Diet and health at Chinikihá, Chiapas, Mexico: some preliminary results

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This study reports stable nitrogen, and carbon isotopic analyses (δ¹³C and δ¹⁵N) from bone collagen and enamel apatite for eight human samples at the site of Chinikihá, Mexico, during the Late Classic (AD 650–850). It has been proposed that, during this time period, an increase in maize consumption combined with a decrease in meat consumption could have been the result of an environmental collapse, reflected in a generalised poor diet and health. However, recent studies demonstrate that there is great intrasite variability, and that access to maize and animal protein may relate more to changes in the distribution of foods among social groups. Data from chemical analyses are combined with other variables, such as health status and mortuary patterns to determine differences among the inhabitants of an upper-class household. Our results indicate that, while the basic staple of all the inhabitants of Chinikihá was maize, access to other wild plants and animal protein may have depended on sex, age and other social factors, and not necessarily be the consequence of an environmental depletion of resources. This article provides more data to the growing body of literature that support local variation and internal differences, and expands our knowledge on differential access to resources within the members of a higher-class unit.

Keywords: maize, white-tailed deer, carbon and nitrogen stable isotopes, Chinikihá, Late Classic Maya

Introduction

Maize (Zea mays Linnaeus 1753) and terrestrial animal protein, with an occasional access to freshwater and marine resources, as dictated by geographic location, have been considered the basic food staples in Mesoamerica from the Preclassic period through to the Terminal Classic. The specific dietary components have been studied through macroscopic and phytolith analyses, traditional zooarchaeology, and other indirect methods including iconography, and the use of ethnohistoric documents (White et al. 2006,143). However, direct measurement of diet was not possible until the 1970s when the use of human tissues for isotopic analyses was first undertaken to identify the introduction of maize agriculture on North American sites, and was then expanded to Mesoamerica (Tykot 2006).

This paper presents the results of an isotope and osseological study of human remains from burials of different status at the site of Chinikihá in Mexico during the Late Classic (AD 650–850). This research aimed to: 1. explore the variability of health and diet of the inhabitants of Chinikihá; 2. examine whether an increased dependency on maize can be detected by examining diets of people from different burial status contexts; 3. explore the relationship between status of human burials on the basis of maize and meat consumption, and the contribution of maize and animal meat to their diet. We also assess the extent to which the δ¹³C isotope signature in human burials comes from direct plant consumption or through the consumption of herbivore animals being fed on maize.

Mesoamerican isotope studies

Isotope analyses have been widely used in the Maya region to determine the proportion of C4 plants in
human and animal diets. These studies have also been important in shedding light on the timing of maize domestication and the importance of this species as an economic crop for humans and animals (DeNiro and Epstein 1981). Understanding the scale and scope of maize consumption may also provide insights to a phenomenon referred to as the ‘Maya-collapse’ (Culbert 1988; Hooton 1940; Santley et al. 1986), which occurred during the Late Classic Period (AD 650–850) and has been the main focus of several isotope analyses (Wright 1994; Wright and White 1996; Emery 1997; 1999). Furthermore, δ13C and δ15N isotopes were used not only to undertake the study of maize consumption, but also to explore variations in human and animal diet through time (covering different time periods, from the Preclassic to the Postclassic and Early Colonial (White and Schwarz 1989; Emery et al. 2000; Gerry 1993; Tykot et al. 1996)), dietary differences based on differences among social classes, age, and sex (Reed 1994; Coyston 1994; Coyston et al. 1999; Gerry 1997), and spatial contexts, e.g. inland and coastal sites (Gerry and Krueger 1997; White 1997; White et al. 2001a; White and Schwarz 1989; Wright 1997; 2003). It has been suggested that chemical analysis of human and faunal remains should reflect changes in diet during the Late Classic period as a consequence of an environmental collapse; however, recent analyses have shown that this may not be as homogeneous as once thought (Emery 2008; 2010; Emery et al. 2000; White et al. 2006). Chiapas (in the south-east area), a key locality in the Maya world, has had little research undertaken on this particular aspect. Any new information produced from isotope studies will be an important contribution to our understanding of maize consumption by humans and animals, particularly in sites occupied during the Late Classic Period in the Maya Lowlands.

Isotope analysis of faunal remains, particularly δ15N, will illustrate differences between aquatic and terrestrial protein (Katzenberg 2000; Wright 1993, 173). On the other hand, δ13C isotope analysis, for example, can be used to document access to maize for specific animal species, resulting in a great variability among different ecological settings and chronological periods (Gerry and Krueger 1997; Tykot 2002; White 1999; Wright 2004). The importance of maize in Mayan society, both as a staple and as a symbol in the Maya ideology, means that a key research question this period is to explore, through analyses of animal diet, whether maize was purposely fed to animals (Emery and Thornton 2008; Emery et al. 2000; White et al. 2001a; 2001b). Parallels have been drawn between pathologies associated with a high consumption of carbohydrates — especially maize — and these events. It is argued that there was a disproportionate population growth that resulted in vast deforestation and an increase in cultivated land. An increase in erosion resulted in a corresponding reduction in the availability of food for large prey animals on which humans relied. The increased dependency on a few resources had a negative impact on health and nutrition of the population (Haviland 1967; Hooton 1940; Saull 1972; Wright 2006). An increase in maize dependence has been observed during the Classic period (e. AD 250–900), but how this development correlates to impacts on animal populations is not clear.

Plant and animal resource use in the Maya region

The Lowland Maya exploited a wide variety of plants and animals from different ecotones, including domesticated and wild species. Among the plants, maize was, and still is considered the basis of the diet. Other plants that were consumed include frijol (Phaseolus vulgaris Linnaeus 1753), chilli (Capsicum annuum Linnaeus 1753), ramón (Brosimum alicastrum Sw), and several wild plants used for medicinal and seasoning (Sharer 1994). Like the rest of Mesoamerica, the Maya did not have a wide array of domesticated animals. During the Preclassic and Early Classic period, the Mayas depended heavily on terrestrial wild species, but also on the dog (Canis familiaris Linnaeus 1758), one of the few domesticated animals in the area (Shaw 1991; Wing 1978). In addition, riverside and coastal resources were exploited when possible, including freshwater turtles and snails (Healy et al. 1990; Nations and Nigh 1980). Although there is great intra-site and temporal variability, it is clear that the Maya elite in general had access to meat, which was used for political and social reasons (Emery 2004). During the Late Classic, men from the elite seemed to have a greater access to exotic species or better meat cuts (Whittington 1999), probably because men were more often engaging in ritual ceremonies than women or lower-class members of society (White et al. 2006).

Stable isotope: theoretical background

As a consequence of physiological processes such as metabolism, what is eaten is not reflected by a one-to-one relationship in the consumer’s remains, rather ‘you are what you eat, plus an isotopic offset (fractionalization)’ (Schwarcz 2006, 316). Some
dietary constituents may be preferentially ‘routed’ to particular organs or tissues (Schwarcz 1991), resulting in a heterogeneous internal distribution of the stable isotopic signal acquired from the food intake. Thus, the constant relationship between diet and tissue (δ\text{at}) for every tissue needs to be calculated. However, because in the archaeological record, bone is the only organic tissue that survives in many cases, it is just the diet to bone fractionalisation that is relevant.

Isotopic indexes are measured through mass spectrometry, and are compared against a universal standard that possesses a known value. For carbon, this is relative to the VPDB standard (Vienna PeeDee formation, a marine fossil limestone from South Carolina from a geological formation known as Belenitella Americana), for nitrogen it is AIR (atmospheric N2), and for oxygen, the standards are VPDB and VSMOW (Vienna Standard Mean Ocean Water) (Craig 1957; Coplen 1994; Gerry 1997, 42, fn. p. 1; Larsen 1997, 271). The relative abundance of isotopes is expressed in parts per thousand, commonly denominated ‘permil’ (‰); the index is expressed as δ\text{13C} and δ\text{15N}, etc., where the value of δ is calculated with the following formula:

\[
\delta(\%) = \frac{[R(\text{sample}) - R(\text{standard})]}{R(\text{standard})} \times 1000
\]

where R = \text{13C}/\text{12C}, and \text{15N}/\text{14N} (Craig 1953). VPDB has an established value of δ as 0‰, which works as a reference point for all the samples of unknown value (Gerry 1997).

Plant consumption provides the pathways for C and N isotopes into the bone (Hedges et al. 2006). Therefore, δ\text{13C} isotope results arising from the consumption of plants will be dependent on photosynthetic pathways, whether C3 (Calvin-Benson) C4 (Hatch-Slack), or CAM (crassulacean acid metabolism) species are consumed (Larsen 1997, 271). The average δ\text{13C} for C3 plants is -26‰, while for C4 plants it is -13-0‰ (Deines 1980). Perhaps the only CAM plants consumed by the Maya were the nopal cactus (Opuntia), pinuila (Bromelia karatas Linnaeus 1753), and pineapple (Ananas cosmosus Linnaeus 1753), but these are not considered to contribute significantly to diet (White et al. 2001a, 373; White et al. 2004, 146). In the Maya area, C3 plants include root crops, legumes, vegetables, nuts, and most fruits; C4 plants include maize, amaranths, chenopods, and other tropical grasses (Emery et al. 2000).

Carbon from plants undergoes fractionation from the diet to the consumer, and it is absorbed differentially among different body tissues (DeNiro and Epstein 1978; 1981; Tieszen et al. 1983). The values for δ\text{13C} of bone collagen (δ\text{13C}\text{col}) are generally accepted as being 5-0‰ higher than those from the diet (Ambrose 1993; van der Merwe and Vogel 1978); and, in terms of identifying maize consumption, it has been shown that δ\text{13C}\text{col} is a good reflection of this dietary component (Coyston et al. 1999, 225). A pure C3 feeder will have a δ\text{13C}\text{col} value of -21-5‰, while a strict C4 diet will be δ\text{13C}\text{col} ratio of -7-5‰ (Gerry and Krueger 1997, 197). A diet which consists of both C3 and C4 plants will produce intermediate values between these two extremes (Gerry and Krueger 1997, 197). However, the 5-0‰ enrichment works well only with agriculturalist societies (Gerry and Krueger 1997), where protein sources are limited. In contrast, wild animals (carnivores and herbivores) and non-agriculturalist societies will obtain protein from different sources, and/or experience secondary fractionation, thus producing a higher variability (White et al. 2001a, 374–75; Lee-Thorp et al. 1989). However, nitrogen also has a constant offset of -4‰ between diet and δ\text{15N} from collagen (δ\text{15N}\text{coll}) (Schwarcz et al. 1985, 189).

Four values are necessary to assess whether δ\text{13C} reflects direct maize consumption or is a result of the consumption of herbivore fauna fed with maize: the δ\text{15N} value, the values from δ\text{13C} from both collagen (δ\text{13C}\text{coll}) and apatite or structural carbonate (δ\text{13C}\text{sc}), and the relationship between the collagen and the apatite, commonly expressed as the ‘spacing’ between collagen and apatite, or \text{13C}\text{sc-col}. The ‘spacing’ is also used to determine the relative importance of meat in the diet (Krueger and Sullivan 1984; Lee-Thorp et al. 1989), and the relationship between a carnivore and a herbivore diet. The agreed values for this ‘spacing’ are larger among herbivores than among carnivorous species, averaging \text{13C}\text{sc-col}=7‰ for herbivores, 5‰ for omnivores, and 3-4‰ for carnivores (Krueger and Sullivan 1984; Lee-Thorp et al. 1989).

Traditionally, \text{13C}\text{sc-col} has been calculated using bone collagen and bone apatite to source protein (Krueger and Sullivan 1984; Lee-Thorp et al. 1989) because it has been shown that the carbon and nitrogen isotopic composition of dentine and enamel undergo very little change through life (Wright and Schwarcz 1999, 1160). In the present analysis, we used dentine collagen and apatite from enamel to reconstruct the protein intake.

The combined use of collagen and apatite data will avoid over-estimating protein intake in diet (Tykot
The $\delta^{13}C$ values from collagen are determined by the protein from plant resources, and reflect the protein component of the diet. On the other hand, $\delta^{13}C$ from the apatite will reflect the total diet (Ambrose and Norr 1993; Tieszen and Fagre 1993; White et al. 2006, 14). In addition, $\delta^{15}N$ isotope may also assist in identifying direct maize and/or maize-fed animals, as well as marine/freshwater resources, as the values of $\delta^{15}N$ vary according to the source of protein and the trophic level of the food source, which increases 3–4% in herbivores where they are in the lowest range (4–8%), followed by omnivorous animals (9–12%), with carnivores at the top ($\geq13\%$) (Schwarcz 2006, 316; DeNiro and Epstein 1981; Schwarcz and Schoeninger 1991). Although fish and molluscs remain occur with relatively low frequency in archaeological sites of this period, it is likely that the Maya had access to these resources. However, values for such foods can mimic those given by a high intake of maize, namely high $\delta^{13}C$ values. The use of $\delta^{15}N$ to differentiate between a high intake of maize or seafood is thus vital: the consumption of fish will give a high $\delta^{13}C$ with a high $\delta^{15}N$ (DeNiro and Walker 1986) — marine creatures follow a different pattern in photosynthesis, with more trophic levels, and hence marine resources will range from $12\%$ to $20\%$ (Gerry and Krueger 1997, 199). In the Maya area, some terrestrial herbivore values have $\delta^{15}N$ that overlap those from reef fish, with values just under 10% (White et al. 2001a, 375). Finally, C3 non-legume plants average 9%, while legumes are around 1% (Whittington and Reed 1999, 159). In general, reef fish will have lower values than those of freshwater fish, which in turn will be slightly higher in $\delta^{15}N$ (Keegan and DeNiro 1988; Katzenberg 2008, 426). However, distinguishing between marine and freshwater food sources by $\delta^{15}N$ may be impossible (Schoeninger et al. 1983, 1382). Furthermore, trophic levels can be affected by many other factors including climate, physiology and pathological conditions (Heaton et al. 1986; Katzenberg and Lovell 1999). These factors mean...
that interpretation of isotope values should be undertaken together with projected food webs for each site considered (e.g. Fig. 1).

Site setting: Chinikihá

The archaeological site of Chinikihá is located in the southern part of the estate of Chiapas in southern Mexico. It is located near the Usumacinta River in the ecological region known as the Lowlands, and is just situated 40 km south-east of the archaeological site of Palenque (Fig. 2). Chinikihá has been known since the end of the 19th century. Excavations were first undertaken in 2008, as part of the Proyecto Arqueológico Chinikihá, directed by Dr Rodrigo Liendo from Universidad Nacional Autónoma de México (UNAM). Chinikihá possesses a great diversity of architectural structures, including a variety of civic-ceremonial structures, such as plazas, a palace and a ball court. All of these elements characterise what Liendo Stuardo (2005a; 2007) has defined as Category I sites, despite the differences in size and construction among different settlements.

Under this typology, Chinikihá is classified as a Category 1 site, with other sites in the region, including the megalopolis of Palenque. Chinikihá was at one time an independent centre that ruled over...
a vast region. With the emergence of a ruling dynasty in Palenque, and an unprecedented increase in population in the area during the Classic Period, the political structures among local hierarchies in the region may have changed through exchange, war, marriage, and royal visits (Liendo Stuardo 2005b; Mathews 1991; Schele and Mathews 1991).

An intensive mapping programme in Chinikihá (Liendo Stuardo 2007; 2009) revealed the presence of a civic-ceremonial core that includes a palatial structure, a ball court and other structures presumably of administrative character. This nucleus is surrounded by several hundred of smaller domestic platforms, some of them arranged around inner patios or plazas (Liendo Stuardo 2009). An excavation programme was undertaken by Rodrigo Liendo Stuardo from 2006 onwards, including test pits and some more extensive excavations, denominated ‘operaciones’ in the following.

Excavations at Chinikihá

Excavations have primarily focused on two main areas inside the site’s monumental core: a residential area, North Structure Complex, located in Sector F (Operaciones 111 and 112), and a refuse context behind the Palace (Operación 114) (Fig. 3). The North Structure Complex is an area formed by four

Figure 3 Distribution of Operaciones 111, 112 (North Structure Complex), and Operación 114 (midden behind the Palace) at Chinikihá’s core area (modified from Liendo 2009:11, fig. 3)
buildings making a rectangle around an internal patio. A total of six graves with nine bodies were discovered in the North Structure Complex, with two individual and two collective graves found inside the patio (Operacion 112). Outside the building complex (Operacion 111), only two individual graves were found. The burial sample includes young and mature adults (females and males), and one infant.

All individuals were oriented to the south, and most were in an extended position, except for two that were flexed. The burials inside the patio presented more elaborate graves, in contrast to the simpler ones located outside the North Structure Complex. Several burials (two adult males and one adult female) had a Balunte monochrome vessel as a mortuary offering and could therefore be identified as belonging to the Balunte phase (AD 750–850) (Table 1).

The second area of study is a midden located behind the Palace (Operacion 114), which is c. 4 m x c. 3 m in size. The midden contains thousands of fragmented animal bones, shell, and ceramic fragments mixed with hundreds of obsidian blades, and other lithic finds. No direct radiocarbon dating of the bones has been undertaken, but the ceramic analysis indicates that this deposit was formed during the Murciélagos and Balunte phases (AD 650–850) (Jiménez Álvarez 2009), which has been interpreted to indicate an intensive occupation during the Late and Terminal Classic Period (AD 750–950).

The most common prey animal found in the midden analysis is the white-tailed deer (*Odocoileus virginianus* Zimmerman 1780), contrasting with the nearby site of Palenque, where there was a preference for freshwater turtles (Montero López 2008; López Bravo 2006). However, other species were present at Chinikihá, such as the domestic dog, two varieties of rabbit (*Sylvilagus brasiliensis* Linnaeus 1758) and *Sylvilagus floridanus* Allen 1890), and collared peccary (*Pecari tajacu* Linnaeus 1758), which were available and could also have been consumed. More than 80% of these remains exhibit cut marks, changes in colour due to fire exposure and fracture patterns among other taphonomic modifications that result primarily from the extraction of soft tissue and butchering for human consumption (Lyman 1994; Reitz and Wing 1999).

Other fauna including jaguar (*Panthera onca* Linnaeus 1758), freshwater turtles (*Kinosternon* sp. Gray 1831 and *Dermatemys mawii* Gray 1847), and a variety of small mammals are also present, but they usually do not present human modifications at all, or the modifications differ from those of consumption. Therefore, these species have been either considered intrusive or the result of bone tool production and ornaments, and are not considered in this article. Nonetheless, all these animals represent a variety of ecotones that reflect the wide catchment area that was exploited by the inhabitants of Chinikihá.

At least 70 isolated human bones were also found in this context, commingled with the animal remains and presenting similar modifications to those found on the faunal assemblage; these include 'greenstick'

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**Table 1** Summary of burial identification at Chinikihá (modified from Liendo 2009:210-211, Table 1), where x = presence of pathology

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<tr>
<td>CM13</td>
<td>40</td>
<td>2</td>
<td>A</td>
<td>Individual</td>
<td>Primary</td>
<td>112 Inner Patio, Behind North Str.</td>
<td>25–29</td>
<td>F filing</td>
<td>jade bead, n/a</td>
<td>x, x</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>n/a</td>
<td>41</td>
<td>3</td>
<td>A</td>
<td>Individual</td>
<td>111 Behind North Str.</td>
<td>3–5</td>
<td>n/a no</td>
<td>n/a no</td>
<td>x, no</td>
<td>x</td>
<td></td>
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<tr>
<td>CM14</td>
<td>42</td>
<td>4</td>
<td>A</td>
<td>Collective</td>
<td>Primary</td>
<td>112 Inner Patio, Behind North Str.</td>
<td>35–39</td>
<td>M filing</td>
<td>incised vessel, no</td>
<td>x, x, x</td>
<td></td>
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</tr>
<tr>
<td>CM15</td>
<td>42</td>
<td>4</td>
<td>B</td>
<td>Collective</td>
<td>Secondary</td>
<td>112 Inner Patio</td>
<td>40–44</td>
<td>M filing/incrust.</td>
<td>no no</td>
<td>x, x, x</td>
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<td>CM16</td>
<td>42</td>
<td>4</td>
<td>C</td>
<td>Collective</td>
<td>Secondary</td>
<td>112 Inner Patio</td>
<td>40–44</td>
<td>M filing/incrust.</td>
<td>no no</td>
<td>x, x, x</td>
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<tr>
<td>CM17</td>
<td>43</td>
<td>5</td>
<td>A</td>
<td>Individual</td>
<td>Primary</td>
<td>111 Behind North Str.</td>
<td>medium adult</td>
<td>F no</td>
<td>no no</td>
<td>x, x, x</td>
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<td></td>
<td>n/a</td>
<td>44</td>
<td>6</td>
<td>A</td>
<td>Collective</td>
<td>112 Inner Patio</td>
<td>34–39</td>
<td>F filing</td>
<td>incised vessel, no</td>
<td>x, x, x</td>
<td></td>
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<tr>
<td>CM18</td>
<td>44</td>
<td>6</td>
<td>B</td>
<td>Collective</td>
<td>Secondary</td>
<td>112 Inner Patio</td>
<td>mature adult</td>
<td>M filing/incrust.</td>
<td>no no</td>
<td>x, x, x</td>
<td></td>
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<tr>
<td>CM19</td>
<td>45</td>
<td>7</td>
<td>A</td>
<td>Individual</td>
<td>Primary</td>
<td>112 Inner Patio</td>
<td>34–39</td>
<td>F no</td>
<td>plain vessel, no</td>
<td>x, x, x</td>
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We measured the fractures, cut marks, and heat exposure, as the result of skinning and butchering. This suggests a similar treatment to the animal bones, and therefore sacrifice and cannibalism may have been practised here. It is likely that the accumulation resulted from a ritual or feasting event that primarily involved consuming meat (Montero López 2008), although it is possible that the human bones were cleaned for the purpose of tool manufacturing (Medina Martín and Sánchez Vargas 2008).

Sample description and methodology
To determine if there were changes in maize and animal protein access at the Late Classic site of Chinikihá, a combined methodology was considered which included visual inspection of the skeletal remains for nutritional pathologies and stable isotope analysis.

Osteological analysis
Bioarchaeological and mortuary patterning was analysed by Luis Núñez from the Archaeology Program at Instituto de Investigaciones Antropológicas (IIA, UNAM-Mexico), who inspected all eight burials from the North Structure Complex. Age, sex, location, body position and presence of associated items were registered for each individual. Presence of specific markers denoting dietary pathologies and trauma were also recorded.

Isotope analysis
We measured the $\delta^{13}C$ and $\delta^{15}N$ values for eight human samples excavated by the Proyecto Arqueológico Chinikihá (Liendo 2009). Only seven out of nine burials from the North Structure Complex were sampled for isotope analysis, excluding the only infant (Elem. 41-3), and a female adult from the inner patio (Elem. 44-6A), due to poor preservation. These were selected by age, with no sub-adults sampled. Of the human remains recovered from the midden behind the Palace (Operación 114), only one mandible, from an adult male, was sampled for isotope analyses.

All samples were processed at the Laboratorio de Isótopos Estables, at the Instituto de Geología from the Universidad Nacional Autónoma de México, in Mexico City. For comparative purposes, a baseline of normal conditions (plants and animals) and five modern specimens (plants and animals) were used for the analysis. This had a precision of 0.2%. The resulting liquid then decanted (neutralising the base before discarding). This was then rinsed in approximately 20 mL of distilled water. The resulting water samples from nearby streams. These data were then used to create a model for diet at Chinikihá, taking into consideration previous studies in the area (Coysont et al. 1999; Scherer et al. 2007; Tykot et al. 1996; White and Schwarcz 1989; White et al. 2001a; Wright 2006) (see Fig. 1).

Collagen
Techniques for the extraction of collagen from long bone and in $\delta^{13}C_{\text{VPDB}}$ and $\delta^{15}N_{\text{AIR}}$ isotope analysis are explained below. Bone collagen samples for $\delta^{13}C$ and $\delta^{15}N$ determination were prepared and analysed following Brock et al. (2007) and Hülls et al. (2007). The values of $\delta^{13}C$ are expressed according to the VPDB standard. A very similar process is carried out for dentine samples, but reagents are usually halved in quantities. All macro-contaminants (roots, leaves) were removed, and the samples were then ultrasonically cleaned in distilled water for 15 minutes. Samples were then brushed clean, and rinsed in distilled water, before drying in a furnace at 60°C for 18 hours. From dry bone, an aliquot between 2-0 and 4-0 g was weighed, and ground in agate mortar and sieved through a mesh (150 microns). In the case of teeth, dentine was separated with a dentist drill from the enamel, leaving the enamel undamaged. The resulting powder was then ground in an agate mortar and sieved through a sieve (150 microns).

Twenty, 20 mL of HCl 0.5 M (pH < 1) was then added to the aliquot for 30 minutes, shaking the container every five minutes, and decanting the liquid. This process was repeated if required. To remove humic acids, 10·0 mL of NaOH 0.1 M was added for 60 minutes, shaking the container every 15 minutes. At the end of this time, the sample was centrifuged for 10 minutes, and the resulting liquid then decanted (neutralising the base before discarding). This was then rinsed in approximately 20 mL of milli-Q water; this was repeated three times.

To dissolve collagen from dentine, 24.0 mL of milli-Q water (adjusting pH to 3 with HCl 0.01 M) was added to the solution, which was then put in a closed tube and heated in a furnace to 80°C for 20 hours. The resulting solution was filtered when wet through a 0.45 microns sieve, and freeze-dried in normal conditions (−52°C, 0.030 mbar) for 12 hours. Finally, 2·0 mg of purified collagen (duplicates) was potted in a 5×9 mm tin capsule.

The obtained samples were then analysed in a Thermo Finnigan Delta Plus XL, with a Dumas elemental analyser attached to the mass spectrometer. This had a precision of 0.2%. The resulting $\delta^{13}C_{\text{VPDB}}$ and $\delta^{15}N_{\text{AIR}}$ values were then normalised according to Coplen (1988), and Coplen et al. (2006). The $\delta^{13}C_{\text{VPDB}}$ analysis for collagen was carried out using the reference laboratory materials NBS 22, IAEA CH6, and IAEA CH7, while $\delta^{15}N_{\text{AIR}}$ for collagen, results were normalised using IAEA N1, USGS 25, and USGS 26 reference materials.
Apatite

The techniques for the extraction of calcium carbonate (CaCO₃) from teeth enamel for δ¹³C isotope analysis are explained below. Sample preparation for δ¹³C in dental enamel was conducted following the methodologies by Koch et al. (1997), and McCrea (1950). Enamel samples were manually cleaned and separated from the dentine with a rotary dental drill. Enamel and dentine samples were obtained from a molar tooth (preferably the second molar (M2), and a sample of cortical bone was removed from the femur of the same individual. Each sample was processed separately and caution was taken to avoid any possible contamination. The enamel was ground in an agate mortar and then sieved through a mesh (150 microns). To remove all organic material, approximately 5·0 mL of H₂O₂ at 30% was added to a minimum of 500 mg of enamel for two hours, shaking the receptacle every 15 minutes. Then the sample was centrifuged for 10 minutes, and the resulting liquid was decanted, and rinsed with distilled water by centrifugation. This was repeated three times. To adsorb exogenous carbonates, the enamel samples were then treated with a 10 mL buffer solution (acetic acid-calcium acetate 1·0 M, pH=4-75), for nine hours. At the end, it was centrifuged for 10 minutes, the liquid was decanted and three more rinses with distilled water by centrifugation was conducted.

Finally, enough pure ethanol was added to cover the enamel, this was then heated at 90°C until total evaporation of the solvent had occurred (approximately 12 hours). The result is a final sample of 9·5 mg purified enamel. To determine δ¹³C from enamel CaCO₃, the techniques proposed by McCrea (1950), and Revez et al. (2001) were followed. Samples were analysed in a Gas Bench attached to a mass spectrometer Thermo Finnigan MAT 253. Apatite isotope analyses used LSVEC, NBS-19, and NBS-18 reference materials.

With this methodology, collagen samples from long bone and dentine, and apatite from teeth enamel were obtained and processed. Unfortunately, extracting apatite from long bones requires another procedure and therefore, was not obtained at this stage.

Limitations

Attempts were made to use cortical bone samples from femur and to use the same tooth in every case, but sometimes this was not possible, due to poor preservation of the skeletal material. In samples CM14 and CM17, only cortical bone was processed, because teeth were not found. In sample CM16, a molar sample was obtained but the cortical bone did not produce enough collagen. In CM18, a cortical sample was obtained from the mandible, since the long bones were poorly preserved. Finally, in the case of the human sampled from the midden (CM11), due to its disarticulated nature, cortical bone was sampled from the mandible, and not from a long bone. Overall, because of the small size in sampling human burials, and considering that data is highly variable, the interpretations offered here are made with caution.

Results

Diagenesis

Isotope results are presented with no correction applied. To assess the integrity of the collagen samples, the C/N ratio was obtained. It has been suggested that the acceptable range of C/N ratios for archaeological samples is between 2·9 and 3·6; this is because the ratio of modern collagen in unburied bone is 3·2 (Ambrose and DeNiro 1986; DeNiro 1985; Katzenberg 2008, 418). More recently, in the Maya area, some authors have suggested ranges of 3·0–3·5 (Wright 1993, 173), and 2·8–3·8 (Emery et al. 2000; Emery and Thornton 2008). For the purpose of this analysis, it was considered that values in the 2·8–3·8 range were suitable for isotope analysis. Only one sample was excluded (CM16 bone collagen), because its values were too high. However, several other samples produced a lower C/N ratio (slightly under 2·8), but with δ¹³C and δ¹⁵N values similar to those from other sites in the Maya area.

The relationship between C/N ratios and δ¹³C for the faunal samples is weak (n=10, r=-0·29428), and the same is true for the human samples (n=8, r=-0·2836). This suggests that there is no significant correlation between the C/N ratios for collagen and the values obtained for δ¹³C/δ¹⁵C isotope analysis, and, therefore, that the samples were not systematically altered by diagenesis.

Osteological analysis

The preliminary osteological analysis suggests that the adult age averaged between 30 to 34 years, with one sub-adult between 3 and 5 years of age (see Liendo 2009 for a detailed description). All the individuals showed periosteal reactions on femora and tibiae, which had resulted from non-specific infections. Other stress marks were also present on teeth and bone, and are characteristic of iron deficiency. Dental pathologies, mainly in the form of enamel hypoplasia, were evident in most of the individuals, except one female found outside the
North Complex Structure (CM17) and one male from the inner patio (CM14), whose teeth could not be recovered. Interestingly, the only infant from the sample presented hypoplasia, suggesting that these individuals were subject to a nutritional stress from a very early age. Furthermore, a diet with a high consumption of carbohydrates was suggested by a high incidence of carious lesions, likely due to a diet dependent on maize. Dental calculus was present among the individuals buried inside the central patio and is associated with a diet high in protein. Bone injuries in the form of porotic hyperostosis and cribra orbitalia on the skull, were observed in the entire sample, except for the infant (Elem. 41-3A). Interestingly, however, the adult male buried individually inside the patio (CM19) did not present any teeth or skull markers that would suggest a period of nutritional arrest during his childhood (see Table 1).

Isotope analysis

A diet entirely based on C4 plants, especially maize, results in isotope values between $\delta^{13}C = -7.5\%$ and $-9.6\%$, while a diet composed of C3 or wild plants is between $-21.5\%$ and $-26\%$ (Emery et al. 2000, 542; Gerry and Krueger 1997, 197). The $\delta^{13}C$ values of all human samples from Chinikihá falls between $-8.15\%$ and $-10.44\%$ (average $-9.55\%$, $\sigma=0.75$) (Table 2). Although there is variation in the consumption of C3 and C4 plants, it is clear that humans were relying heavily on C4 plants (maize), complemented with some C3 plants. These values are similar to those of other Classic sites, including Copán, Caracol, Piedras Negras, and several sites from the Petén area (Reed 1994; Wright 1994; 2003; Chase et al. 2001). However, the consumption of maize was not homogeneous among the sample, with the highest $\delta^{13}C$ value (and therefore the highest consumer of maize) obtained from the individual from the midden (CM11), and the lowest $\delta^{13}C$ value from an adult male buried inside the patio (CM19). The latter individual may have had had access to a wider variety of plants than the rest of the sample.

The source of protein is also reflected by $\delta^{15}N$, with values ranging from 8.43%o to 11.73%, with an average of 9.45%o, ($\sigma=1.044$) (see Table 2). The values obtained for the burials suggest that the protein source for the Chinikihá humans predominately comes from herbivore flesh, with freshwater fish and marine resources eaten infrequently. The $\delta^{15}N$ values from these samples are again similar to those from other sites dating to the Classic Period (Wright 2006). Altogether, $\delta^{13}C$ and $\delta^{15}N$ values fall clearly in the trophic level above a herbivorous diet, i.e. in the omnivorous category (DeNiro and Epstein 1981; Schwarz and Schoeninger 1991). While the $\delta^{13}C$ values show a diet predominantly focused on C4 plants for all samples, the variability in the $\delta^{15}N$ values suggest a larger diversity in protein sources. The ‘spacing’ between $^{13}C_{sc}$ and $^{13}C_{col}$ for enamel and dentine (collagen) suggest a similar trend, with a mean $\Delta^{13}C_{sc-coll}$ value of 6.68%o ($\sigma=1.01$), again, confirming an omnivorous diet (Lee-Thorp et al. 1989). These results will, however, reflect diet during childhood (Wright and Schwarz 1999, 1161), and vary according to the tooth sampled.

Discussion

In general, it would appear that the members of the North Structure Complex were eating more meat from wild herbivorous animals than other species. Thus, although the inhabitants of Chinikihá had access to other species, including other terrestrial

<table>
<thead>
<tr>
<th>Lab code</th>
<th>Bag/ Burial No.</th>
<th>Level/ Individual</th>
<th>Description</th>
<th>Tissue</th>
<th>Collagen $^{15}N_{\text{coll}}$ (%)</th>
<th>Collagen $^{15}C_{\text{coll}}$ (%)</th>
<th>C/N</th>
</tr>
</thead>
<tbody>
<tr>
<td>CM11</td>
<td>833</td>
<td>V</td>
<td>Adult male? (behind Palace)</td>
<td>2M</td>
<td>8.43</td>
<td>-9.40</td>
<td>2.9</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Mandible</td>
<td>8.73</td>
<td>-9.09</td>
<td>3.2</td>
</tr>
<tr>
<td>CM13</td>
<td>40</td>
<td>2</td>
<td>Adult fem. (Inner patio)</td>
<td>3M</td>
<td>8.71</td>
<td>-10.35</td>
<td>2.7</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Femur</td>
<td>8.50</td>
<td>-9.53</td>
<td>2.7</td>
</tr>
<tr>
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<td>42</td>
<td>4A</td>
<td>Adult male (Inner patio)</td>
<td>Femur</td>
<td>8.63</td>
<td>-9.17</td>
<td>2.7</td>
</tr>
<tr>
<td>CM15</td>
<td>42</td>
<td>4B</td>
<td>Adult fem. (Inner patio)</td>
<td>2M</td>
<td>11.73</td>
<td>-8.15</td>
<td>2.6</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Femur</td>
<td>10.45</td>
<td>-9.60</td>
<td>2.7</td>
</tr>
<tr>
<td>CM16</td>
<td>42</td>
<td>4C</td>
<td>Adult male (Inner patio)</td>
<td>1M</td>
<td>10.57</td>
<td>-8.52</td>
<td>2.6</td>
</tr>
<tr>
<td>CM17</td>
<td>42</td>
<td>1</td>
<td>Adult fem. (behind North Structure)</td>
<td>Femur</td>
<td>8.36</td>
<td>-10.44</td>
<td>3.3</td>
</tr>
<tr>
<td>CM18</td>
<td>44</td>
<td>6B</td>
<td>Adult male (Inner patio)</td>
<td>2M</td>
<td>9.90</td>
<td>-9.38</td>
<td>2.9</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Mandible</td>
<td>9.22</td>
<td>-10.34</td>
<td>3.0</td>
</tr>
<tr>
<td>CM19</td>
<td>45</td>
<td>7</td>
<td>Adult male (Inner patio)</td>
<td>Femur</td>
<td>10.15</td>
<td>-10.37</td>
<td>2.8</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1M</td>
<td>11.28</td>
<td>-11.89</td>
<td>2.8</td>
</tr>
</tbody>
</table>
animals, and freshwater turtles and snails, terrestrial game were favoured. This is supported by the preliminary zooarchaeological analyses.

It has been proposed that the ritual consumption of meat occurred during feasting events that biased the consumption of meat towards the elite (Montero López 2009; Yaeger and Robin 2004). This trend cannot be explored at Chinikihá as there are no samples available from lower social strata. However, it is possible to explore dietary diversity among the elite.

The two burials with the lowest \( \delta^{15}N \) value, correlating with a lower consumption of meat, are an adult female located outside the North Structure Complex (CM17), and an adult male from the midden (CM11). The burial with the highest indicated consumption of meat is that of an adult female buried inside the inner patio of the North Structure Complex. This individual had filed teeth with pyrite incrustations (CM15), symbols commonly found among elite burials. One other individual with higher \( \delta^{15}N \) values is an adult male located inside the patio; this individual was buried with a monochrome vessel as an offering (CM19) (Table 3).

While there is no significant difference between females and males for \( \delta^{13}C \) (F=0.143, df 1), and \( \delta^{15}N \) (F=0.784, df 1), the \( \delta^{15}N \) and \( \delta^{13}C \) values for the female burials seem to be less variable than those of the males (Table 2). Interestingly, the \( ^{12}C \) values for the females showed greater variation while the males had a more variable \( ^{13}C \) values. This may suggest that the C4 intake by women was more stable that among the males. Meat may have been consumed more sporadically among women, but men had more access to animal protein.

Gender-based differences appear to be significant during the Classic Period in larger and densely populated sites, such as Copan (Reed 1994, 216; Whittington 1999; White et al. 2006). These differences are not exclusive to high-status individuals, but are also present among low-class burials and indicate that men were having more access to exotic or sparse resources, such as meat (Whittington 1999) or maize in places where it is difficult to obtain (Hammond 1999, 94). It has been suggested that men consumed maize as a beverage during the Preclassic, and later throughout the Classic Period, regardless of a sites’ location (Tykot et al. 1996; Whittington and Reed 1999, 163). Christine White and colleagues (2006, 153), have argued that this is because men were engaging more often in ritual ceremonies which included the consumption of meat and maize, although participation of women in ritual activities may vary temporally and/or regionally (White 2005, 360). In short, women may not have been able to consume many of the foods that had an ideological value (White et al. 2006, 152).

Although the human sample from Chinikihá is small, there are individuals represented from three different locations: seven burials from the inner patio in a domestic compound, two burials outside the same compound, and human remains from behind the Palace. The human sample from Chinikihá is homogeneous and corresponds with the results from other Late Classic sites. However, two samples in particular are worth discussing further. Burial 45-7 (CM19), an adult male buried inside the patio and with a monochrome vessel as an offering, had one of the lowest values of \( \delta^{13}C \) (-10.37%), and one of the highest values of \( \delta^{15}N \) (10.15%). These results

Table 3 Distribution of \( \delta^{15}N \) and \( \delta^{13}C \) by location

<table>
<thead>
<tr>
<th>Location</th>
<th>Type</th>
<th>Sample Size</th>
<th>( \delta^{15}N_{AIR} ) (%)</th>
<th>( \delta^{13}C_{VPDB} ) (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inner patio north structure</td>
<td>Bone</td>
<td>6</td>
<td>9.22</td>
<td>-9.94</td>
</tr>
<tr>
<td></td>
<td>Teeth</td>
<td>4</td>
<td>10.23</td>
<td>-9.10</td>
</tr>
<tr>
<td>Behind north structure</td>
<td>Bone</td>
<td>1</td>
<td>8.36</td>
<td>-10.44</td>
</tr>
<tr>
<td></td>
<td>Teeth</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Behind palace</td>
<td>Bone</td>
<td>1</td>
<td>8.73</td>
<td>-9.09</td>
</tr>
<tr>
<td></td>
<td>Teeth</td>
<td>1</td>
<td>8.43</td>
<td>-9.4</td>
</tr>
</tbody>
</table>

Table 4 Distribution of \( \delta^{15}N \) and \( \delta^{13}C \) by sex

<table>
<thead>
<tr>
<th>Sex</th>
<th>Type</th>
<th>Sample Size</th>
<th>( \delta^{15}N_{AIR} ) (%)</th>
<th>( \delta^{13}C_{VPDB} ) (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Male burials</td>
<td>Bone</td>
<td>4</td>
<td>9.18</td>
<td>-9.74</td>
</tr>
<tr>
<td></td>
<td>Teeth</td>
<td>3</td>
<td>9.63</td>
<td>-9.10</td>
</tr>
<tr>
<td>Female burials</td>
<td>Bone</td>
<td>3</td>
<td>9.10</td>
<td>-9.92</td>
</tr>
<tr>
<td></td>
<td>Teeth</td>
<td>2</td>
<td>10.22</td>
<td>-9.25</td>
</tr>
</tbody>
</table>
indicate that, although his diet was based primarily on maize, he also had access to a variety of wild plants. Furthermore, his diet was complemented by a greater access to wild meat than that of the rest of the sample. While the rest of the individuals buried inside the patio had a greater access to animal protein, the intake of this individual was the largest. This individual also registered less stress indicators as result of a poor diet, with no dental pathologies or anaemia markers — including cribra orbitalia, and porotic hyperostosis — as did the rest of the burials from the inner patio.

On the other hand, the human sample obtained from the midden behind the palace (CM11) had the lowest value for meat consumption ($\delta^{15}N_{AIR}=8.43\%$) and the highest for maize consumption ($\delta^{13}C_{VPDB}=-9.09\%$). This mandible presented dental diseases that included an abscess and tooth loss of M2, as well as curios lesions and an occlusal-wear pattern that is consistent with a diet rich in carbohydrates. It would appear that location and wealth of the burials, combined with data from their diet, can inform us of the general status of the individuals.

Furthermore, even though the diet was rich in carbohydrates, the health of the inhabitants of Chinikihá seems to have been better than that of other larger sites, such as Copán (Reed 1994) (Table 5). It seems that some settlements were more affected by a restricted access to plant and animal resources. However, the answer is not straightforward and may be a combination of different factors. This study contributes to the growing literature of isotope analysis in the Maya area, and helps to understand the similarities and differences in resource access during the Late Classic.

### Conclusions

Nine human samples were chemically analysed ($\delta^{13}C$ and $\delta^{15}N$) in order to assess their diet, and access to maize and animal protein at Chinikihá. These results were then contrasted with a visual inspection of the remains in order to assess the presence of palaeopathologies due to nutritional arrest. It was observed that the individuals buried in the inner patio of the upper elite North Structure Complex possessed in general a better diet, and,

<table>
<thead>
<tr>
<th>SITE</th>
<th>PRECLASSIC</th>
<th>CLASSIC</th>
<th>POSCLASSIC</th>
<th>CONTEXT</th>
<th>REFERENCES</th>
</tr>
</thead>
<tbody>
<tr>
<td>Copan</td>
<td>(n=48)</td>
<td>$^{13}C=-9.26$</td>
<td>$^{15}N=7.56$</td>
<td></td>
<td>Reed 1994</td>
</tr>
<tr>
<td>Cuello</td>
<td>(n=28)</td>
<td>$^{13}C=-12.9$</td>
<td>$^{15}N=8.9$</td>
<td></td>
<td>Tykot et al. 1996; Van der Merwe et al. 2000:29, table 2.1</td>
</tr>
<tr>
<td>Lamanai</td>
<td>(n=3)</td>
<td>$^{13}C=-12.4$</td>
<td>$^{15}N=10.2$</td>
<td>Burials at ceremonial core</td>
<td>White 1996; White and Schwartz 1989</td>
</tr>
<tr>
<td>Kaminaljuyu</td>
<td>(n=6)</td>
<td>$^{13}C=-9.8$</td>
<td>$^{15}N=7.2$</td>
<td>Tombs at ceremonial core</td>
<td>Wright and Schwartz 1999:1162</td>
</tr>
<tr>
<td>Chinikihá</td>
<td>(n=1)</td>
<td>$^{13}C=-9.09$</td>
<td>$^{15}N=8.73$</td>
<td>Scattered human remains behind Palace</td>
<td>This study</td>
</tr>
<tr>
<td>Chinikihá</td>
<td>(n=6)</td>
<td>$^{13}C=-9.09$</td>
<td>$^{15}N=9.21$</td>
<td>Burials assoc. to North Structure</td>
<td>This study</td>
</tr>
<tr>
<td>Yaxuna</td>
<td>(n=3)</td>
<td>$^{13}C=-12.3$</td>
<td>$^{15}N=7.1$</td>
<td></td>
<td>Mansell et al. 2006:175</td>
</tr>
<tr>
<td>Chunchucmil</td>
<td>(n=3)</td>
<td>$^{13}C=-14.7$</td>
<td>$^{15}N=7.0$</td>
<td></td>
<td>Mansell et al. 2006:175</td>
</tr>
<tr>
<td>Mayapan</td>
<td>(n=34)</td>
<td>$^{13}C=9.0$ to $12$</td>
<td>$^{15}N=7.0$ to $7.5$</td>
<td>'Royal' and 'Elite' burials</td>
<td>Wright 2009</td>
</tr>
<tr>
<td>Piedras Negras</td>
<td>(n=7)</td>
<td>$^{13}C=-9.0$ to $-8.1$</td>
<td>$^{15}N=7.6$ to $9.8$</td>
<td>'Royal' and 'Elite' burials</td>
<td>Scherer et al. 2007:92</td>
</tr>
<tr>
<td>Altun Ha</td>
<td>(n=34)</td>
<td>$^{13}C=-11.76$</td>
<td>$^{15}N=10.69$</td>
<td></td>
<td>White et al. 2001a:377, table 1</td>
</tr>
</tbody>
</table>
although maize was the base of their diet, they had access to a wide range of other wild plants. Animal protein, primarily in the form of white-tailed deer, probably was more restricted to the male members of the Complex, but females could have had sporadic access to this and other sources of meat. In contrast, a human sample recovered from a midden behind the palace resulted in the highest consumption of maize with the lowest consumption of animal protein, suggesting differences in diet among the different social strata. The results from Chinikihá are similar to those obtained for other sites during the Late Classic period, and support that during this period of time, the consumption of maize and animal protein remained constant.

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