New insights into the Early Neolithic economy and management of animals in Southern and Central Europe revealed using lipid residue analyses of pottery vessels

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Analyses of organic residues preserved in ceramic potsherds enable the identification of foodstuffs processed in archaeological vessels. Differences in the isotopic composition of fatty acids allow differentiation of non-ruminant and ruminant fats, as well as adipose and dairy fats. This paper investigates the trends in milk use in areas where sheep and goats are dominant in the faunal assemblage and in some sites from the *Linearbandkeramik* culture. Sites include: Colle Santo Stefano, Abruzzo, Italy, and the Oldest to Young *Linearbandkeramik* sites of Zwenkau, Eythra and Brodau, Saxony, and Wang and Niederhummel, Bavaria, Germany. More than 160 potsherds were investigated including cooking pots, bowls, jars, and ceramic sieves. The lipid residues presented provide direct evidence for the processing of ruminant and non-ruminant commodities at Zwenkau and Eythra, despite the absence of faunal remains at the sites. No dairy residues were detected in potsherds from LBK sites, except in a ceramic sieve at Brodau. Lipids from non-ruminant and ruminant fats, including from dairy fats, were detected at the site of Colle Santo Stefano showing a reliance on dairy products during the first half of the sixth millennium at this site; where sheep and goats were the major domestic animals.

KEYWORDS
European prehistory
Neolithic
pottery vessels
sieves
lipids
fatty acids
$\delta^{13}C$ values
animal products
milk

RÉSUMÉ

Nouvelles perspectives dans l'exploitation et la gestion des animaux au Néolithique ancien en Europe Centrale et Méridionale révélées par analyses de résidus lipidiques dans des céramiques

Les analyses de résidus organiques préservés dans les tessons de céramique permettent l'identification des aliments transformés dans les poteries archéologiques. Les différences de composition isotopique des acides gras rendent possible la distinction entre les graisses de ruminants et de non-ruminants, ainsi qu'entre les viandes et les produits laitiers. Cet article s'intéresse aux tendances dans l'utilisation du lait dans des sites où les moutons/chèvres dominent l'assemblage faunique et dans des sites du Rubané. Les sites étudiés sont Colle Santo Stefano (Abruzzes, Italie) et les sites du Rubané ancien à récent Zwenkau, Eythra et Brodau (Saxe, Allemagne), et Wang et Niederhummel (Bavière, Allemagne). Plus de 160 tessons ont été analysés, représentant des vases à cuire, des bols, des bouteilles et des « tessons perforés ». Les analyses des résidus lipidiques présentées ici montrent de façon directe l'exploitation de denrées provenant d'animaux ruminants et non-ruminants à Zwenkau et Eythra, même en l'absence de restes de faune dans ces sites. Aucun résidu laitier n'a été détecté dans les sites du Rubané, excepté dans un « tesson perforé » de Brodau. Des lipides provenant d'animaux non-ruminants et ruminants (viande et lait) ont été détectés dans le site de Colle Santo Stefano, montrant une utilisation des produits laitiers pendant la première moitié du sixième millénaire dans ce site où les moutons/chèvres étaient les principaux animaux domestiques.

MOTS CLÉS
Préhistoire européenne
Néolithique
tessons de poterie
faisselles
lipides
acides gras
valeurs de $\delta^{13}C$
produits animaux
lait

INTRODUCTION

The archaeozoological studies of faunal remains can provide evidence for milk exploitation of animal herds. Kill-off patterns from Early Neolithic sites in the Near East and Mediterranean Europe show that milk from cattle, sheep and goats was exploited from the earliest Neolithic times (Vigne & Helmer 2007). Complementary direct evidence for the processing of animal products can be obtained from remnant fats preserved in pottery vessels. Determination of the $\delta^{13}C$ values of the two major saturated fatty acids ($C_{16:0}$ and $C_{18:0}$) allow ruminant and non-ruminant fats, and adipose and dairy fats, to be distinguished in lipid extracts of potsherds, providing further insights into the use of pottery vessels in addition to the economy and management of animals (for a review, see e.g. Evershed 2008a). The development of this technique has provided a new way of investigating the emergence of dairying and testing the Secondary Product Revolution hypothesis (Sherratt 1983, 1997).

An extensive study of pottery vessels recovered from Neolithic, Bronze Age and Iron Age sites in southern Britain revealed direct evidence for the use of dairy products from the fourth millennium BC onwards (Copley *et al.* 2003; 2005a, b, c, d). Significantly, the results of the organic residue analyses correlated well with the archaeozoological evidence, e.g. the presence of non-ruminant fats was linked to the proportion of pig bones at sites, while the high ratio of female *versus* male cattle bones at some sites suggested an emphasis on milk exploitation. Furthermore, lipid residue analyses performed on 2,225 potsherds from 23 different archaeological sites from southeastern Europe, Anatolia and the Levant, dating from the seventh to the fifth millennia BC provided the earliest direct evidence to date of prehistoric milk use (Evershed *et al.* 2008). The reliance on cattle was higher in southeastern Europe around the Sea of Marmara than in the other sites studied, probably because of the local environment. Indeed, a positive correlation exists between the proportion of potsherds containing dairy residues and the proportion of cattle bones found at sites (Evershed *et al.* 2008). Nevertheless, this study did not shed light on the role of sheep and goats in the production of milk during the Neolithic, as suggested by Vigne and Helmer (2007), because the analyses of potsherds from the sites with a predominance of small ruminants (La Quercia, Makriyalos) showed only low incidences of dairy residues. As the Neolithic spread *via* the Mediterranean route into regions where sheep and goats were the major domesticates, and *via* the Danubian route into Central Europe where cattle predominate; the variety of landscapes and domesticates raises the question of the links between the presence of cattle or sheep and goats and the evidence of milk use in these regions.

Directly related to the undertaking of dairying by early pastoralists is the question of whether Early Neolithic Europeans were lactase persistent. Computer-based simulations have shown that the lactase persistence (LP) allele -13.910*T underwent a strong selection among Neolithic farmers around 7,500 years ago in a region between the central Balkans and central Europe, perhaps connected with the *Linearbandkeramik* (LBK) culture (Itan *et al.* 2009). The presence of milk fats in pottery vessels from southeastern Europe predates the increase in frequency of the lactase persistence allele in the area to the northwest by several millennia, and might seem contradictory with the modelling evidence. However, processing milk into various dairy products removes most of the lactose from fresh milk, allowing lactase non-persistent populations to consume milk-based products without deleterious health effects (Flatz and Rotthauwe 1977). Moreover, as Itan *et al.* (2009) point out, the early consumption of milk products is necessary to exert the selection pressure. Interestingly, investigations of ancient DNA from the skeletal remains of Neolithic farmers from the LBK region have so far failed to detect the -13.910*T variant, although this is probably due to the low frequencies (Burger *et al.* 2007). Thus, given that pottery vessels would likely have been the container for processing milk to reduce the lactose content, they provide a potentially important, and sensitive, artefact for detecting milk processing, and by inference, consumption by Neolithic farmers. The aforementioned studies raise two important questions relating to potential milk use in less well-studied areas of mainland Europe, namely: (i) Are milk fats detectable at high frequencies on sites where sheep and goats dominate the faunal assemblage? and, (ii) Are milk residues detectable in LBK pottery, *i.e.* in the core region linked to the increased frequency of the lactase persistence allele? These questions are addressed herein using molecular and isotopic methods to characterise organic residues preserved in pottery vessels from sites dating from the Early Neolithic.

MATERIAL AND METHODS

Background to archaeological sites

The site of Colle Santo Stefano is located southeast of the village of Ortucchio (Abruzzo, Italy; Fig. 1A). The surface area of the settlement is estimated at 1 ha, although only *ca.* 250 sq m have been excavated. Eight radiocarbon dates indicate that the settlement was occupied during the Early Neolithic for nearly four centuries, from 5840 to 5460 cal. BC (Fabbri & Angeli 2007), making this one of the earliest Neolithic sites in the region (Skeates & Whitehouse 1994; Radi & Danese 2001; Radi 2002). The site is related to the central Adriatic phase of the Early Neolithic *ceramica impressa* (impressed ware) complex, although the style of some of the pottery decoration suggest a southern Italian influence (*Guadone* type; Fabbri & Angeli 2007). Most (90% of the number of remains, NR) of the faunal remains excavated derive from domestic animals. The assemblage was largely dominated by sheep/goats (44% NR) and small ruminants (28% NR, mostly sheep/goats but also roe deer and chamois), whereas cattle bones represented 6% of the number of remains. Wild animals (10% NR)

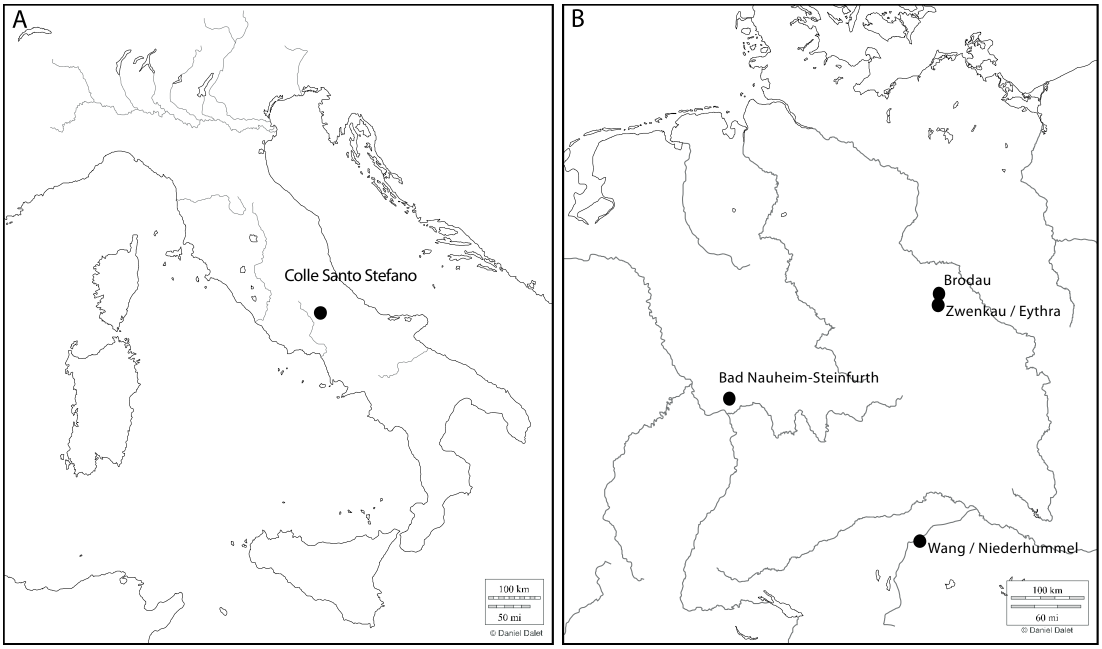

Fig. 1.– Maps of **A.** the Italian Peninsula indicating the location of Colle Santo Stefano and **B.** Central Europe indicating the location of Wang, Niederhummel, Zwenkau, Eythra, Brodau and Bad Nauheim-Steinfurth, from which the potsherds were selected.

were represented by red deer (2% NR; Radi & Wilkens 1989; Radi 2002). *Sus* species bones (pig and wild boar) represent 14% of the bones. The importance of domestic animals at the site was underlined by the excavation of a zoomorphic pottery vessel in the form of a pig or cow (Radi & Wilkens 1989).

The sites of Wang and Niederhummel are located *ca.* 40 km northwest of Munich (Bavaria, Germany; Fig. 1B). Wang was first excavated in the 1980's (Lüning 1987; Hillemeyer 1990, 2003) and dates to the Oldest and developed phases of the LBK (Whittle 1990, Stäuble 1995). A new excavation campaign initiated in 2008 provided freshly excavated potsherds from the Oldest LBK for analysis. The faunal assemblage at Wang comprises red deer (35%), pig (23%), *Bos* species (19%, mainly from domesticated cattle), sheep/goats (13%) and roe deer (7%). The economy at Wang relied on a mixture of hunting (49% of the bone assemblage derives from wild animals) and husbandry (51% from domestic animals; Arbogast *et al.* 2001). The neighbouring site of Niederhummel is also attributed to the Oldest phase of the LBK (Pechtl 2009), three dates with a weighted average of 5360-5220 cal. BC are available (Griffiths, pers. comm.). Due to the absence of faunal remains recovered during the 2008 excavations, no conclusions can be drawn about the management of animals.

The sites of Zwenkau and Eythra lie on both sides of the river Weiße Elster in Saxony, Germany (Fig. 1B). The site of Zwenkau, to the east, was occupied during the Oldest to the Younger phases of the LBK, whereas in Eythra, 2.5 km to the west, occupation began in the Older phase of the LBK and continued until the late *Stichbandkeramik* (Stroked Pottery culture, SBK; Cladders *et al.* 2012). The two sites cover a period of 800 to 1000 years, *i.e.* 5500/5300 to 4500 cal. BC. Eythra encompasses an area of 28 ha, being the largest excavation of a settled area in the early Neolithic ever discovered in Central Europe. Two wooden wells, *ca.* 300 houses, two circular enclosures and a circular palisade structure have been discovered (Staüble 2010). Due to the acidity of the lignite soil at both sites, no bone remains survive, preventing archaeologists from gaining any insights into the management of animals.

The excavations at the LBK settlement of Brodau (17 km north of Leipzig, Saxony; Fig. 1B) revealed traces of about 10 more or less preserved house plans. Typological ceramic analysis dates the site into the Middle LBK, and a well was dated dendrochronologically to 5200±10 BC (Staüble and Frölich 2006). The archaeozoological study of the remains at Brodau showed a high reliance on cattle, followed by sheep/goats and pigs (Kroll, unpublished data), as seen in many other LBK sites (Marciniak 2005). The final site studied herein, Bad Nauheim-Steinfurth (Hesse, Germany; Fig. 1B) belongs to the Rössen culture, which follows the LBK.

Selection of the potsherds

When possible, rim and upper body sherds were sampled, as analyses of replica cooking and ethnographic vessels used to process meat (and vegetables) show preferential absorption of lipids near the rim (Charters *et al.* 1997; Evershed 2008b). A total of 79 sherds from Colle Santo Stefano were selected for organic residue analyses. Sherds coming from pots of known forms were selected where possible: shallow bowls with hemispherical or very open truncate conical forms (n = 9 and 6, respectively); deep vessels with deep truncate conical shape, cylindrical or ovoid forms (n = 9, 7 and 14, respectively); globular shaped closed vessels (n = 11) and jars with long and narrow, or short and wide neck (n = 12 in total; Fig. 2). Undecorated (n = 58) and decorated (n = 21) sherds were selected. Lipid residue analyses were also performed on freshly excavated sherds from the LBK sites of Niederhummel (n = 18) and from Wang (n = 12). The sherds were sampled on site and not cleaned. Thirty-five sherds from the Oldest phase of the LBK site of Zwenkau and a further 22 sherds from Eythra (Older LBK, n = 11 and Middle/Young LBK, n = 11) were sampled for lipid residues analyses. The three shapes known in LBK pottery assemblages, *i.e.* globular-shaped vessels (*Kumpf*, n = 27), bottle (*Flasche*, n = 8) and open bowl (*Schale,* n = 8) were selected (Fig. 3). Fourteen sherds from vessels of unknown shape were also included. Decorated (n = 18 for Zwenkau and n = 5 for Eythra) and undecorated potsherds (n = 17 for Zwenkau and n = 17 for Eythra) were sampled. Lipid residue analyses were also performed on two ceramic sieves from the site of Brodau (Middle LBK) and one from Bad Nauheim-Steinfurth (Rössen culture; Fig. 4).

Analytical protocol

Lipid residue analyses were performed following the protocol described in detail elsewhere (Evershed *et al.* 1990; Copley *et al.* 2005a). Briefly, a sub-sample (*ca*. 2 g) from the archaeological potsherd was cleaned with a modelling drill to remove any exogenous lipids from handling and soil; and then crushed into a powder in a mortar with a pestle. An internal standard (IS, 20 µg of *n*-tetratriacontane) was added to enable the quantification of the lipid extract. The powdered potsherd was then extracted with 2 x 10 mL of a mixture chloroform-methanol (2:1 *v/v*) and sonicated for 2 x 20 min. Following separation from the ground potsherds, the solvent was evaporated under a gentle stream of nitrogen to obtain the total lipid extract (TLE). The TLE was then refrigerated until required for analysis.

An aliquot of the TLE (1/4) was treated with *N,O*-bis(trimethylsilyl)trifluoroacetamide (BSTFA) to trimethylsilylate (TMS) protic sites prior to analysis by high-temperature gas chromatography (HT-GC). A further aliquot was saponified by adding a methanolic sodium hydroxide solution (5% *v/v*; 70 °C, 1 h). After acidification, free fatty acids were extracted with 3 x 3 mL of chloroform and solvent removed under a gentle stream of nitrogen. The fatty acid methyl ester (FAME) derivatives

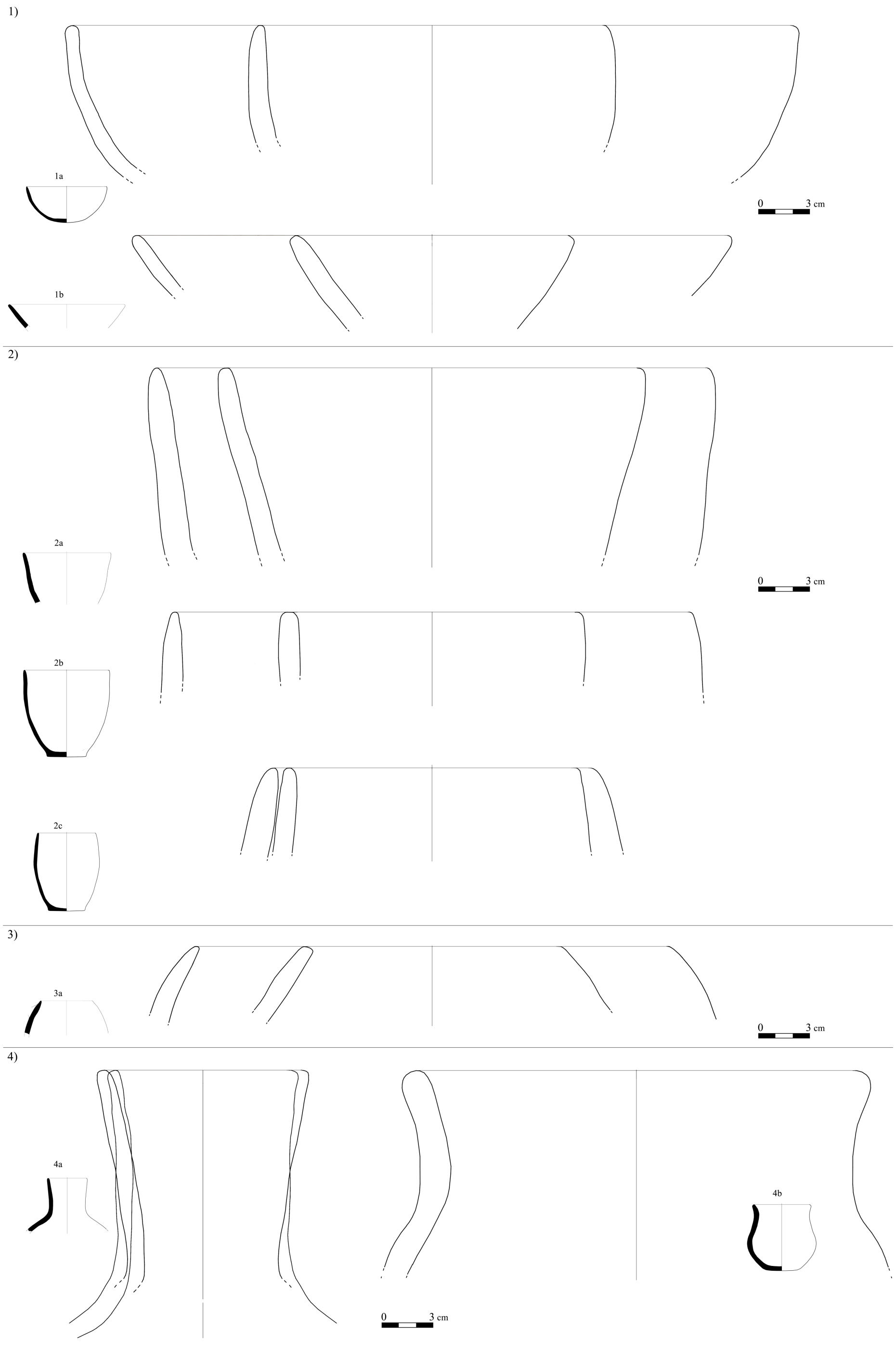

Fig. 2.– Most common types of the pottery from the Early Neolithic site of Colle Santo Stefano with 1. shallow bowls: 1a. hemispherical form, 1b. very open truncate conical form; 2. deep vessels: 2a. deep truncate conical form, 2b. cylindrical form, 2c. ovoid form; 3. closed vessels, globular form; 4. jars: 4a. with long and narrow neck, 4b. with short and wide neck. Scale bar: 3 cm.

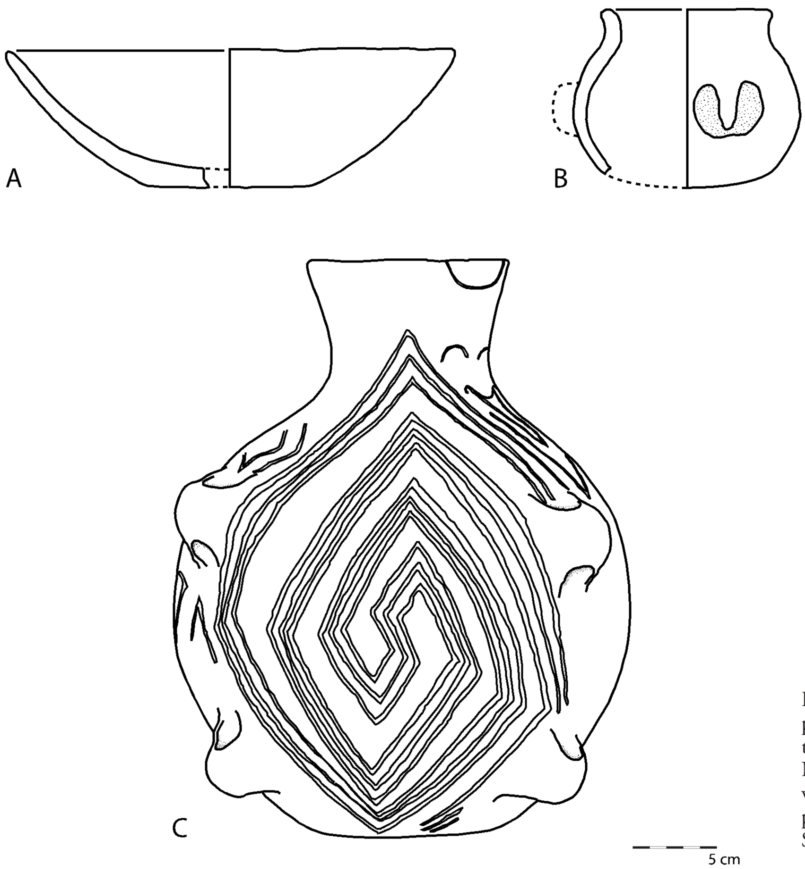

Fig. 3.– Most common types of pottery from the Oldest phase of the LBK from Wang (A and B) and Niederhummel (C);
with **A**. open bowl, **B**. globular-shaped vessel, **C**. bottle.
Scale bar: 5 cm.

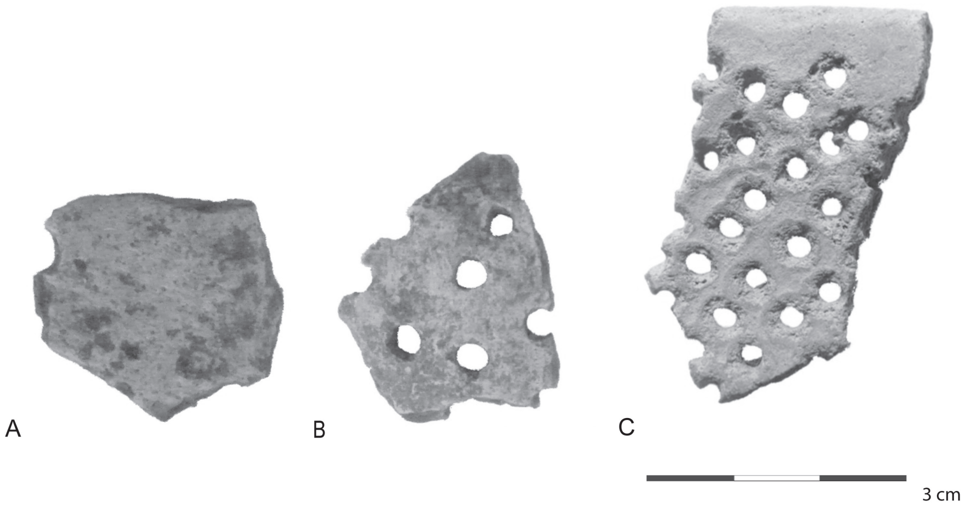

Fig. 4.– Potsherds from ceramic sieves from the site of Brodau (Middle LBK, Early Neolithic, **A** and **B**) and from Bad Nauheim-Steinfurth (Rössen culture, Middle Neolithic; **C**). Scale bar: 3 cm.

were prepared by heating the hydrolysed TLE aliquot with BF_3/methanol (14% *w/v*, 100 µL; 70 °C, 1 h). FAME derivatives were then extracted with 3 x 2 mL of chloroform and the solvent removed under a gentle stream of nitrogen to dryness. They were stored in freezer and dissolved in hexane prior analyses by GC, GC/MS and GC-combustion-isotope ratio mass spectrometry (GC/C/IRMS; Evershed *et al.* 2002; Regert 2011).

RESULTS AND DISCUSSION

Survival of absorbed lipids

Approximately 74% of the total number of potsherds analysed in this paper did not contain extractable lipid residues. The absence of lipids in extracts can be explained by anthropogenic and diagenetic degradation of lipid residues in pottery vessels or by the low concentration of lipids in foodstuffs prepared in the vessel (e.g. cereals or roots). The recovery rate was defined as the proportion of potsherds containing significant concentrations of lipids (usually 5 µg of lipids g^{-1} of powdered sherd) compared with the total number of sherds. The recovery rate for Early Neolithic sites of Colle Santo Stefano, Wang and Niderhummel[1], Zwenkau, Eythra were 28%, 20%, 23% and 36%, respectively. All the ceramic sieves analysed (n = 3) yielded sufficient lipid to allow identification of the source. These recovery rates were notably higher than those obtained in a previous investigation of pottery from sites in central and southeastern Europe (6.5%), Northern Greece (18.5%), Anatolia (13%) and the Levant (6.5%; Evershed *et al.* 2008) but lower than the recovery rate obtained for British Neolithic sites (43%; Copley *et al.* 2005) and prehistoric sites from the Eurasian Steppe (73.5%; Stear 2008). The contrasting incidences of lipid residues in the pottery from these new sites, and the overall variability in lipid concentrations may be related to the differences in vessel use, clay type, taphonomic history and/or preservation conditions during burial (Fig. 5).

Lipid residue analyses were carried out on 58 undecorated and 21 decorated potsherds from Colle Santo Stefano, leading to 20/58 and 1/21 interpretable residues, respectively. The lower recovery rate obtained for decorated potsherds (5%) relative to that obtained for undecorated potsherds (35%) reflects the relative rarity of decorated potsherds at the site (from 3 to 10% through the stratigraphy; Fabbri *et al.* 2011), as undecorated pottery may have been preferred for everyday-use, such as cooking, leading to a greater concentration of lipids in undecorated relative to decorated potsherds.

Evidence for the exploitation of animal products

Figure 6 illustrates typical gas chromatograms obtained from lipid residues extracted from archaeological potsherds. The GC profile is usually dominated by free fatty acids (palmitic and stearic acids). Monoacylglycerols (MAGs), diacylglycerols (DAGs) and triacylglycerols (TAGs) are observed in well-preserved residues. Free fatty acids, MAGs and DAGs are known to be produced by the hydrolysis of TAGs, the major components of fresh animal fats, during vessel use and burial (Evershed *et al.* 2002). The stable carbon isotope composition of the two major fatty acids ($\delta^{13}C_{16:0}$ and $\delta^{13}C_{18:0}$ values) present in the archaeological potsherds are plotted in Figure 7A-D. The values are compared to three ellipses generated (SYSTAT 7.0, SPSS Inc.) from the $\delta^{13}C$ values of the same fatty acids from fats of modern animals raised on a strict C_3 diet (Copley *et al.* 2003). The $\Delta^{13}C$ values (defined as $\delta^{13}C_{18:0}$ - $\delta^{13}C_{16:0}$), shown in Figure 7E-H are calculated in order to remove the dietary, environmental and seasonal variations in the $\delta^{13}C$ values (Mukherjee *et al.* 2005).

1. Due to the low number of lipid residues recovered from the sites of Wang and Niederhummel, the results of the analyses performed on the two sites were combined.

Colle Santo Stefano

More than 54% of the potsherds from undecorated globular vessels and about 36% from deep vessels (33%, 71% and 21% from truncate conical, cylindrical and ovoid shapes, respectively) yielded interpretable lipid signals. The high recovery rate of lipids in these potsherds reflects their use as cooking pots. Approximately 20% of the shallow bowls lead to sufficient amount of lipids. None of the potsherds from bottles contained any significant residue, suggesting the use of bottles in connection with substances containing low concentrations of lipids, such as water.

Most of the $\delta^{13}C$ values of fatty acids from Colle Santo Stefano did not plot in the area encompassed by the ellipses generated from the UK reference fats from animals raised on pure C_3 plants (Copley *et al.* 2003), probably as a result of the contribution from C_4 and/or water-stressed plants (Farquhar *et al.* 1989; Evershed *et al.* 2008). Thus, the archaeological data from this Italian site showed an increase in the $\delta^{13}C_{16:0}$ and $\delta^{13}C_{18:0}$ values compared to the Northern European archaeological sites (Copley *et al.* 2005a). The $\Delta^{13}C$ values showed the majority of the potsherds contained ruminant adipose fats or a mixture of ruminant and non-ruminant fats (67%), most of these potsherds being deep or globular vessels. Porcine adipose fats were detected in 19% of the potsherds, from globular closed vessels and truncate conical deep vessels. Dairy fats were detected in 14% of the potsherds, leading to identifiable residues (n = 3), all of which originated from cylindrical deep vessels or conical-shaped shallow bowls. No link between the nature of the residue and the nature of the fabrics was identified.

The faunal assemblage from the early Neolithic site of Colle Santo Stefano is composed of sheep/goats (44% NR), small ruminants (28% NR, *Ovis aries*, *Capra hircus*, *Capreolus capreolus* and *Rupicapra rupicapra*), pig (11% NR) and cattle (6% NR; Radi and Wilkens 1989). The meat yield for a cow being higher than for a sheep or a goat (~17 times according to Flannery 1969 and Robb 2007), thus, despite the low number of cattle remains recovered at the site, cattle could have been a major source of meat in the early Neolithic of Colle Santo Stefano (more than 50% of the meat; Radi & Wilkens 1989).

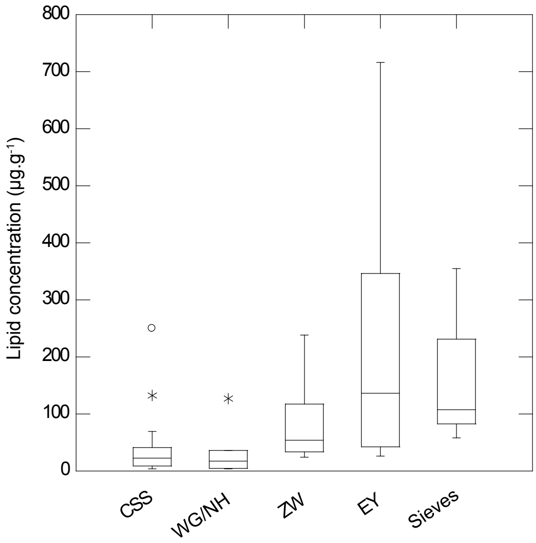

Fig. 5.– Box plot of concentration in lipids (µg.g^{-1}) of residues with a significant lipid content for the Neolithic sites Colle Santo Stefano (CSS), Wang and Niederhummel (WG/NH), Zwenkau (ZW), Eythra (EY) and the ceramic sieves (Sieves).

In order to examine the way sheep/goats and cattle were exploited at the site, further archaeozoological studies were performed on their remains from Colle Santo Stefano (Tagliacozzo & Pino Uria, unpublished data). A total of 96 mandibles from sheep/goats (56 from sheep, 20 from goats and 20 from sheep or goat; MNI = 92) and 10 mandibles from cattle (MNI = 8) were studied in order to construct kill-off patterns. The results of these analyses reflected selective killing in the management of the small ruminants. By considering all the ovicaprines (largely dominated by sheep), we showed that animals were commonly killed between 2 and 6 y (class E-G, Payne 1973). Low number of subadults between 1 and 2 y (class D) and rare

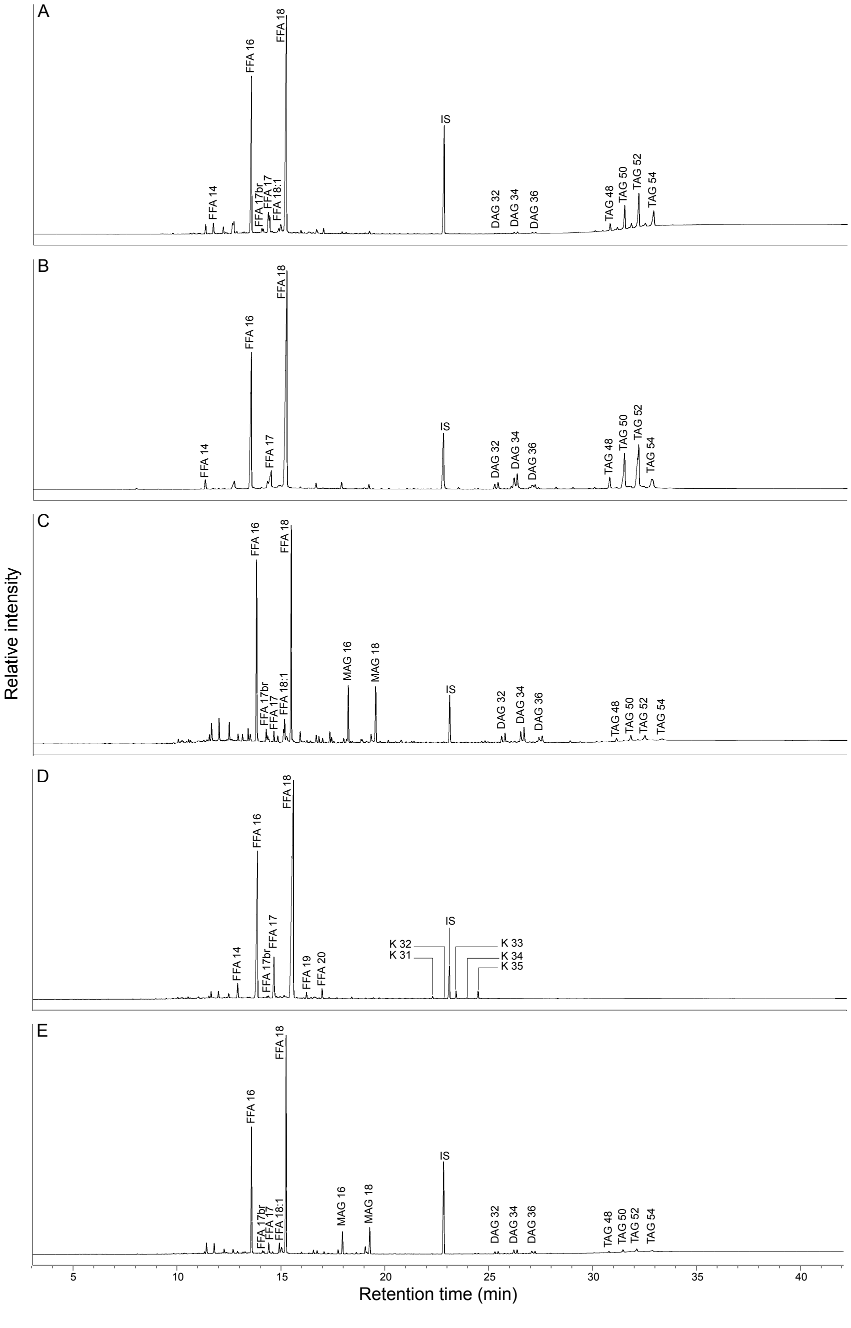

Fig. 6.– Partial gas chromatograms obtained from the total lipid extracts of a deep ovoid-shaped vessel from Colle Santo Stefano (**A**), a potsherd from an unknown type of vessel from Wang (**B**), some globular-shaped vessels from Zwenkau (**C**) and Eythra (**D**), and a sieve from Brodau (**E**). Peak identities are: FFA n and FFA n:i, free fatty acids containing n carbon atoms and i double bonds; MAG 16 – MAG 18, monoacylglycerols containing 16-18 acyl carbon atoms, respectively; DAG 32 – DAG 36, diacylglycerols containing 32-36 acyl carbon atoms, respectively; TAG 48 – TAG 54, triacylglycerols containing 48-54 acyl carbon atoms, respectively; K 31 – K 35, mid-chain ketones containing 31-35 carbon atoms respectively; IS = internal standard, n-tetratriacontane (C^{34}).

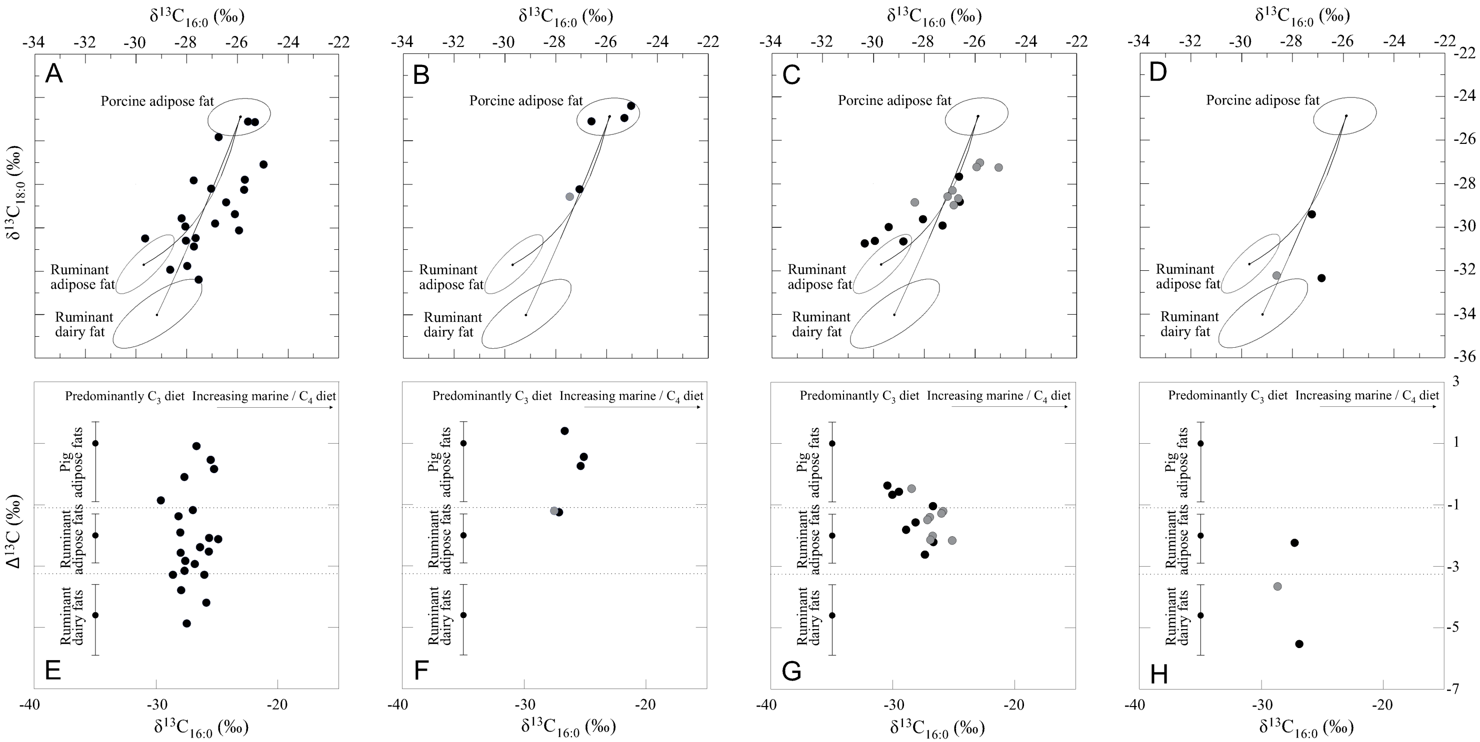

Fig. 7.– : $\delta^{13}C$ values of the FAMEs of $C^{16:0}$ and $C^{18:0}$ prepared from lipid extracts from the pottery assemblages from **A**. Colle Santo Stefano, **B**. Wang (black circles, Oldest LBK) and Niederhummel (grey circle, Oldest LBK), **C**. Zwenkau (black circles, Oldest LBK, *n* = 8) and Eythra (grey circles, Older, Middle and Young LBK, *n* = 8) and **D**. ceramic sieves from Brodau and Bad Nauheim-Steinfurth. Ellipses indicate the $\delta^{13}C$ values of the reference animal fats based on which the archaeological extracts are classified (Copley *et al.* 2003). **E. to H**. are $\Delta^{13}C$ values (= $\delta^{13}C^{18:0}$ - $\delta^{13}C^{16:0}$) of the extracts plotted against their $\delta^{13}C^{16:0}$ values from the same sites listed above. Reference materials are represented by their ranges and mean $\Delta^{13}C$ values (Copley *et al.* 2003).
Analytical precision is ±0.3 ‰.

kids and lambs (classes B-C) were slaughtered (Fig. 8). This kill-off profile is likely to reflect a model of mixed farming where wool exploitation is probably associated with milk production (but with a low slaughtering rate of lambs; Vigne & Helmer 2007). The corpus of cattle mandibles was much more limited, with the totality of the age classes represented (from very young calves to adults and senile cattle), preventing a reliable interpretation of the kill-off pattern. Thus, the breeding sheep/goats at Colle Santo Stefano fits into the typical Italian Early Neolithic model, where it has been demonstrated that sheep/goats (and cattle) were exploited both for primary products (meat) and secondary products (Tagliacozzo & Pino Uria 2010).

The results of lipid residue analyses and archaeozoological studies therefore agree in suggesting that the economy in Colle Santo Stefano was geared primarily towards subsistence rather than specialised production of "secondary products". Dairy products were indeed part of the diet of the people living in the Early Neolithic site of Colle Santo Stefano di Ortucchio as early as the first half of the sixth millennium BC. The detection of dairy lipids in some potsherds suggests that milk was processed into dairy products, such as butter, yoghurts or cheese, unprocessed milk being difficult to detect in archaeological pottery (Copley *et al.* 2005). These results showed that dairy products were likely consumed at the site despite the lack of lactase persistence in the population at that time (Burger *et al.* 2007; Itan *et al.* 2009), pointing to the processing of milk to diminish the concentration of lactose.

Wang, Niederhummel, Zwenkau, Eythra and ceramic sieves

In Zwenkau and Eythra, the recovery rate of lipids was higher in globular-shaped vessels (37%), compared to bottles (25%) and open bowls (12%) and sherds from unknown vessel types (18%), reflecting the intensive use of globular-shaped vessels as 'cooking' pots. One of the residues contained long-chain ketones, demonstrating that the vessel had been heated at high temperature during its use (Evershed *et al.* 1995; Fig. 6D).

The mean $\delta^{13}C_{16:0}$ value for residues in Eythra (-28.4‰) was higher than in Zwenkau (-26.6‰; two-tailed Student's t-test, significant at $P = 0.05$; Fig. 7C). This difference in the $\delta^{13}C$ value of palmitic acid is independent of the type of fats (ruminant or non-ruminant fats, dairy or adipose fats) but strongly dependent on the diet of animals. Depleted $\delta^{13}C_{16:0}$ values refer to fats from animals raised on a C_3 diet, while enriched values are observed in animals raised on diets comprising C_4 or marine components (Copley *et al.* 2003). The enrichment in the ^{13}C content of palmitic acid in Eythra (Older, Middle and Young LBK), compared to Zwenkau (Oldest LBK) is possibly the result of the greater consumption by animals of plants from a waterlogged environment at the younger site. The presence of ruminant and non-ruminant fats was attested by the $\Delta^{13}C$ proxy of fatty acids in the potsherds from Zwenkau and Eythra, showing that the whole spectrum of available animals was raised at these sites. Most of the pots would have been used for cooking mixtures of ruminant and non-ruminant products, underlying the non-specific use of the vessels. As no faunal remains were found at the sites of Zwenkau and Eythra, the lipid residues preserved in pottery vessels offer the only way to derive information about how animals were managed at the sites through time.

Lipid residues detected at the sites of Wang and Niederhummel exhibited $\Delta^{13}C$ values indicative of porcine adipose fats and mixtures of ruminant and non-ruminant fats, showing a high reliance on domestic pig and possibly wild boar products (Gregg *et al.* 2009; Fig. 7B). None of the small number of sherds from the Oldest LBK sites of Niederhummel and Wang displayed values characteristics of dairy fats.

The lipid residues extracted from the three ceramic sieves display $\delta^{13}C$ values showing a vari-

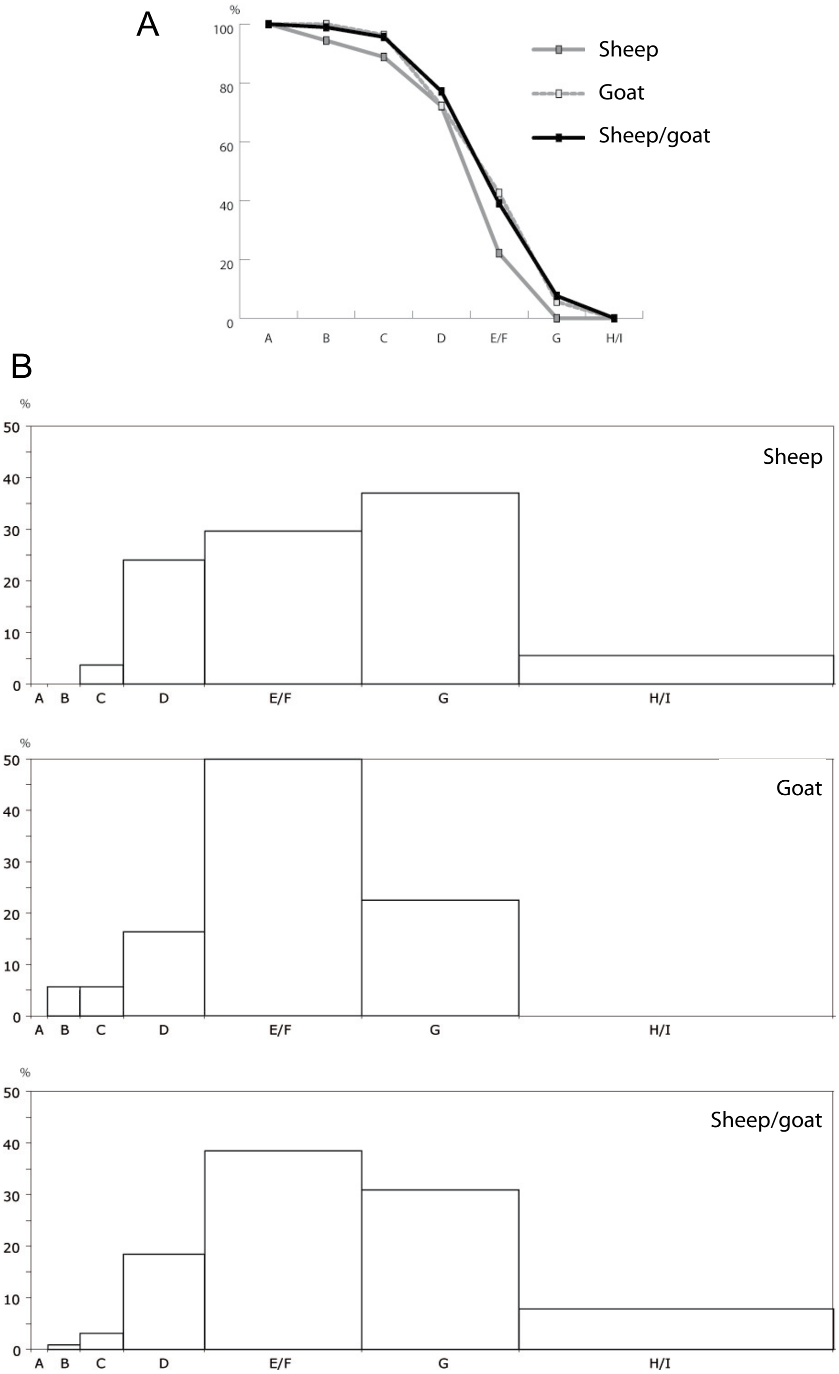

Fig. 8.– **A**. Survival diagram for sheep, goat and sheep/goats from the site of Colle Santo Stefano.
B. Sheep, goat and sheep/goats slaughtering profiles from Colle Santo Stefano according to Payne (1973) and Vigne and Helmer (2007) (Tagliacozzo & Pino Uria, unpublished data).

ability in fat content including ruminant dairy fat and mixtures of animal fats. The presence of dairy fat in one of the sieves would be consistent with earlier suggestions concerning the use of such ceramic sieves as "cheese-strainers" (Bogucki 1984). However, the results from the other two sieves indicate that they were certainly not used exclusively for milk processing, but perhaps for straining meat pieces from stock. Hence, organic residue analyses have shown for the first time that the use of these famous ceramic sieves may have been diverse, and not only for cheese-making.

Since no dairy fats were detected in any of the 'cooking' potsherds from the studied LBK sites (Wang, Niederhummel, Zwenkau and Eythra) it remains unconfirmed whether: (i) sheep/goat and cattle milk and dairy products were not produced and processed at these sites, (ii) milk was produced but processed in perishable containers, such as bark baskets, leaving no dairy residues in potsherds, or (iii) milk and meat were mixed in pottery vessels, thereby masking the milk fat isotopic signal. The presence of dairy fats in a ceramic sieve from the LBK site of Brodau definitively shows milk was exploited at this Middle LBK site. Nevertheless, the nature of lipid residues from the studied ceramic sieves from the LBK onwards is diverse, requiring the ceramic sieve corpus to be increased in order to draw firm conclusions regarding their use.

CONCLUSIONS

The results presented above show how lipid analyses of absorbed organic residues from Neolithic pottery vessels can be used to gain new insights into the economy and management of animals, specifically in relation to the production and processing of dairy products in early Neolithic sites, even at sites where the faunal data is scarce. With respect to the questions posed above:

(i) Lipid residue analyses on 79 potsherds from Colle Santo Stefano di Ortucchio confirm that dairy products were consumed at this Early Neolithic site by the first half of the sixth millennium BC. Archaeozoological studies suggested that sheep/goats (and probably cattle) were likely to have produced milk for human consumption at this site. Nevertheless, it is still difficult to access the species from which these dairy residues are derived. The trend is comparable to the Early Neolithic of Çayönü Tepesi, Çatalhöyük and Tell Sabi Abyad where even if small ruminants dominate the assemblage, a weak dairy signal is detected (Evershed *et al.*, 2008). Hence, the omnipresence of cattle at a site is not the condition *sine qua non* for the milk use at the site. In contrast to northeastern Anatolian sites, the presence of non-ruminant fats is making false negative for milk a possibility, when non-ruminant and ruminant dairy fats were mixed in the same vessel.

(ii) Lipid residue analyses of 87 sherds from LBK sites, dating from the Oldest to the Young LBK in Germany, indicated that animal products were the major lipid yielding foodstuffs prepared in ceramic vessels at these sites. Dairy products were not definitively identified in any of the lipid residues, which appears at odds with fact that gene co-evolution modelling predicts that the lactase persistence allele increased in frequency in this area at that time (Itan *et al.* 2009). Nevertheless, milk and dairy products may have been produced and consumed in this region, but were mixed with other commodities in the vessels or processed in perishable containers that did not survive in the archaeological record. Further studies of pottery vessels are required to confirm whether or not milk was intensively produced and processed in the LBK and whether spatio-temporal patterns exist.

(iii) The presence of dairy lipids in one of the ceramic sieves from the Middle LBK confirms that milk was processed at the site of Brodau. However, because of the variability in lipid content in these strainers and the limited number of this type of artefacts analysed so far, more studies have to be undertaken in order to define the general use of strainers during the LBK and beyond.

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