the animal fat source and allowing the distinction between non-ruminant and ruminant fats, and adipose from dairy fats, to be drawn²⁴.

Comparison of the $\Delta^{13}\text{C}$ values obtained for the 16 animal fat residues preserved in sieve fragments and corresponding to 12 individual sieves with modern reference fats²⁴ showed that all the residues but one exhibited $\Delta^{13}\text{C}$ values expected for dairy fats (Fig. 3c, e). Likewise, the residues in bowls ($n = 2$) displayed the same range of values characteristic of dairy fats. Significantly, all the extracts from cooking pots ($n = 24$) show a very different signature plotting within, or on the edge of, the isotopic range expected for ruminant adipose fats (Fig. 3d, f). The presence of odd-carbon number ketones (C_{31} to C_{35}) in two cooking pots implies that they were heated to high temperatures²⁶ (Fig. 2b). All the biomarker and isotopic evidence indicate markedly different uses of the cooking and strainer vessels.

The presence of beeswax in 80% of the collared flasks with residues was confirmed by GC–MS through the identification of odd-carbon numbered alkanes (C_{21} to C_{33}), even-carbon numbered alcohols (C_{24}

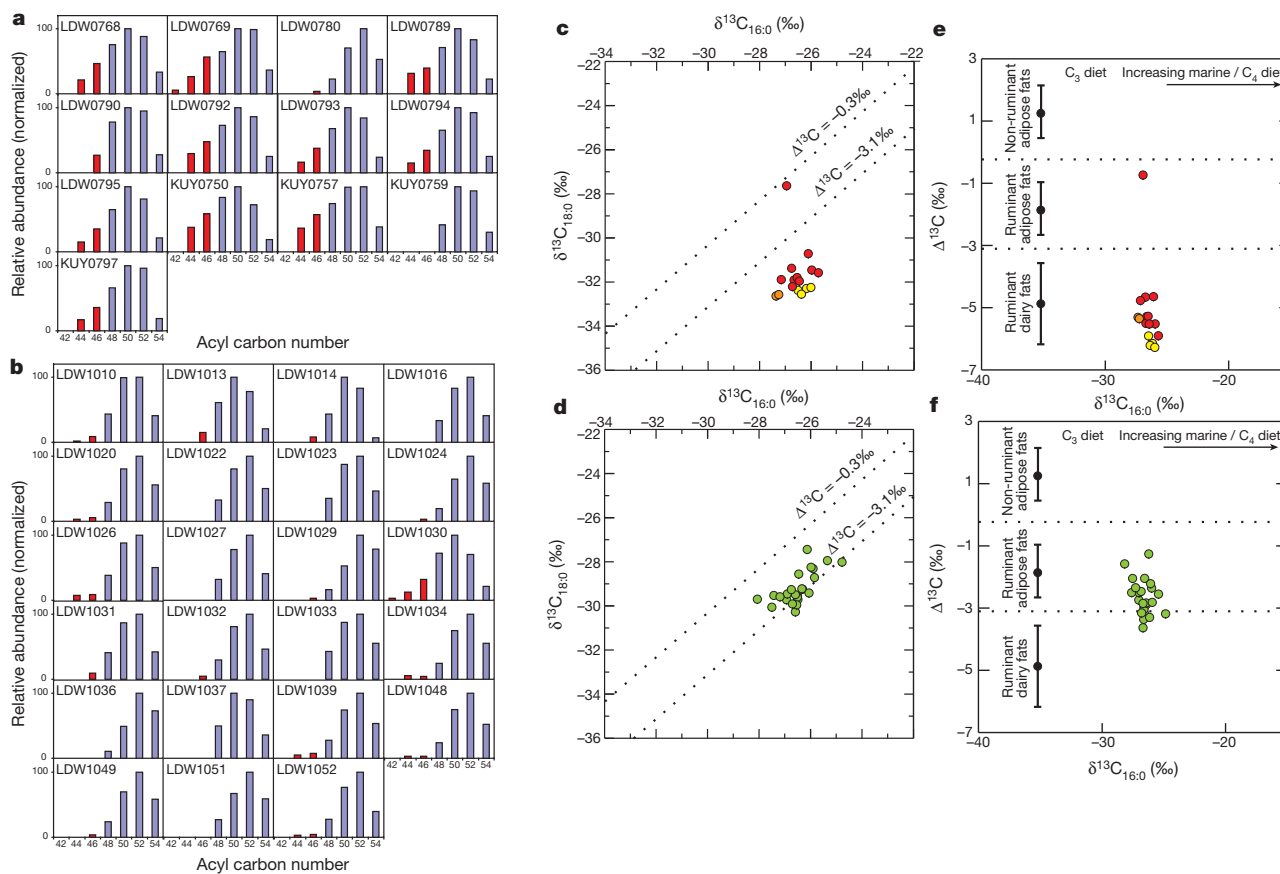


Figure 3 | Histograms of triacylglycerol distributions and fatty acid carbon isotope compositions of lipids extracted from Kuyavia pottery. TAG distributions of total lipid extracts of sieves from the region of Kuyavia (including Ludwinowo 7) (a), and cooking pots from Ludwinowo 7 (b). The blue bars denote TAGs present in both adipose and milk fats whereas those in red are only detectable in milk fat. c, d, Plots of the $\delta^{13}\text{C}$ values for the $\text{C}_{16:0}$ and $\text{C}_{18:0}$ fatty acids prepared from animal fat residues extracted from sieves and cooking pots (see Supplementary Tables 1 and 2). Each data point represents an individual vessel (the orange and yellow data points represent duplicates—of two and four fragments, respectively—of one sieve vessel each). The analytical error ($\pm 0.3\text{‰}$) is

approximately the size of the points on the graph. e, f, $\Delta^{13}\text{C}$ values ($= \delta^{13}\text{C}_{18:0} - \delta^{13}\text{C}_{16:0}$) of the extracts plotted against their $\delta^{13}\text{C}_{16:0}$ values from the same potsherds. Ranges show the mean ± 1 s.d. of the $\Delta^{13}\text{C}$ values for a global database comprising modern reference animal fats from United Kingdom (animals raised on a pure C_3 diet), Africa, Kazakhstan, Switzerland and the Near East². Significantly, the residues extracted from sieves (c and e) mostly contain dairy fats, whereas cooking pots (d and f) contain ruminant adipose fats. The difference in the $\Delta^{13}\text{C}$ means is $\sim 2.5\text{‰}$, which is highly significant (*t*-test; $P < 0.0005$). The figure clearly demonstrates the presence of dairy residues in sieves from the region of Kuyavia and specialization in pottery use at the Linear Pottery site of Ludwinowo 7.

to C₃₄), even-carbon numbered wax monoesters and hydroxymonoesters (C₄₀ to C₅₀), and in some cases diesters^{27,28} (Fig. 2c). Beeswax was also detected in one cooking pot.

These data provide evidence for the use of the Linear Pottery sieves to process milk, between around 5,200 and 4,900–4,800 cal. BC. The specific features of the potsherds, characterized by the presence of randomly distributed holes and the presence of high concentration dairy residues in the sieves support arguments in favour of the use of Linear Pottery sieves for cheese making, as butter making would not require such technology^{11,14}. Beeswax was present in three sieves, probably for waterproofing, helping to turn the cheese out of the mould or straining honey from the comb. Interestingly, the bowl-form vessels contained dairy fats and could have been used in combination with the sieves to collect filtered whey¹¹.

Hence, we demonstrate the first evidence for specialized use of vessels during the early Neolithic between approximately 5,400/5,300 and 4,900/4,800 cal. BC. No obvious evolution in use exists through the period studied, with vessels of different ages containing analogous lipids. In contrast to the sieves and the bowls, the cooking pots were largely used for processing ruminant carcass products, probably cattle or sheep and goats. Animal bone assemblages from Linear Pottery settlements in Kuyavia are characterized by high proportions of the bones of domestic cattle (from 68% to 80% of the overall number of identified specimens), relatively few sheep and goat bones (from 13% to 18% of the overall number of identified specimens), and very few pig or wild herbivore bones, indicating a high reliance on domestic ruminants, especially cattle²⁰ (M. Osypińska, unpublished observations). The high abundance of cattle at milk-yielding sites points to the importance of this ruminant in the intensification of milk use. The presence of beeswax in most of the collared flasks suggests either honey storage or, more probably, of the use of beeswax as a waterproofing agent²⁷, allowing their use in the storage or transport of water-based commodities. One collared flask appears to have been waterproofed with ruminant adipose fat rather than beeswax. The extensive recovery of beeswax in pottery from Ludwinowo 7 underlines the importance of bee products during the early Neolithic in Europe^{27–30}.

The evidence for the specialized use of Linear Pottery sieves in association with milk is important for three main reasons: (1) the typology of the sieves and the presence of dairy fats are consistent with milk processing, providing the earliest evidence of cheese making, which is notable because the manufacture of cheese increases the ease of handling of milk and allows the nutritional properties of milk to be readily available through the year; (2) the processing of milk to manufacture low-lactose-content cheese is consistent with the predicted low level of lactase persistence in northern Europe in the early Neolithic⁷; and (3) the evidence of milk use by the people of the Linear Pottery culture is consistent with the predicted increase in frequency of the –13,910*T allele associated with lactase persistence among prehistoric northern Europeans in this region⁶.

METHODS SUMMARY

Fifty fragments of sieves, representing 34 vessels, were sampled from the Kuyavia region (Poland), of which 37 fragments representing 21 sieves were excavated in Ludwinowo 7 (Supplementary Table 1). A further 66 potsherds from Ludwinowo 7 were analysed, of which 44 were cooking pots, the rest originating from collared flasks ($n = 15$) and bowls ($n = 7$, Supplementary Table 2). Lipid residue analyses and interpretations were based on established protocols^{1,2,4,22,23}. Briefly, ~1 to 3 g potsherds were sampled and their surfaces cleaned with a modelling drill to remove any exogenous lipids. The sherds were then ground to a powder, an internal standard added and solvent extracted by ultrasonication (chloroform/methanol, 2:1 v/v, 2 × 10 ml). Solvent was evaporated under a gentle stream of nitrogen to obtain the total lipid extract. Aliquots of the total lipid extract were trimethylsilylated (*N,O*-bis(trimethylsilyl)trifluoroacetamide, 40 µl, 70 °C, 1 h) and submitted to analysis by gas chromatography and GC–MS. Further aliquots of the total lipid extract were treated with NaOH/H₂O (9:1 w/v) in methanol (5% v/v, 70 °C, 1 h). Following neutralization, lipids were extracted into chloroform (3 × 3 ml) and excess solvent evaporated under a gentle stream of nitrogen. Fatty

acid methyl esters were prepared by reaction with BF₃-methanol (14% w/v, 70 °C, 1 h). Fatty acid methyl esters were extracted with chloroform (3 × 2 ml) and the solvent removed with a gentle stream of nitrogen. Fatty acid methyl esters were then re-dissolved into hexane for analysis by gas chromatography and GC–C–IRMS.

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- Evershed, R. P. *et al.* Earliest date for milk use in the Near East and southeastern Europe linked to cattle herding. *Nature* **455**, 528–531 (2008).
- Dunne, J. *et al.* First dairying in green Saharan Africa in the fifth millennium BC. *Nature* **486**, 390–394 (2012).
- Craig, O. E. *et al.* Ancient lipids reveal continuity in culinary practices across the transition to agriculture in Northern Europe. *Proc. Natl Acad. Sci. USA* **108**, 17910–17915 (2011).
- Copley, M. S. *et al.* Direct chemical evidence for widespread dairying in prehistoric Britain. *Proc. Natl Acad. Sci. USA* **100**, 1524–1529 (2003).
- Craig, O. E. *et al.* Did the first farmers of central and eastern Europe produce dairy foods? *Antiquity* **79**, 882–894 (2005).
- Itan, Y., Powell, A., Beaumont M. A., Burger J. & Thomas M. G. The origins of lactase persistence in Europe. *PLoS Comput. Biol.* **5**, e1000491 (2009).
- Burger, J., Kirchner M., Bramanti B., Haak W. & Thomas M. G. Absence of the lactase-persistence-associated allele in early Neolithic Europeans. *Proc. Natl Acad. Sci. USA* **104**, 3736–3741 (2007).
- Flatz, G. & Rotthauwe, H. W. The human lactase polymorphism: physiology and genetics of lactose absorption and malabsorption. *Prog. Med. Genet.* **2**, 205–249 (1977).
- McCracken, R. D. Lactase deficiency: an example of dietary evolution. *Curr. Anthropol.* **12**, 479–517 (1971).
- Bogucki, P. I. Ceramic sieves of the Linear Pottery culture and their economic implications. *Oxf. J. Archaeol.* **3**, 15–30 (1984).
- Gouin, P. Ancient oriental dairy techniques derived from archaeological evidence. *Food Foodways* **7**, 157–188 (1997).
- Sherratt, A. in *Pattern of the Past: Studies in Honour of David Clarke* (eds Hodder, I., Isaac, G. & Hammond, N.) 261 (Cambridge Univ. Press, 1981).
- Hallo, W. W. The house of Ur-Meme. *J. Near East. Stud.* **31**, 87–95 (1972).
- Houdet, V. *Laiterie, Beurrerie, Fromagerie* 7th edn (Hachette, 1919).
- Poplin, F. L'origine de la production laitière. *Initiation à l'Archéologie et à la Préhistoire* **17**, 13–17 (1980).
- Wood, J. in *Fire as an Instrument: The Archaeology of Pyrotechnologies* (ed. Gheorghiu, D.) Vol. 1619, 53 (Archaeopress, 2007).
- Clark, J. G. D. *Prehistoric Europe: the Economic Basis*. (Cambridge Univ. Press, 1952).
- Kindstedt, P. S. *Cheese and Culture: a History of Cheese and its Place in Western Civilization* (Chelsea Green Publishing Company, 2012).
- Bourgeois, G. & Gouin, P. Résultats d'une analyse de traces organiques fossiles dans une 'faisselle' harappéenne. *Paléorient* **21**, 125–128 (1995).
- Grygiel, R. *Neoliti i Początki Epoki Brązu w Rejonie Brzeźcia Kujawskiego i Osłonek (The Neolithic and Early Bronze Age in the Brzeźcia Kujawski and Osłonki Region)*, Vol. 1 (Konrad Jażdżewski Foundation for Archaeological Research, Museum of Archaeology and Ethnography, 2004).
- Pyzel, J. in *Creating Communities: New Advances in Central Europe Neolithic Research* (eds Hofmann, D. & Bickle, P.) 71 (Oxbow books, 2009).
- Dudd, S. N. & Evershed, R. P. Direct demonstration of milk as an element of archaeological economies. *Science* **282**, 1478–1481 (1998).
- Charters, S. *et al.* Quantification and distribution of lipid in archaeological ceramics: implications for sampling potsherds for organic residue analysis and the classification of vessel use. *Archaeometry* **35**, 211–223 (1993).
- Keeney, M., Katz, I. & Allison, M. J. On the probable origin of some milk fat acids in ruminant microbial lipids. *J. Am. Oil Chem. Soc.* **39**, 198–201 (1962).
- Evershed, R. P. *et al.* Chemistry of archaeological animal fats. *Acc. Chem. Res.* **35**, 660–668 (2002).
- Raven, A. M., van Bergen P. F., Stott A. W., Dudd S. N. & Evershed R. P. Formation of long-chain ketones in archaeological pottery vessels by pyrolysis of acyl lipids. *J. Anal. Appl. Pyrolysis* **40–41**, 267–285 (1997).
- Heron, C., Nemchek, N., Bonfield K. M., Dixon D. & Ottaway B. S. The chemistry of neolithic beeswax. *Naturwissenschaften* **81**, 266–269 (1994).
- Regert, M., Colinart, S., Degrand, L. & Decavallas, O. Chemical alteration and use of beeswax through time: accelerated ageing tests and analysis of archaeological samples from various environmental contexts. *Archaeometry* **43**, 549–569 (2001).
- Clark, J. G. D. Bees in antiquity. *Antiquity* **16**, 208–215 (1942).
- Crane, E. *The Archaeology of Beekeeping* (Cornell Univ. Press, 1983).

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