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The cooked and the raw: A taphonomic study of cooked and burned fish

Irit Zohar [a,b,*], Ahiad Ovadia [a], Naama Goren-Inbar [a]

[a] Institute of Archaeology, Hebrew University, Mt. Scopus, Jerusalem 91905, Israel
[b] Oranim Academic College, Kiryat Tivon, Israel

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ABSTRACT

This article presents an experimental approach to examining the effects of different heating temperatures (300–900 °C) on the survivorship of cranial skeletal elements and pharyngeal teeth in modern black carp. In addition to the traditional visual inspection of the taphonomy of skeletal remains, we examined the potential use of SEM and powder X-ray diffraction (XRD) as an accurate method for assessing the thermal alteration of teeth following heating.

Our findings reveal that differential preservation of thermally-heated fish can be identified from remains disposed of in an open fire. We found a relationship between the anatomical location of bones and their probability of surviving the heat. Overall, pharyngeal teeth exhibited the best survival rate, up to 900 °C. The findings from this experiment and the regression equation obtained from the XRD can be applied in future research for identifying cooking and waste disposal practices for carp remains found in archaeological contexts.

1. Introduction

In his book *The Descent of Man*, Charles Darwin stated that the making of fire was "*probably the greatest* [*discovery*], *excepting language*, *ever made by man, dates from before the dawn of history*" (Darwin, 1871:137). Many anthropological theories are concerned with the effect of food composition, cooking, heating and eating habits on human evolution, brain enlargement, social interactions and social status (Aiello and Wheeler, 1995; Belcher, 1994; Blumenschine, 1987; Clark, 1989; Domínguez-Rodrigo, 2002; Kaplan et al., 2000; Koon et al., 2010; Wandsdiner, 1997; Wrangham, 2009; Wrangham and Carmody, 2010). The precise antiquity of human control of fire and its use for cooking have nonetheless remained controversial issues (Alperson-Afil and Goren-Inbar, 2010; Alperson-Afil et al., 2007; Barbetti, 1986; Goren-Inbar et al., 2004; Karkanas et al., 2007; Roebroeks and Villa, 2011; Shimelmitz et al., 2014; Wrangham, 2009; Wrangham and Carmody, 2010).

Since the cooking of food has been linked to key changes in hominin dentition and brain enlargement (Aiello and Wheeler, 1995; Cunnane and Stewart, 2010), it is crucial to develop accurate methods for identifying thermally-modified bones. A review of experimental studies on the effect of heat and fire on skeleton preservation reveals a wide range of variables involved in bone preservation and modification patterns (e.g., Äikäs et al., 2010; Arora et al., 2010; Asmussen, 2009; Bennett, 1999; Bosch et al., 2012; Ellingham et al., 2015; Gifford-Gonzales, 1989; Hanson and Cain, 2007; Koon et al., 2010; Lebon et al., 2008; Michel et al., 2006; Shipman et al., 1984; Spenneman and Colley, 1989; Speth, 2000; Stiner et al., 1995; Wandsdiner, 1997; Weiner and Bar-Yosef, 1990). A recent study (Bosch et al., 2012) has provided a comprehensive list of attributes for distinguishing between different models of accumulation of heat-altered bones (natural fire, bones used as fuel, roasted, etc.). However, most of these studies focus on large mammal exploitation and cremation practices, while fewer examine the effects of heat and fire on fish (Äikäs et al., 2010; Beisaw, 1998; Conard et al., 2008; Lubinski, 1996; Nicholson, 1993, 1995, 1998; Spenneman and Colley, 1989; Steffen and Mackie, 2005).

Overall, several problems arise with regard to the identification of cooked meat:

1) The range of cooking temperatures is relatively low. Attempts to identify temperature-induced mineral changes have shown that significant alterations do not occur under the normal range of "cooking temperatures", i.e., 100–250 °C, and a maximum of 400 °C for campfires (Ellingham et al., 2015; Koon et al., 2003, 2010; Munro et al., 2007; Piga et al., 2008; Richter, 1986; Shipman et al., 1984; Trueman et al., 2008).
2) In waterlogged sites, burned (black) bones are difficult to identify, since the bones are dark in colour as a result of mineralogical staining (Stathopoulou et al., 2013; Zohar, 2003; Zohar and Biton, 2011; Zohar et al., 2001).
3) There is a correlation between the anatomy (taxonomy) and body size of a fish and the probability of its bones surviving human

* Corresponding author at: Institute of Archaeology, Hebrew University, Mt. Scopus, Jerusalem 91905, Israel.
E-mail addresses: zoharir@gmail.com (I. Zohar), ahiadov@gmail.com (A. Ovadia), naama.g@mail.huji.ac.il (N. Goren-Inbar).

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activity. This prevents the use of a generalized model (Butler and Chatters, 1994; Lubinski, 1996; Nicholson, 1995, 1998; Steffen and Mackie, 2005; Zohar and Cooke, 1997; Zohar et al., 1994).

Taking into account recent experimental studies (Ellingham et al., 2015), the above-noted problems and the relatively small number of studies focusing on parameters for the identification of thermally-modified fish, this article examines the effects of heating temperatures on the survival of cranial remains of large carp (Cyprinidae). We focus on carp since this fish plays a major economic role in fisheries worldwide (Garibaldi, 1996), was the earliest fish to be domesticated and aquacultured (Balon, 1995, 2004; Nakajima et al., 2012) and has had a long history of exploitation since the Lower Paleolithic (Van Neer et al., 2005; Zohar and Biton, 2011; Zohar et al., 2014).

We present here an experimental approach that examines the effects of different heating temperatures (300–900 °C) on the survival of cranial skeletal elements in modern black carp. Since the pharyngeal teeth of Cyprinidae are frequently recovered from archaeological sites (Nakajima et al., 2012; Nakajima and Peiqi, 1989; Nakajima and Yue, 1995; Zohar and Biton, 2011; Zohar et al., 2014), we particularly examine the possibility of a differential preservation between cranial bones and pharyngeal teeth.

In addition to a traditional visual inspection of the state of preservation of the remains, on a sample of molariform teeth, we also examined the potential of powder X-ray diffraction (XRD) as an accurate method for assessing the heating temperature applied (Munro et al., 2007; Piga et al., 2008). The findings from this experiment have application as a model for identifying cooking and waste disposal practices in archaeological contexts.

2. Materials and methods

2.1. Experimental modern material

The methodology presented in this study follows previous burning experiments conducted on mammals and fish (e.g., Asmussen, 2009; Bennett, 1999; Ellingham et al., 2015; Koon et al., 2003, 2010; Lebon et al., 2008; Michel et al., 2006; Munro et al., 2007; Nicholson, 1993, 1995, 1998; Patidar et al., 2010; Piga et al., 2008; Schiegl et al., 1996; Shahack-Gross et al., 1997; Shipman et al., 1984; Spenneman and Colley, 1989; Stathopoulou et al., 2008; Steffen and Mackie, 2005; Stiner et al., 1995; Surovell and Stiner, 2001; Thompson, 2004; Ubelaker, 2009) and was here modified to suit cyprinid anatomy. For this study we purchased[1] 12 cultivated black carp (*Mylopharyngodon piceus*) (Fig. 1). This species grows to large dimensions (up to ca. 1.8 m in length) and features large molariform teeth that are similar in structure and shape to the teeth that are frequently recovered at archaeological sites (Nakajima et al., 2012; Nakajima and Yue, 1995; Sisma-Ventura et al., 2015; Zohar and Biton, 2011) as well as to those of the native and currently endangered species *Luciobarbus longiceps* (Valenciennes, 1842; Jordan Barbel, or *Binit* in Hebrew). For each fish we performed external measurements of body size: body mass (in gr), total length, standard length, head length and body depth (in mm) (Fig. 2). As we intentionally selected large fish, their weight ranged between 1.34 and 3.0 kg and their total length between 480 and 620 mm (Table 1).

2.2. The heating experiment

For the heating experiment we used a gas ceramic kiln located in the grounds of the "Jerusalem House of Quality" (Fig. 3). Heating temperatures were monitored precisely and continually using a digital probe thermocouple (Fig. 3A). As in this study we examined the effect of heat and fire on cooked fish, the fish were not filleted prior to cooking but, rather, "cooked" either whole or head only, on a ceramic plate (Fig. 3B and C). Ten of the 12 experimental fish were cooked, while two were retained as control. As we focused on the effect of heat on the cranial bones, of the ten cooked fish three were cooked whole while for seven only the heads were cooked (Table 1). Since large carp are rich in oil, each fish was cooked for 20–30 min at 300 °C prior to being cooked for a further 45 minutes at the chosen temperature. The cooking temperatures ranged between 300 °C and 900 °C at intervals of 100 °C (due to the nature of the gas kiln, the temperature could be maintained within ±20 °C of the target temperature) (Table 1). Each cooked/burned fish was then air-cooled and carefully placed in a separate labelled bag for further analysis in the zooarchaeology laboratory at the Edmond J. Safra Campus of the Hebrew University of Jerusalem.

2.3. Taphonomic parameters recorded

A series of parameters were recorded in order to examine the effect of heating temperature on the survival of selected skeletal elements that are species-specific and frequent finds at archaeological sites (Leach, 1986; Wheeler and Jones, 1989). These comprised the atlas, axis, articular/angular, basioccipital, cleithrum, dentary, maxilla, opercular, premaxilla, urohyal, pharyngeal bone and the pharyngeal teeth (Gifford-Gonzales, 1989; Koon et al., 2003, 2010; Nicholson, 1993, 1995, 1996; Shipman et al., 1984; Speth, 2000; Stathopoulou et al., 2013; Steffen and Mackie, 2005). For the selected bones and teeth we recorded the state of preservation (%), fragmentation pattern and colour (evidence of charring). For the molariform teeth we recorded the number of teeth preserved out of the total number expected. For a sample of teeth, we used SEM to determine which chemical elements were present on the enameloid surface.

2.4. Cyprinid molariform teeth and X-ray diffraction (XRD) analyses

Teeth are regarded as the most highly mineralized and hardest tissues, due to the particular hierarchical arrangement of the constituent carbonated calcium-deficient hydroxyapatite ("bioapatite") crystals (Smith and Tchernov, 1992; Suga et al., 1983; Tütken and Vennemann, 2011; Weiner and Addadi, 1997). A layer of hard, mineral-rich tissue, called enamel in mammals and reptiles and enameloid in fish and amphibians, covers the teeth. A softer and less mineralized layer of dentine appears beneath it (Enax et al., 2012; He et al., 2013).

The oromandibular region of cyprinids is toothless and their teeth are located on the pharyngeal bone (modified fifth branchial arch; Fig. 4) (Nakajima et al., 2012; Nakajima and Peiqi, 1989; Nakajima and Yue, 1995). The molariform teeth of molluscivore carp are round and relatively large (Fig. 4), adapted in their strength and structure to the high pressure necessary for crushing molluscs (Gidmark et al., 2013; He et al., 2013).

In this study we chose the XRD rather than the FTIR-KBr method for examination of changes in crystal size, since the preparation of samples for the FTIR-KBr method is highly prone to inter-user error and the handling of KBr poses a health risk (Ellingham et al., 2015; Thompson et al., 2009). Powder from the molariform tooth of each of the fish used in this experiment (Table 1) was tested for average crystallite size using an X-ray diffractometer (XRD) housed at the Center of Nanoscience and Nanotechnology at the Edmond J. Safra Campus of the Hebrew University of Jerusalem. The X-ray powder diffraction measurements were performed using the D8 Advance diffractometer (Bruker AXS, Karlsruhe, Germany) with Göbel Mirror parallel-beam optics, 2° Sollers slits and 0.2 mm receiving slit. Each tooth was ground individually in an agate mortar to a powder with a grain size of ca. 5 μm, which was then placed in a low-background quartz sample holder. XRD patterns within the range of 8° to 68° 2θ were recorded at room temperature using CuKα radiation ($\lambda = 1.5418$ Å) under the following measurement conditions: tube voltage 40 kV, tube current 40 mA, step-scan mode with a step

[1] See ethics statements at the end of the article.