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The identification of poultry processing in archaeological ceramic vessels using *in-situ* isotope references for organic residue analysis

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ABSTRACT

Poultry products are rarely considered when reconstructing pottery use through organic residue analysis, impinging upon our understanding of the changing role of these animals in the past. Here we evaluate an isotopic approach for distinguishing chicken fats from other animal products. We compare the carbon isotopes of fatty acids extracted from modern tissues and archaeological bones and demonstrate that archaeological bones from contexts associated with pottery provide suitable reference ranges for distinguishing omnivorous animal products (e.g. pigs vs. chickens) in pots. When applied to pottery from the Anglo-Saxon site of Flixborough, England, we succeeded in identifying residues derived from chicken fats that otherwise could not be distinguished from other monogastric and ruminant animals using modern reference values only. This provides the first direct evidence for the processing of poultry or their products in pottery. The results highlight the utility of '*in-situ*' archaeological bone lipids to identify omnivorous animal-derived lipids in archaeological ceramic vessels.

1. Introduction

Products from omnivorous animals, such as pigs and poultry, dominate global meat production and are important for fuelling the next 'Livestock Revolution' (Delgado et al., 1999). Undoubtedly, these were also important commodities in many past contexts, as attested by the frequent occurrence of their skeletal remains on a wide range of archaeological sites (Maltby, 2014; O'Connor, 2014; Redding, 2015; Sykes, 2012). Whilst it is generally accepted that pig bones on archaeological sites provide evidence for the consumption of pork products, the use of poultry in the past is complicated by other historically and ethnographically documented uses, from recreation to ritual (Sykes, 2012). Even as a foodstuff, poultry have been overlooked and underinvestigated in the past despite their undisputed importance today as a major global resource. Therefore, whilst there is clear faunal evidence attesting to the presence of domestic chicken on European archaeological sites since later prehistory (Peters et al., 2015; Serjeantson, 2009), it is unclear when, where and why poultry became routinely raised for their meat and eggs and viewed primarily as a foodstuff. One way to unequivocally demonstrate this link is by directly detecting poultry products in domestic cooking vessels.

Archaeological ceramic vessels provide a wealth of information on resource use, offering a window into past production, storage, transport and processing of food and other commodities. Lipids (fats, oils and waxes) can be readily absorbed in unglazed, porous ceramic vessels (Evershed et al., 1999), and preserved for hundreds to thousands of years (Craig et al., 2013). Analytical techniques, involving gas chromatography (GC) and GC-mass spectrometry (GC-MS), provide a means of associating broad classes of compounds to their biological precursors (Evershed et al., 1999;

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Evershed, 2008). Stable carbon isotope analysis of palmitic ($C_{16:0}$) and stearic ($C_{18:0}$) acids by GC-combustion–stable isotope ratio MS (GC-c-IRMS) provides a complementary method for animal fat identification in archaeological ceramic vessels (Copley et al., 2003; Craig et al., 2013; Evershed et al., 2002b; Mukherjee et al., 2008; Salque et al., 2013). This latter approach is routinely used to identify ruminant products (Craig et al., 2012), and dairying activities in the archaeological record. However, relatively few studies have considered using this approach to identify poultry products or to distinguish these from other omnivorous animals, such as pigs (Evershed et al., 2002b).

In a first attempt to determine the processing of poultry in ceramic vessels, we investigate a pottery assemblage from the Anglo-Saxon site of Flixborough in North Lincolnshire (England). The site was chosen as its faunal assemblage shows clear evidence of mixed monogastric and omnivorous animal exploitation, i.e. geese, chickens, pigs. To distinguish these, we measured carbon isotope values of fatty acids obtained from archaeological bones of monogastric-omnivorous animals associated with the pottery to provide *in-situ* reference values. Our aim was to determine whether different monogastric commodities were processed in ceramic vessels.

1.1. *Isotopic variability in monogastric-omnivorous animal fats*

The stable carbon isotopic ratios of monogastric and ruminant adipose fatty acids differ due to fundamental variations in digestive physiology and metabolic processes (Copley et al., 2003; Howland et al., 2003; Jim et al., 2004; Stott et al., 1997a). Notably, ruminants incorporate specific saturated compounds (e.g. $C_{18:0}$) directly from their diet into their tissues, following biohydrogenation of the unsaturated precursors in the rumen (Harrison and Leat, 1975; Krogdahl, 1985). This process leads to measurable ^{13}C depletion compared to *de novo* synthesized components (e.g. $C_{16:0}$). However, distinguishing fat from economically important monogastric and omnivorous animals (e.g. pigs and poultry) is less straightforward using this approach. Omnivorous animals consume a broader range of food sources compared to herbivores and consequently the carbon in fatty acids can be derived from a wider range of macronutrient sources, including lipids, carbohydrates and proteins from both animals and plants (Budge et al., 2011; Howland et al., 2003; Stott et al., 1997a; Trust Hammer et al., 1998). Therefore, fatty acids from omnivores exhibit considerably larger isotopic variability (e.g. Delgado-Chavero et al., 2013; Recio et al., 2013) compared to ruminant and monogastric herbivores, depending on the animal's diet and therefore husbandry practices. As these are variable in the past and most likely different from the present, modern references for omnivores may be inappropriate and ideally site specific "*in-situ*" baselines need to be constructed.

1.2. *Archaeological bone as an in-situ baseline for organic residue analysis*

All previous attempts to interpret fatty acids from archaeological pottery rely on comparison with reference fats from modern animals raised on known diets and preferably sourced close to the archaeological sites under investigation (Copley et al., 2003; Dudd and Evershed, 1998; Dunne et al., 2012; Evershed et al., 2002b; Gregg et al., 2009; Salque et al., 2013; Spangenberg et al., 2006). In Northern Europe, for example, comparative reference fats are typically derived from animals raised on C_3 vegetation with the assumption that they represent the variety of environmental/dietary conditions experienced by past animals (Dudd and Evershed, 1998). While this is entirely reasonable for herbivore ruminants, it does not account for the greater variability in the diet of omnivores. Furthermore modern omnivore references may not be suitable analogues for animals raised in areas that have undergone substantial changes in vegetation composition during the Holocene (e.g. Near East, (Goodfriend, 1990); North Africa, (Castañeda et al., 2009)) or in cultural contexts where foddering strategies are known to have changed in the past (Hamilton and Thomas, 2012; Madgwick et al., 2012). Both geographic and temporal variability must be considered when deriving suitable isotopic reference ranges in order to capture environmental and cultural effects. Moreover, the use of modern reference fat inherently implies that animal fat preserved in ceramic vessels originate predominantly, or exclusively, from adipose tissue. Nevertheless, other animal tissues are similarly lipid rich (e.g. bone marrow) and thus are potential sources of animal fat preserved in ceramic vessels. The boiling of bone to release nutrients, for example in soups and broths, may provide another mechanism for transferring bone lipids to archaeological ceramics.

As soft tissues are very rarely preserved in archaeological contexts, animal bone may provide an alternative or complementary source of fatty acids for comparison. Animal bones are often found directly associated with pottery (i.e. in the same contexts, stratigraphic units or site areas, and in rare instances within the pots themselves) and are therefore chronologically coherent with cultural and environmental contexts. The lipid composition in adipose tissues and cortical bone are similar in nature (Kagawa et al., 1996; Ren et al., 2008) and studies have shown that lipids are preserved in archaeological bone (Evershed et al., 1995b; Spangenberg et al., 2014; Stott and Evershed, 1996). Recently Colonese et al. (2015) have demonstrated that endogenous palmitic ($C_{16:0}$) and stearic ($C_{18:0}$) fatty acids can be recovered in sufficient quantity from archaeological bones from a range of environments to permit stable isotope analysis by GC-C-IRMS. In agreement with earlier studies (Stott et al., 1997a, 1999) it has been shown that stable carbon isotope composition of bone lipid covaries with bone collagen (Colonese et al., 2015), supporting the endogenous origin of fatty acids and their potential for paleodietary reconstruction.

2. Flixborough

2.1. *The site and economy*

Excavations at Flixborough, North Lincolnshire, exposed a high-status Anglo-Saxon site with an occupation sequence stretching from the 7th to 11th centuries AD (with subsequent use in the 12th–15th centuries) (Loveluck and Gaunt, 2007; Loveluck, 1998). Over 200,000 fragments of animal bone were recovered from Flixborough, making it one of the largest assemblages of Middle to Late Anglo-Saxon date in England (Jaques et al., 2007). A hand-collected and coarse-sieved assemblage of over 41,000 mammal and bird bone fragments dating from the early 7th to late 10th century was identified to taxon. The most numerous domesticates (average %NISP) were cattle (*Bos taurus,* 29.4%), followed by sheep/goat (*Ovies aries/Capra hircus*, 27%), pig (*Sus scrofa domesticus*, 19.4%), chicken (*Gallus gallus domesticus*, 15%), and goose (*Anser* sp., 9.2%) respectively, although the relative proportions of these changed through time (Jaques et al., 2007).

Whilst cattle and sheep/goat could have provided multiple secondary products such as milk, wool and traction, pigs would have primarily been a meat resource. Chickens would have been a useful source of meat and feathers, eggs and potentially fertiliser in the form of dung. However, so far the role of ceramic vessels for processing and preparing these various animal products has been only preliminarily considered (Young and Vince, 2009). In particular, the identification of domestic poultry in pottery would help clarify their role at the site and provide the first insights into the