

Stable Isotopes and Maize Consumption in Central Western Argentina

A. F. GIL,^{a*} G. A. NEME,^a R. H. TYKOT,^b P. NOVELLINO,^a
V. CORTEGOSO^c AND V. DURÁN^c

^a *Departamento de Antropología, Museo de Historia Natural, Parque Mariano Moreno, (5600) San Rafael, Argentina*

^b *Department of Anthropology, University of South Florida, Tampa, Florida, USA*

^c *Facultad de Filosofía y Letras, Universidad Nacional de Cuyo, Parque General San Martín, Mendoza, Argentina*

ABSTRACT In this paper we present stable isotope information ($\delta^{13}\text{C}$ in bone collagen and apatite, and $\delta^{15}\text{N}$) in order to discuss the significance of maize consumption in the human diets of central western Argentina. We also contribute bioanthropological information based on the study of caries, hypoplasia, *cribra orbitalia* and dental abscess frequencies. This study shows a large variability in the significance of C_4 resources (e.g. maize) during the last 2500 years, and on this basis we propose that maize was significant in the human diet mainly after 1000 yrs BP. Copyright © 2009 John Wiley & Sons, Ltd.

Key words: maize consumption; human diet; stable isotopes; agriculture transition

Introduction

The incorporation of maize (*Zea mays*) in human life is a central theme in American prehistory (Pearsall, 1994; Staller *et al.*, 2006). Classically assumed as the most important product in the diet of farming populations, this conception has recently been changing (Barlow, 2006; Greenlee 2006; Winterhalder & Kennett, 2006). But to understand the chronology of its incorporation and dietary changes through time, we need significant information regarding the spread of farming and its role in human organisation (Staller *et al.*, 2006). This paper presents an approach to understanding this process using new stable isotope analyses and bioarchaeological

information from central western Argentina. This region has classically been considered as the southernmost cultural area with evidence of farming in the Americas (García, 1992; Pearsall, 1992; Lagiglia, 1999; Novellino *et al.*, 2004; Gil *et al.*, 2006; Chiavazza & Mafferra, 2007). Indeed, there is good preservation of the biological record, but few attempts have been made to understand the variability of subsistence in relation to cultural change.

In general, culture history has been the theoretical perspective applied to understand the variability in ceramic styles, while subsistence has been considered as basically 'static punctuated' with abrupt changes (e.g. presence/absence of cultigens). Nevertheless, an analysis of the variation present in the archaeological record is a necessary step to understanding human organisation and system change. In this paper we present the results of stable isotope analyses of collagen

* Correspondence to: Museo de Historia Natural de San Rafael, Departamento de Antropología, Parque Mariano Moreno, (5600) San Rafael, Argentina.
e-mail: afgil1@infovia.com.ar

and apatite from archaeological human bones and from food resources in order to understand variation in human diet during the last 2500 years. This information is considered together with preliminary trends in the associated bioarchaeological record. Finally, the results are discussed in order to understand the meaning of this information in terms of human organisation. The aim is to improve our understanding of the introduction of corn in the human diet and its role in the human history in the southern boundary of farming in the Americas. Similar stable isotope research has recently been done in neighbouring regions that are significant for the present study, including the southern part of Mendoza (Gil, 2003; Gil *et al.*, 2006), San Juan, located to the north of Mendoza, and central Chile (Falabella *et al.*, 2007, 2008).

Stable isotope data, bioarchaeological information, and maize consumption

The origin and dispersal of farming has been classically studied (Smith, 2001; Zeder *et al.*, 2006) and different research strategies have been used (Hard *et al.*, 1996; Staller *et al.*, 2006; Zeder *et al.*, 2006); different theoretical focuses have also been employed (Hastorf & Johannessen, 1994; Kennett & Winterhalder, 2006; Smith, 2006). In the present paper an approach to human diet and the incorporation of maize is focused on the analysis of stable isotopes, and preliminary bioarchaeological data from the human archaeological population are also used. Both lines of research have strongly developed in the last 20 years and have shown their potential to address this topic.

The inorganic and organic chemical constituents of bone provide a long-term record of dietary intake. The chemical composition of human bone can be used to investigate prehistoric access to food. The study of palaeodiet through stable isotope analysis proceeds from the experimental observation that the isotopic composition of animal tissues generally reflects their diet (Schwarcz & Schoeninger, 1991; Ambrose & Krigbaum, 2003). Such analyses utilise the

variation in the ratios of the stable isotopes of carbon and nitrogen within ecosystems to measure the relative contribution of different resources to animals' diets (DeNiro & Epstein, 1978). Since some foods, such as maize, have distinctive isotopic signatures, it is often possible to identify their consumers (Norr, 1995). The stable isotopes of carbon (^{13}C and ^{12}C) and nitrogen (^{15}N and ^{14}N) are expressed in per mil (‰) as δ values:

$$\delta = [(R_{\text{sample}}/R_{\text{standard}}) - 1] \times 1000$$

where $R = ^{13}\text{C}/^{12}\text{C}$ for the measurement of carbon and $^{15}\text{N}/^{14}\text{N}$ for the measurement of nitrogen. The standards to which samples are compared are the limestone Vienna PeeDee Belemnite (VPDB) and atmospheric nitrogen (AIR) for carbon and nitrogen, respectively. As most materials including plant and animal tissues have less ^{13}C than VPDB, $\delta^{13}\text{C}$ values are typically negative. The overwhelming majority of plants use the Calvin Cycle (C_3) and have tissues with an average $\delta^{13}\text{C}$ value of -26.5‰ . The $\delta^{13}\text{C}$ values of plants relying upon the Hatch-Slack pathway (C_4), mainly tropical grasses, millet and sugarcane, are much higher, averaging -12.5‰ . Plants utilising a third pathway, Crassulacean acid metabolism (CAM), have $\delta^{13}\text{C}$ values ranging from -27 to -12‰ . Most CAM plants are succulents and do not constitute staple crops. Controlled feeding studies of laboratory animals reveal that the carbon isotope signature of animal proteins, such as collagen in bone and keratin in hair and nails, predominantly reflects the protein component of diet, as essential amino acids are preferentially routed from diet to be incorporated into body tissue (Lee-Thorp *et al.*, 1989; Ambrose & Norr, 1993; Tieszen & Fagre, 1993). $\delta^{13}\text{C}$ values of the collagen of large herbivores are enriched (more positive) by about 5‰ relative to their dietary average (Lee-Thorp *et al.*, 1989). The collagen of carnivores, in turn, reflects the isotopic signature of the animal protein in their diets, ultimately derived from the plants eaten by primary consumers. The isotopic signature of omnivore collagen represents the contribution of both plant and animal protein to diet.

It is accepted that bone collagen has a slow turnover rate (Ambrose, 1993), so that the isotope results obtained would represent the average diet over at least the last 5–7 years of life. A similar turnover time applies to bone apatite as well. It became clear from studies of animals

raised on controlled diets that bone collagen is produced basically from dietary protein, whereas bone apatite is a product of the whole diet, with the difference between diet and bone apatite estimated at around 9.5‰ (Ambrose & Norr, 1993), while a larger gap of about 12‰ is suggested for humans (Schwarcz, 2006). Taking into consideration the actual state of research, it could be proposed, at least for omnivores, that animal food would make a much greater contribution to bone collagen, at least when meat/fish are more than a minimal part of the overall diet. Non-essential amino acids may be produced from consumed carbohydrates and lipids, as well as proteins, so that overall collagen values may be strongly influenced for agriculturalists highly dependent upon plant products. Differences between individuals in the proportion of maize versus C_3 plants in the diet would be more apparent in apatite than in collagen (Harrison & Katzenberg, 2003). For pure C_3 feeders the collagen value expected is around -21.5‰ , and the apatite value expected around -14.5‰ . For pure C_4 feeders, the collagen value expected is around -7.5‰ , and the apatite value expected is around -0.5‰ , as with maize. Intermediate values are expected for mixed diets (Tykot, 2006).

On the other hand, $\delta^{15}\text{N}$ indicates differences caused by trophic level effects, especially in marine/continental ecosystems (Pate, 1997). Recent studies have shown the effects of climate and environment on both plant and animal $\delta^{15}\text{N}$ values and trophic level increases in both terrestrial and marine ecosystems (Ambrose & De Niro, 1986; Hedges & Reynard, 2006). In any case, the construction of regional isotopic ecology (see below) is a necessary foundation to understanding stable isotope data for humans and their meaning in terms of diet.

It has been shown in different archaeological contexts that there is a relationship between changes in human subsistence and variations in health (Cohen, 1989; Lukacs *et al.*, 2001). Biological information from human remains has the potential to explore indications, usually non-specific, of stress and/or association with changes in human diet and health. It has been demonstrated that a more intensive use of domesticates is associated with an increase in the frequency of

caries (Cohen & Armelagos, 1984). As Lukacs (1989) proposed, shifts in the prevalence of dental diseases and changes in the robusticity of jaws and teeth accompanied a dietary shift from hunting and gathering to intensive agriculture. We apply this biological approach as complementary to the chemical analyses of human bone from the same archaeological contexts. The human samples were studied in order to characterise caries, hypoplasia, *cribra orbitalia* and dental abscess frequencies (see below).

The regional environments

Central western Argentina is a heuristic region included between 30° and 40°S (Novellino *et al.*, 2004; Figure 1). It has significant environmental heterogeneity (Abraham & Rodríguez, 2000). This paper focuses between 30° to 32°S on the Mendoza province which is characterised by the presence of two physical regions with perceptibly different reliefs (Gonzalez Díaz & Fauqué, 1993): a very high mountainous area to the west (*highland*), and a relative flat relief that forms the eastern plains (*lowland* or *oriental plain*).

The study area is located in a temperate zone, a Mediterranean and continental region with an arid to semi-arid climate and average annual precipitation of around 250 mm. It is exposed to the action of the Atlantic anticyclone (piedmont, depressions and oriental plains) and the Pacific Ocean anticyclone (western mountains). From the morphoclimatic perspective, these regions are highly contrasted due to their relief, dominant masses of maritime air, and the season in which precipitation takes place. The humid winds of the Atlantic precipitate scarce humidity for the great distance travelled, while the winds from the Pacific Ocean precipitate at the Andes Mountain Range, entering this region as dry and warm winds (Abraham & Rodríguez, 2000). The oriental plains and the Precordillera range are characterised by summer precipitation, whereas the western mountains have predominantly winter precipitation in the form of snow (Norte, 2000).

The Andes, under the influence of Pacific Ocean anticyclones, belong to the Andean

phytogeographic province; the central and oriental plains, conditioned for the influence of Atlantic anticyclones, are part of the Monte phytogeographic province. The highlands include two vegetation provinces: the Altoandina Province, between 2200 and 4500 m.a.s.l., and the Puneña Province, developed from the north to approximately 32°S (Roig *et al.*, 2000). This environment features scarce vegetation that corresponds basically to xerophilous steppe, low bushes, and grassland (*Stipa* sp.). Characteristic vegetal cover in mountainous environments is composed of small shrubs (*Schinus* sp., *Chacaya trineryis*, *Adesmia* sp.). The *Piedmont fringe* consists of several late Cenozoic alluvial fans and aggradations roughly situated between 1800 and 1000 m.a.s.l., producing a series of gently sloping surfaces where the present fluvial system is degraded. It is the transitional unit between the mountains and the plains and its extension is related to the mass from which it has originated.

The *oriental plain* is an extensive landform situated from 400 to nearly 200 m.a.s.l. The flood plains occupy the greatest extent of the oriental plain; the geographically dominant forms are the several freight forwarders' consequence and sedimentation of the modern or recent deposits. The eolian dynamics have formed important chains of sand dunes; the open forest with *Prosopis*, which formerly covered great areas, is now only in good condition in inaccessible regions (Abraham & Prieto, 1991; Tripaldi & Forman, 2007). The shrub-like steppes that characterise the vegetation of the plains are represented by *Larrea divaricata* and *L. cuneifolia*. The forests are constituted principally by *Prosopis flexuosa*, leguminous shrubs that can reach up to 8–10 m in height (Roig *et al.*, 2000).

The fauna can be divided into two main biogeographical units: 'Fauna de Montaña' and 'Fauna de Llanura'. The first, typical in the highlands, is characterised by the presence of camelids (*Lama guanicoe* and *Lama vicugna vicugna*), carnivores such as the grey fox (*Duscion griseus*) and puma (*Felis concolor*), small rodents, and several birds. The 'Fauna de Llanura', basically in the lowlands, is more diverse, including the previously mentioned species plus other small mammals and large flightless birds like *Pterocnemia pennata* and *Rhea americana*.

Archaeological background

In historical times, the area was occupied by the Huarpes (Michieli, 1983; Prieto, 1997–1998), which have been described as a medium-scale society with a sedentary settlement pattern and a farming economy. Two main changes in human strategies that occurred during the Late Holocene can be described as an 'economic intensification process' and 'incorporation of several domestic plants to subsistence' (Gil, 2006; Neme, 2007). The effective occupation of all the available environments had taken place between 2000 and 1000 years BP (Neme *et al.*, 2005; Cortegoso, 2006; Gil, 2006). A cultural divergence process has been proposed for this date (Novellino *et al.*, 2004), resulting in two different subsistence patterns: the northern area (30°–34°S) was characterised by the presence of farming populations who adopted cultigens already present in northwestern Argentina, like maize, while the southern area (38°–40°S) showed the persistence of societies living on a hunter-gatherer subsistence basis (Gil *et al.*, 2006). A central buffer area has been proposed resulting from a mix of these subsistence strategies (Lagiglia, 1977; Figure 1).

In the regional culture-history the concepts of *agroalfarero*, corresponding to 'Agrelo' (early *agroalfarero*) and 'Viluco' (late *agroalfarero*) cultures respectively, were used to include those village societies developed in north and central Mendoza during the first millennium AD, and the first half of the second, until the arrival of the Incas (Schobinger, 1971; Bárcena, 2001). Those societies had relatively egalitarian social organisation with occupation patterns based on dispersed villages (Durán *et al.*, 2006). They would have had permanent agricultural camps in the valley bottoms of the principal rivers, with seasonal use of highland resources.

The antiquity of maize in central western Argentina is a controversial topic (García, 1992; Bárcena, 2001; Lagiglia, 2001). Bárcena *et al.* (1985; Bárcena, 2001) proposed an early entry of maize at *ca.* 4000 years BP, while other researchers accept a later chronology for this domesticate, at *ca.* 2000 years BP (Lagiglia, 1980, 2001; García, 1992). The direct radiocarbon maize chronology is concordant with this last

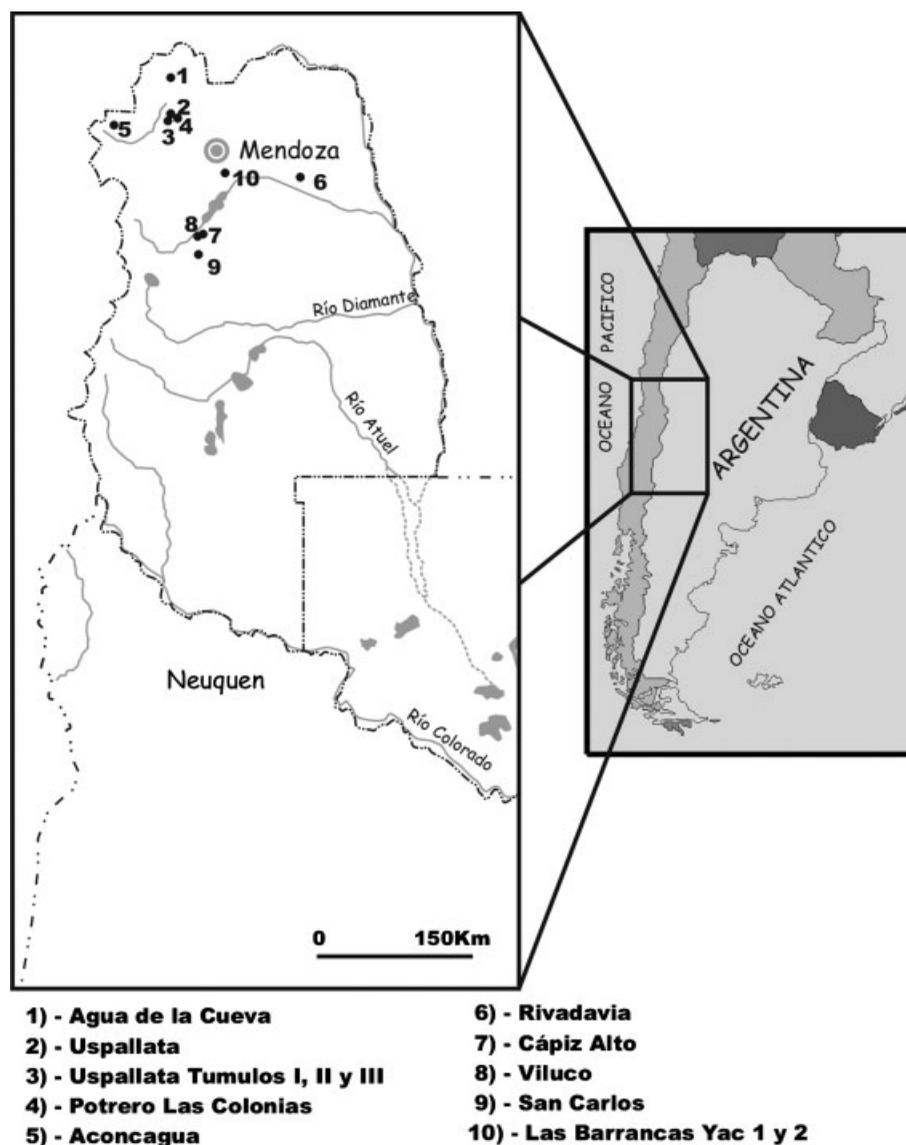


Figure 1. Location of the study area, Argentina.

proposition, but the few *Zea mays* samples directly dated are recorded archaeologically in the southern part of this region (Gil, 2003). In general, the record of domesticates has been interpreted as the consequence of farming society settlement (see details in Gil, 1997–1998), and generally proposed in its first phase as 'incipient farming' (Lagiglia, 1980). Recently, alternative strategies to a hunter-gatherer/farming dichotomy have been proposed, and temporo-spatial variation in corn incorporation and use is starting

to be considered (Gil, 2003; Novellino *et al.*, 2004; Gil *et al.*, 2006).

A similar subsistence practice had been proposed for the entire region during the Agroalfarero period (the last 1000–1500 years). Only recently has variation in subsistence, basically the significance of maize in the diet, been proposed (Gil *et al.*, 2006; Chiavazza & Mafferra, 2007; Johnson *et al.*, 2007), breaking the static vision about human subsistence during the last 2000 years. The incorporation of

domesticates in the diet could have caused a more significant occupation of the valley floors as well as progressive colonisation of lower lands (Gambier, 1976). Around 1000 years BP the archaeological record suggests the beginning of a significant occupation of the mountain valleys and lowlands, with the greater amount of sites in this period in northern Mendoza possibly showing growth in population density (Cortegoso, 2006). Few studies of palaeoethnobotany have been carried out in the region and were basically focused on the highlands (Bárcena & Roig, 1983; Bárcena *et al.*, 1985; Roig & Martínez Carretero, 1991), showing the exploitation of local wild vegetation with some minor presence of cultigens (Bárcena *et al.*, 1985; Roig & Martínez Carretero, 1991: Table 1).

Human archaeological samples

The stable isotopic analysis presented in this paper is based on new information from 18 human samples from 12 archaeological sites, most of which were excavated during the 1950s, including the cases of Aconcagua and Uspallata archaeological sites (Schobinger, 1971, 2001; Bárcena, 1974–1976). We provide a brief overview of available contextual information for these archaeological sites. Although the global sample size is small, it is adequate to present a first analytical step to refine our sampling and our question. Future studies already planned will reject or confirm our preliminary trends and their meaning in terms of dietary stability/change.

The archaeological sites considered in the present study are Viluco (Reed, 1918), San Carlo (Rusconi, 1962), Cápiz Alto (Durán & Novellino, 1999–2000), Barrancas (Rusconi, 1962), Uspallata Túmulo I, II, and III, Potrero Las Colonias (Rusconi, 1962), Uspallata Usina Sur (Schobinger, 1971; Bárcena, 1974–1976), and Aconcagua (Schobinger, 2001).

The Viluco archaeological site is located in the oriental plain (Figure 1) and was discovered by Reed (1918) who excavated an aeolian landform 2 km long, where he found scattered human burials. These burials were found lying on their side, left or right, in a flexed position with the face looking to the east, contained many diverse

associated materials such as textiles, metal objects (tips of spears, silver spoons, rings), pottery, molinos and hand stones, beads of glass, and shells (Rusconi, 1962). After this first research, Lagiglia (1976) conducted an exhaustive analysis of the archaeological pottery, defining the Viluco Culture, which he associated with the historical Huarpes. Recently human samples were dated to *ca.* 200 ¹⁴C years BP (Table 2).

Near Viluco there is another archaeological cemetery named San Carlos. Rusconi (1962) excavated this site near a local pillbox (Figure 1). There appeared human remains belonging to nine individuals attributed by Rusconi to the Pre-Hispanic period, and the remains of a mud wall that he ascribed to the first chapel built by the Jesuits in the region. There is no mention of objects associated with the burials. As part of the present research a human sample was dated to *ca.* 150 ¹⁴C years BP (Table 2). In the same locality there is the Cápiz Alto archaeological site, 14 km NNW of San Carlos (Figure 1), containing 19 human burials dated to the late 16th and 17th centuries (Durán & Novellino, 1999–2000). The type of burial is simple and primary in all cases, and the positions were extended in some cases and flexed in others. Individuals recovered are mostly adult females and children (only two were males). Almost all individuals have an important accompaniment of diverse archaeological materials (Durán & Novellino, 1999–2000). The only human sample dated (Table 2) is not concordant with the cultural context and has been rejected.

The archaeological locality of Maipú Barrancas (Figure 1) includes the archaeological sites Yacimiento 1 and 2. Rusconi (1962) located 12 individuals of both sexes and different ages in Yacimiento 1, but few of them were recovered due to poor conservation. At 50 m from the previous site is Yacimiento 2, with 22 skeletal remains (Figure 1) disposed in different positions: some were lying flexed on their face with the arms to the sides of the torso, while others were fully extended. Rusconi (1962) mentioned that on several of the adults recovered were the skeletal remains of a subadult. Few pottery remains were recovered in the burials. As part of this study one human sample was dated to *ca.* 2000 ¹⁴C years BP (Table 2).

Table 1. Resources and their stable isotope values

Lab code	Taxa	Procedence	$\delta^{15}\text{N}$	$\delta^{13}\text{C}_{\text{COL}}$	$\delta^{13}\text{C}_{\text{CAP}}$
<i>Regional</i>					
USF-8859	<i>Lama</i> sp.	Potreros Casa 1 (arch)	4.9	-18.7	
USF- 8860	<i>Pterocnemia pennata</i>	Agua de La Cueva (arch)	7.6	-18.6	
USF- 8862	<i>Lama</i> sp.	La Manga, Casa de Piedra (arch)	4.4	-19.7	
USF- 8863	<i>Lama</i> sp.	Agua de La Cueva (arch)	6.4	-17.5	
<i>Macro-regional</i>					
USF-5905/6170	<i>Lama guanicoe</i>	Arroyo El Desecho 10 (arch)	4.3	-19.1	-10.7
USF-5906/6171	<i>Lama guanicoe</i>	Agua de los Caballos 1 (arch)	5.0	-14.7	—
USF-5907/6172	<i>Lama guanicoe</i>	Cueva de Luna (arch)	4.6	-19.4	-11.1
USF-6173	<i>Lama guanicoe</i>	El Indígena (arch)	—	—	—
USF-8354	<i>Lama guanicoe</i>	La Gotera (arch)	6.2	-18.7	—
USF-8355	<i>Lama guanicoe</i>	Arroyo Malo 3 (arch)	4.8	-18.8	—
USF-8356	<i>Lama guanicoe</i>	Ojo de Agua (arch)	6.6	-18.7	—
USF-8357	<i>Lama guanicoe</i>	El Sosneado 3 (arch)	6.1	-18.9	—
USF-5913/6179	<i>Lama guanicoe</i>	Arroyo El Desecho 10 (arch)	4.3	-18.8	-8.9
USF-7368	<i>Lama</i> sp.	Angualasto (arch)	9.0	-14.2	—
USF-7370	<i>Lama</i> sp.	Morrillos (arch)	5.6	-18.1	—
s/d	<i>Lama</i> sp.	Neuquén (arch)	—	-19.8	—
s/d	<i>Lama</i> sp.	Neuquén (arch)	—	-19.7	—
USF-5911/6177	<i>Lagidium viscacia</i>	Alero Puesto Carrasco (arch)	3.7	-19.3	-9.1
USF-5912/6178	<i>Chaetophractus villosus</i>	Alero Puesto Carrasco (arch)	5.6	-17.7	-11.1
USF-5908/6174	<i>Cholephaga melanoptera</i>	El Indígena (arch)	4.1	-22.0	-11.5
USF-5914/6180	<i>Pterocnemia pennata</i>	Alero Puesto Carrasco (arch)	4.9	-21.0	-11.5
USF-5910/6176	<i>Pterocnemia pennata</i>	Alero Puesto Carrasco (arch)	4.6	-20.6	-12.1
USF-5909/6175	<i>Rhea americana</i>	Malargüe (actual)	5.7	-20.0	-11.8
USF-7369	<i>Rhea</i> sp.	Angualasto (arch)	6.7	-18.3	-17.1
USF-8864	<i>Lama guanicoe</i>	La Payunia-La Corredera (arch)	6.3	-19.3	—
USF-8865	<i>Lama guanicoe</i>	Agua de Los Caballos 1 (arch)	7.6	-18.5	—
USF-8866	<i>Lama guanicoe</i>	Gruta El Manzano (arch)	7.6	-17.6	—
USF-7372	<i>Zea mays</i>	Iglesia (arch)	9.6	-9.7	—
USF-7373	<i>Zea mays</i>	Calingasta (arch)	10.2	-9.1	—
USF-7374	<i>Zea mays</i>	Iglesia (arch)	9.5	-10.3	—
USF-6181	<i>Zea mays</i>	Cueva Zanjón del Buitre (arch)	3.4	-9.7	—
USF-6182	<i>Zea mays</i>	Gruta del Indio (arch)	3.9	-9.6	—
USF-6183	<i>Cucurbita maxima</i>	Gruta del Indio (arch)	13.1	-23.2	—
USF-7375	<i>Curcubita maxima</i>	Iglesia (arch)	6.0	-26.7	—
USF-7376	<i>Curcubita maxima</i>	Calingasta (arch)	7.0	-24.3	—
USF-7379	<i>Curcubita maxima</i>	Iglesia (arch)	9.8	-24.2	—
USF-6184	<i>Lagenaria</i> sp.	—	10.4	-25.4	—
USF-6185	<i>Chenopodium</i> sp.	—	6.9	-27.6	—
USF-6186	<i>Prosopis</i> sp.	Rincón del Atuel (actual)	—	-23.9	—
USF-7377	<i>Prosopis</i> sp.	Calingasta (arch)	2.1	-21.0	—
USF-6190	<i>Geoffroea decorticans</i>	Rincón del Atuel (actual)	—	-20.8	—
USF-6191	<i>Prosopis</i> sp.	Agua de Los Caballos 1 (arch)	11.6	-24.9	—
USF-6187	<i>Cassia arnottiana</i>	Arroyo Malo (actual)	1.6	-25.4	—
USF-6188	<i>Phaseolus vulgaris</i> Var. oblo	Gruta del Indio (arch)	5.5	-24.0	—
USF-6189	<i>Geoffroea decorticans</i>	Agua de Los Caballos 1 (arch)	14.0	-20.2	—
USF-6192	<i>Condalia microphylla</i>	Cuadro Benegas (actual)	—	-25.3	—
USF-6193	<i>Schinus polygamus</i>	Arroyo Malo (actual)	1.6	-24.4	—
USF-7371	<i>Phragmite australis</i>	Iglesia (arch)	4.2	-23.6	—
R-V-8	<i>Phragmite australis</i>	Iglesia (arch)	9.5	-22.4	—
s/d	Tubérculo amiláceo	Neuquén (arch)	—	-24.6	—
s/d	<i>Araucaria araucana</i>	Neuquén (arch)	—	-23.6	—

(arch): archaeological sample; (actual): actual sample.

The Uspallata archaeological locality is located in the western mountains (Figure 1). The Uspallata Túmulo I of El Canal was excavated in 1938, recovering human remains

of 20 individuals of both sexes and different ages. A human bone sample has recently been dated to ca. 980 ^{14}C years BP (Table 2). At 20 metres from that site is Uspallata Túmulo II (Figure 1), where

Table 2. Sample characteristics and stable isotope values

Latitude	Human sample	Archaeological site	Temporal unit	Area	Sex	Age (yrs)	¹⁴ C lab code	¹⁴ C	USF code	δ ¹⁵ N	δ ¹³ C _{COL}	USF code	δ ¹³ C _{AP}	Δδ ¹³ C _{COL-AP}
32	MMy-1241	Barrancas yac. 1	0	Lowland	♀	17-20	—	—	8288	8.0	-10.8	8301	-5.0	5.8
32	S/C	Aconcagua (*)	2	Highland	♀	30-45	GX-19991	370 ± 70	—	10.4	-10.8	—	—	—
32	MMy-284	Potreros Las Colonias	2	Highland	♀	30-45	AA-66564	568 ± 38	8296	10.0	-11.0	8309	-4.2	6.8
32	S/C	Uspallata (*)	2	Highland	—	>50	S/C	580 ± 90	—	9.8	-13.5	—	—	—
32	MMy-229	Uspallata Túmulo I	2	Highland	?	>50	AA-66568	977 ± 35	8294	9.7	-16.4	8307	-11	5.4
32	MMy-1097	Uspallata Túmulo III	2	Highland	?	?	AA-66566	671 ± 40	8297	7.8	-11.2	8310	-3.4	7.8
32	MMy-243	Uspallata Túmulo II	3	Highland	♀	38-53	AA-66565	1178 ± 41	8293	10.1	-12.1	8306	-6.5	5.6
32	MMy-245	Uspallata Túmulo II	3	Highland	♂	35-45	—	—	8292	9.8	-12.4	8305	-6.6	5.8
32	MMy-239	Uspallata Túmulo II	3	Highland	♀	>50	AA-66561	1269 ± 35	8291	9.6	-11.9	8304	-7.5	4.4
32	MMy-259	Uspallata	3	Highland	♀?	Adult	AA-66558	1922 ± 52	8290	9.9	-15.6	8303	-6.6	9.0
32	MMy-1471	Rivadavia-Alto Vede	3	Lowland	?	>45	AA-66563	1736 ± 49	8295	6.9	-15.9	8308	-10.0	5.9
32	MMy-1263	Barrancas 2	4	Lowland	♂	>45	AA-66560	2084 ± 40	8289	9.9	-18.0	8302	-13.6	4.4
32	S/C	Agua de la Cueva	4	Highland	—	>45	S/C	2480 ± 50	UGA8660	—	-14.6	—	—	—
33	ENT-2	Cápiz Alto	1	Lowland	♀	40-45	—	—	8226	11.7	-14.9	6227	-10.6	4.3
33	MMy-1223	San Carlos	1	Lowland	♀	19-23	AA-66562	177 ± 34	8287	10.7	-17.9	8300	-10.2	7.7
33	MMy-1197	Viluco	1	Lowland	♀	40-45	AA-66559	208 ± 38	8286	10.3	-17.2	8299	-12.9	4.3
33	MMy-1221	San Carlos	1	Lowland	♀	40-49	AA-66567	142 ± 41	8298	8.4	-18.7	8311	-12.3	6.4
33	ind6	Cápiz Alto	1	Lowland	♀	35-45	—	—	UGA8661	—	-15.6	—	—	—
33	ind1	Cápiz Alto	1	Lowland	♂	45-49	—	—	UGA8662	—	-16.7	—	—	—
33	ind2	Cápiz Alto	1	Lowland	♂	40-45	LP-1381	1120 ± 60	UGA8663	—	-15.9	—	—	—

The apatite (carbonate) values are from bone samples.

Note: (*) Fernández et al. (1999).

ten individuals were found mostly articulated, in extended positions in some cases, while in others the arms were folded on the chest, but all had their heads looking to the east. Two human bone samples have been dated, as part of this study, to ca. 1200 ¹⁴C years BP (Table 2). In 1939 Rusconi excavated the Uspallata Túmulo III, approximately 10 m from Uspallata Túmulo II. Here he recovered disarticulated human bone remains of both sexes, mostly young and immature, and some pottery was also found in the graves (Rusconi, 1962). Based on the geological stratigraphy, Rusconi assigned a Pre-Hispanic chronology to the human remains found in these graves. A recent radiocarbon date on one human bone sample adjusts this chronology to ca. 670 ¹⁴C years BP (Table 2).

The Potrero Las Colonias archaeological site is located in Uspallata (Figure 1). In 1939 Rusconi worked on this mound recovering nearly 60 individuals, which were disarticulated and mixed, forming an ossuary. According to Rusconi (1962), it could be a common grave where individuals were buried with some speed and without apparent order. Some pottery remains were found near the human skeletons and all the findings were assigned to Pre-Hispanic times (Rusconi, 1962). The radiocarbon date obtained as part of the present study is ca. 570 ¹⁴C years BP (Table 2).

The Alto Verde archaeological site is located in northeastern Mendoza (Figure 1). In 1960 Rusconi explored several kilometres of the river Tunuyán, finding a multiple burial with human remains of three individuals (Rusconi, 1962).

During the 1970s a multiple human burial was discovered in the western margin of the Uspallata, called Uspallata Usina Sur (Figure 1; Schobinger, 1971; Bárcena, 1974–1976). There were primary burials in an extended position lying on their back. In most cases the skulls could not be associated with post-cranial bones. Several objects were found associated with the burials including tips, tembetás, pipes, stone vessels, bronze objects, necklace ornaments with stone and clay impressions, and basketry (Schobinger, 1971; Bárcena, 1974–1976). According to Bárcena (1974–1976), the people of Uspallata Usina Sur would have had a diet low in carbohydrates, relying on hunter-gatherer activities, because of

the low percentage of dental caries present. This site has a relative chronology of 1000–1200 years BP based on the associated artefacts (Bárcena, 1974–1976). A date of ca. 580 ¹⁴C years BP was obtained from one human bone sample from this site (Fernández *et al.*, 1999).

Close to Uspallata Usina South (15 km) there is the Agua de la Cueva-North site. This is an extended cave with human occupations dating from the Pleistocene–Holocene limit up to the Late Holocene (García, 2003; Lucero *et al.*, 2006). This shelter is located 2900 m.a.s.l. on the western slopes of the Precordillera plateau in the 'puneño' desert (Figure 1). The remains of a child were found and dated at 2480 ± 50 ¹⁴C years BP. This is coincident with the first record of farmers' groups from northwestern Mendoza and western San Juan provinces (Gambier, 2000). In a domestic context near the burial area there are domestic seeds of maize (*Zea* sp.) and pumpkin (*Cucurbita* spp.), and shells of mate (*Lagenaria* sp.) (Durán & García, 1989).

In 1985 a mummified male child of 7–8 years old was found in the Aconcagua mountain (Figure 1), at 5300 m.a.s.l. It was in a flexed position, wrapped with numerous textile pieces, and accompanied by diverse utensils. This individual was clearly attributed to the Inca period. A radiocarbon age determination of ca. 370 ¹⁴C years BP was obtained for a bone sample from this individual (Schobinger, 2001).

Methods and techniques

Well-established procedures for extracting bone collagen, and bone and tooth enamel apatite, were performed in the Laboratory for Archaeological Science at the University of South Florida (Tykot, 2004). Whole and fragmented bone (about 1 g) and tooth samples were cleaned using ultrasonic vibration and distilled water. From the cleaned bone, 10 mg of bone powder were extracted for apatite analysis. Likewise, 10 mg of tooth enamel were extracted using a dental drill. Bone collagen was extracted using 2% HCl for 72 hrs, dissolving base-soluble contaminants using 0.1 M NaOH (24 hrs before and after demineralisation), and separating residual lipids with a mixture of methanol,

chloroform and water for 24 hrs. After drying and weighing the overall yield, collagen pseudomorphs were analysed using a CHN analyser coupled with a Finnigan MAT Delta Plus XL stable isotope ratio mass spectrometer set up with continuous flow. The reliability of collagen results was determined by percentage yields during processing, and validated by C:N ratios during analysis. Carbonate from apatite and enamel samples was also extracted using established techniques, specifically the removal of organic components using bleach (24 hrs for enamel, 72 hrs for apatite), and of non-biogenic carbonates using buffered 1M acetic acid (24 hrs). Carbonate samples were analysed using a similar Finnigan MAT Delta Plus XL mass spectrometer, coupled with a Kiel III device. The precision of the USF analyses is about $\pm 0.1\%$ for carbon and $\pm 0.2\%$ for nitrogen. Results are reported relative to the PDB and AIR standards.

In order to contextualise these human samples and their stable isotopic values, we discuss the bioarchaeological trends from the associated human samples (Table 3). The bioarchaeological analysis includes 68 human individuals of both sexes and a range of ages which have permanent tooth pieces. The sex and age determinations were performed according to the procedures suggested by Buikstra and Ubelaker (1994). The samples used are part of the collection of human bones deposited in the Museum Cornelio Moyano (Mendoza, Argentina). Based on these remains, several categories of bioarchaeological data were considered. The diet-related indicators studied are the presence of dental caries, *cribra orbitalia* (Mensforth, 1991; Holland & O'Brien, 1992), dental enamel hypoplasia, and dental abscesses as indicators of infectious processes (Scott, 1979; Smith, 1984; Buikstra & Ubelaker, 1994; Larsen, 1995, 1997; Novellino & Gil, 2007).

Stable isotope ecology

Knowledge of the stable isotope ecology of the region is a first step to understanding the isotopic values in human samples. The archaeofaunal and archaeobotanical studies define, in the same way, the species considered and their dietary significance (Table 1). Although there are scarce

Table 3. Non-specific bioindicators of health and diet: preliminary data from north Mendoza (32–33°S)

Archaeological site	n	No. with teeth	No. teeth permanent	No. individuals with caries	Individuals with caries	No. teeth with caries	Teeth with caries	No. individuals with abscesses	Individuals with abscesses	No. abscesses	Cribr orbitalia	Hypoplasia
Las Barrancas 1	5	4	37	2	50%	3	8%	0	0%	0	1	1
Las Barrancas 2	19	6	40	1	17%	1	3%	4	44%	7	1	0
Viluco	5	3	34	2	67%	2	6%	1	25%	1	0	1
San Carlos	3	3	29	3	100%	5	17%	1	33%	1	0	0
Cápiz Alto	6	3	189	4	44%	6	3%	2	22%	5	0	2
Túmulo I	3	2	28	0	0%	0	0	2	67%	3	1	0
Túmulo II	5	5	91	2	40%	3	3%	2	40%	4	0	0
Túmulo III	1	1	3	0	0%	0	0%	0	0%	0	0	0
P. Las Colonias	12	11	123	2	18%	2	2%	3	25%	3	0	0
Total	68	47	618	18	38%	-	-	15	28%	-	3	4

subsistence studies based on archaeofaunal and archaeobotanical records in the region, the general trends in faunal exploitation indicate the intensive use of camelids, ostrich and small mammals. Among the wild plants, the use of *Prosopis* sp. is probably the most significant. The focus in this study is to identify the isotopic signature of corn. The majority of the samples used to evaluate the isotopic ecology are archaeological, therefore avoiding the Sues effect. The isotopic ecology is presented at regional and macro-regional spatial scales. At the regional level (32–34°S), isotopic values were obtained for four faunal samples corresponding to two taxa (Table 1), while at the macro-regional level (30–40°S) isotopic values were obtained for 20 faunal resources (8 taxa) and 24 plant resources (13 taxa).

The isotopic analyses indicate that, on a regional level, faunal samples have low $\delta^{13}\text{C}$ values (average = -18.6‰ ; SD = 0.9; $n = 4$) and an average $\delta^{15}\text{N}$ value of 5.8‰ (SD = 1.45; $n = 4$). The stable isotope values for faunal samples on a macro-regional scale show a similar average value of -18.7‰ (SD = 1.7; $n = 22$). The more enriched isotopic values are recorded in *Lama* sp., while the other taxa are basically more negative than this average value (Table 1). The average value for $\delta^{15}\text{N}$ is 5.8‰ (SD = 1.6; $n = 20$). On the other hand, plants from the macro-regional spatial scale have low $\delta^{13}\text{C}$ values (average = -21‰ ; $n = 24$) with a $\delta^{15}\text{N}$ average of 7.3‰ ($n = 19$). The wild resources have an average $\delta^{13}\text{C}$ value of -23.3‰ (SD = 1.8; $n = 12$) and a $\delta^{15}\text{N}$ average of 6.4‰ (SD = 5.2; $n = 7$). Among domesticate plants the $\delta^{13}\text{C}$ average value is -18.6‰ (SD = 8; $n = 12$) with a $\delta^{15}\text{N}$ average of 7.9‰ (SD = 2.9; $n = 12$). Clearly, the $\delta^{15}\text{N}$ values for plants are highly variable, with examples in *Cucurbita maxima* (from 6.0 to 13.1), *Prosopis* sp. (from 2.1 to 11.6) and *Zea mays* (see below). $\delta^{15}\text{N}$ values for wild plants are higher in lowland than in highland areas, with significant differences between the samples tested so far. This contrast may be due to differential responses to arid conditions, and is the subject of further testing. Future studies that consider more samples, climatic differences and phytogeographical context could improve our understanding of these differences. *Zea mays*

$\delta^{13}\text{C}$ values (average = -9.7‰ ; SD = 0.42; $n = 5$) have no significant difference from corn samples from other regions, and they are enriched in carbon isotopic values, in contrast to all non-corn plants tested (Table 1; Figure 2). The *Zea mays* $\delta^{15}\text{N}$ values have an average of 7.3‰ with a standard deviation of 3.4‰ ($n = 5$). Two aspects are remarked on from the results presented in Table 1 and Figure 2. First is the significant variation in the $\delta^{13}\text{C}$ isotopic values for camelids (Figure 2) as was demonstrated by Fernández & Panarello (1999–2001) for northwest camelid samples. While the variability in the photosynthetic pathways in the region (Cavagnaro, 1988; Llano, 2009) is one of the probable explanations for isotopic variation in the camelid diet, the existence of different taxa (Finucane *et al.*, 2006) within central western camelids could be another explanation. At present the archaeofaunal studies do not indicate the presence of domesticated camelids nor of a clear pastoralist structure. The variations in the $\delta^{15}\text{N}$ values for camelid tissue (between 4‰ and 9‰) are consistent with expected responses to camelids' physiological adaptation to aridity (Sponheimer *et al.*, 2003; Finucane *et al.*, 2006). A second interesting aspect is the variation in $\delta^{15}\text{N}$ values for archaeological samples of *Zea mays* (Table 1) that is noticeable when comparing samples of northern and southern *Z. mays*. The southern samples (USF-6181, USF-6182) have lower values in comparison with the northern samples (USF-7372, USF-7373, USF-7374; Table 1). One hypothesis that needs to be investigated is the difference in the application of manuring techniques (Finucane, 2007), but specific studies still need to be performed.

Human stable isotope data

The isotopic values ($\delta^{13}\text{C}$, $\delta^{15}\text{N}$) for human samples from the last 2200 years are presented in Table 2. Twenty samples (ten from lowlands and ten from highland-piedmonts) are included, from 14 archaeological sites (Table 2). These samples produced 20 $\delta^{13}\text{C}$ values based on bone collagen, 14 $\delta^{13}\text{C}$ values based on bone apatite, and 16 for $\delta^{15}\text{N}$. Table 2 also includes new AMS radiocarbon dates directly from human bone. The few

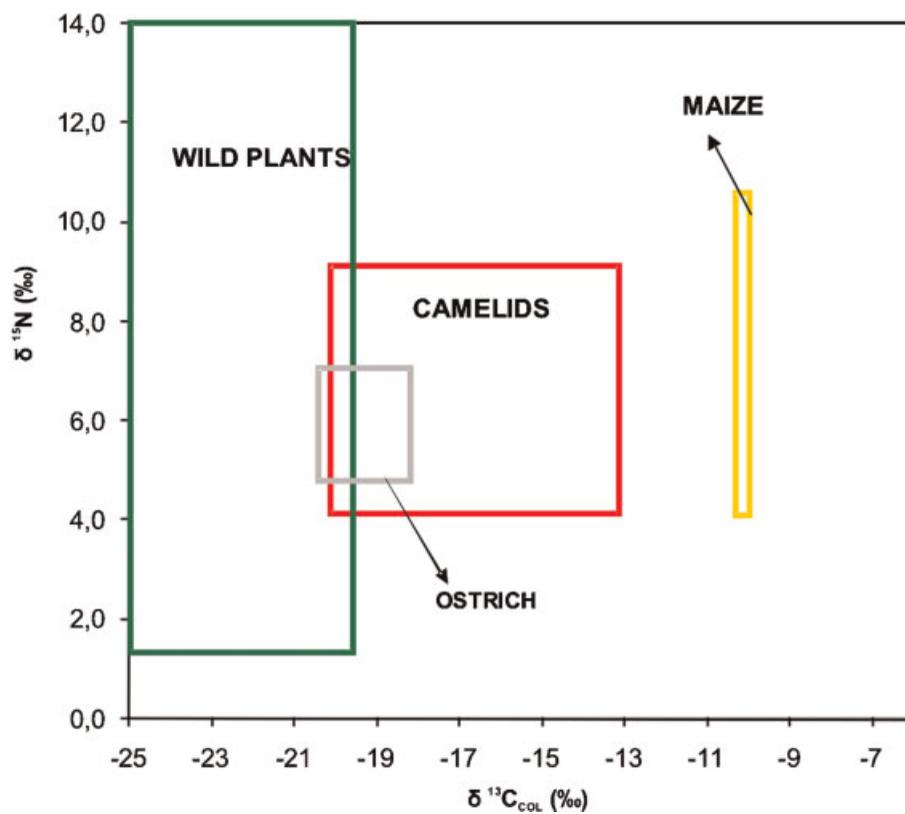


Figure 2. Ranges in value of $\delta^{15}\text{N}$ and $\delta^{13}\text{C}_{\text{COL}}$ for ecological resources in central western Argentina. This figure is available in colour online at www.interscience.wiley.com/journal/oa.

previous stable isotopic values (for samples from Aconcagua, Uspallata Usina Sur) and radiocarbon dates are also included.

The $\delta^{13}\text{C}$ values of human bone collagen ($\delta^{13}\text{C}_{\text{COL}}$) range from -18.7‰ to -10.8‰ (average = -14.6‰ ; $n = 20$); the $\delta^{13}\text{C}$ values of human bone apatite ($\delta^{13}\text{C}_{\text{AP}}$) range from -13.6‰ to -3.4‰ (average = -8.6‰ ; $n = 14$). Finally, the $\delta^{15}\text{N}$ values of human bone range between 7.8‰ and 11.7‰ (average = 9.5‰ ; $n = 16$) (Table 2). These results show a great variability in $\delta^{13}\text{C}$ and a minor variation in $\delta^{15}\text{N}$ values.

The high variability in the $\delta^{13}\text{C}$ values (8‰) needs to be interpreted in terms of differences in the terrestrial resource components of human diets. The most significant point to be discussed here is the variation in C_4 proportions which, accepting the actual isotope ecology (Figure 2), could be interpreted basically as the consumption of corn, at least in Pre-Hispanic times (see below). If the variation in $\delta^{13}\text{C}$ can be interpreted

as a difference in the proportion of C_3/C_4 resources, and if maize is probably the most significant C_4 food in the region, then variability in the $\delta^{13}\text{C}$ values may be interpreted as variation in corn consumption (Bender, 1968; Tieszen & Fagre, 1993; Tykot, 2006). In order to understand this variability in $\delta^{13}\text{C}$, the temporal and spatial variation of the isotopic data is examined.

Figure 3 shows the temporal trend in $\delta^{13}\text{C}_{\text{COL}}$ and $\delta^{13}\text{C}_{\text{AP}}$, showing no significant patterns through time. Coltrain & Leavitt (2002) proposed three categories that represent real but not strictly categorical differences in diets from the Great Salt Lake region (US). This could be a useful heuristic tool to apply in the analysis of the isotopic variation in Mendoza. Coltrain & Leavitt (2002) suggested the following three dietary categories: category 1, those individuals who subsisted on diets high in C_3 foods ($< -17\text{‰}$); category 2, individuals who consumed diets relatively high in C_4 foods ($> -14\text{‰}$); and

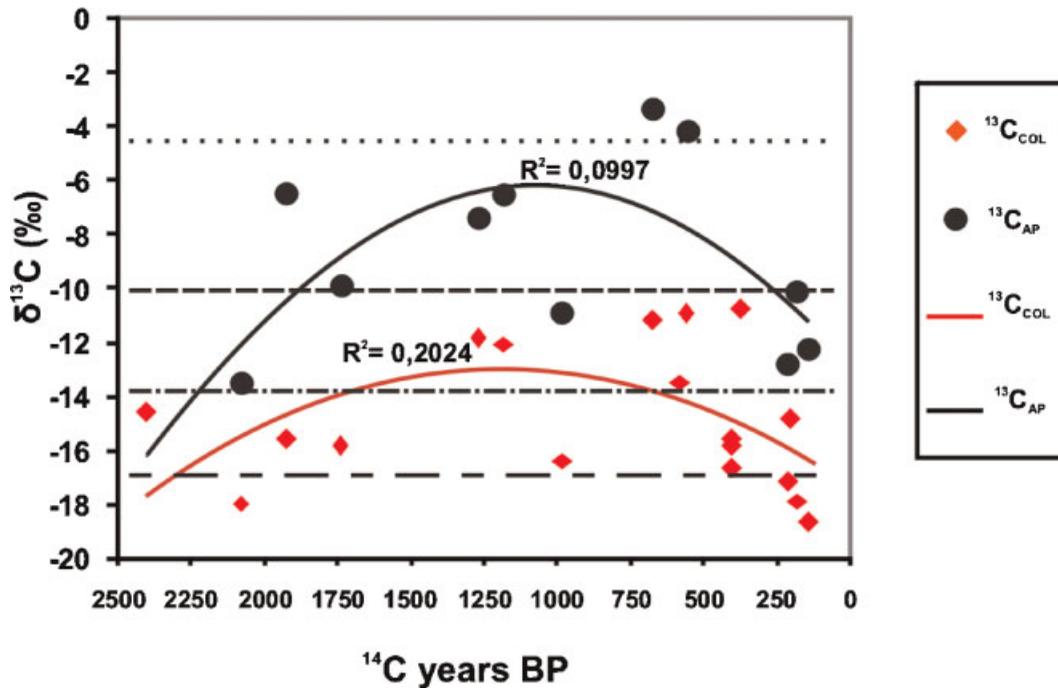


Figure 3. Chronological plot of $\delta^{13}\text{C}$ values for the samples. This figure is available in colour online at www.interscience.wiley.com/journal/oa.

category 3, those subsisting on mixed diets (-17 to -14‰). Certainly, it is useful to separate photosynthetic pathway trends but not specific taxa consumption. However, it is suggested here that maize is the most significant C_4 resource used directly as food on the basis of the regional archaeological record. On the other hand, during historical times there were other vegetal staples introduced into human diets, whether C_4 like sugar-cane, or C_3 like wheat.

Using these categories the samples analysed in the present study show significant variability. The oldest samples, between *ca.* 2400 and 1750 ^{14}C years BP, include the lowest isotopic values (Figure 3). The 'category 2' of individuals with high consumption (direct or indirect) of C_4 resources is recorded between approximately 1250 and 300 years BP (Figure 3). It is between these dates that corn consumption was probably most significant, but important variation is observed. A significant drop in isotopic values is recorded after this date. Isotopically depleted individuals are recorded in the late human samples, after 300 years BP. This is a significant

trend given the late introduction of European resources into the regional menu of available staples.

Taking into consideration the $\delta^{13}\text{C}$ values for apatite ($\delta^{13}\text{C}_{\text{AP}}$) and considering an adaptation of Coltrain & Leavitt's (2002) categorisation (see Gil *et al.*, 2006), the trends show temporal differences in comparison with the $\delta^{13}\text{C}$ based on collagen. The $\delta^{13}\text{C}_{\text{AP}}$ values indicative of significant consumption of C_4 foods are recorded from approximately 2000 years BP (sample MMy 259). On the other hand, similar trends are found with $\delta^{13}\text{C}$ based on collagen. The earlier evidence of significant C_4 consumption recorded in the inorganic fraction could be explained by the biochemical nature of bone turnover. As shown by experimental studies (Ambrose & Norr, 1993; Tieszen & Fagre, 1993), the stable carbon isotopic composition of extracted collagen varies more closely with the isotopic composition of dietary protein. If collagen $\delta^{13}\text{C}$ reflects dietary protein, then carbon atoms from the protein portion of diet must be preferentially routed to collagen. On the other hand, since the carbon atoms in bone

mineral are derived from all the macro-nutrients, $\delta^{13}\text{C}$ in bone mineral will reflect the whole diet (Harrison & Katzenberg, 2003).

Maize is a relatively low-protein food and its contribution to the overall diet is likely to be underrepresented by the isotopic composition of collagen, but not by the isotopic composition of the inorganic fraction (Greenlee, 2006). If correct, $\delta^{13}\text{C}_{\text{COL}}$ shows clearly when maize came to dominate the diet, but is less sensitive to low-level maize use (for a similar situation, see Harrison & Katzenberg, 2003). This is probably the situation for sample MMy259. The trend in $\delta^{13}\text{C}_{\text{COL}}$ and $\delta^{13}\text{C}_{\text{AP}}$ shows a preliminary non-gradual and non-directional change in human diet, contrary to the actual models of cultural change in the region. Different regions of the Americas show different patterns, following different 'pathways' of change in reference to the enrichment of $\delta^{13}\text{C}$ and the causes which are explored (e.g. Johnson *et al.*, 2007) but not yet completely understood. Obviously our sample size is small, but we accept that there is concordance between the data and this proposal. Future studies can corroborate or refute this trend. The first step is to refine our question about human dietary variation in the southern frontier of American maize farming.

In order to explore the meaning of this variability in terms of human diet, we present temporal-spatial trends through the use of temporal units. These temporal units are heuristic tools without any intrinsic cultural meaning. These units take into consideration the radiocarbon dates and include unit 1 (2001–3000 years BP), unit 2 (1001–2000 years BP); unit 3 (501–1000 years BP); and unit 4 (100–500 years BP). If the human bone samples are grouped by temporal unit, temporal trends in $\delta^{13}\text{C}$ values are significant as shown in Figure 4. The Aconcagua mummy is not included in this figure because it is an outlier (not representative of the general human strategies of the region), but no significant change is observed if this sample is considered. This figure shows differences in the average value with parabolic trends. The earliest and the latest groups (2000–3000 and 0–500 years BP) show the more depleted average (-16.5‰) with similar ranges between -18.5‰ and -14.5‰ . It shows that the diet in both groups looks very similar. The middle groups (1000–2000 and 500–1000 years BP) have a similar average notably enriched (-13‰) in comparison with the previous case. These middle groups have a significant variation, approximately from -16.4‰ to -10.8‰ . An ANOVA one-way test between groups shows a

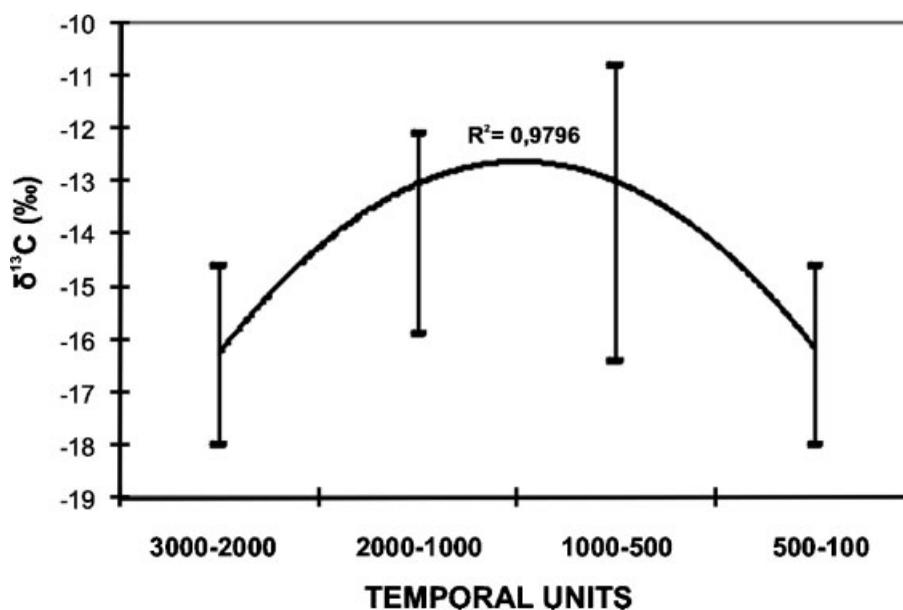


Figure 4. Chronological plot of $\delta^{13}\text{C}$ values for the samples, grouped by temporal unit.

probability of $p \leq 0.008$, rejecting the null hypothesis and accepting the statically significant difference between the groups. This significant internal variation is clearly shown in Figure 4 and could be interpreted as a dietary difference in terms of maize consumption between 'contemporary' individuals. A similar trend is observed for $\delta^{13}\text{C}_{\text{AP}}$.

These results show, firstly, that corn was clearly significant in the human diet only after *ca.* 1250 years BP but probably used in low levels from 2000 years ago (considering $\delta^{13}\text{C}_{\text{AP}}$). Secondly, there is an important difference between individuals with similar chronologies. Thirdly, a drop in the $\delta^{13}\text{C}$ value during the last 300 years can be interpreted as a change in diet where the importance of maize declines. A different alternative, the introduction of European products (Eurasian domestic animals and plants), may be proposed. The introduction of sugar cane could produce an increase in $\delta^{13}\text{C}$, but the available isotopic values show precisely the contrary. A classic approach used in archaeological research in central western Argentina is based on the extrapolation of historical and ethnohistorical information (Abraham & Prieto, 1991; Prieto, 1997–1998; Bárcena, 2001) to the archaeological past. This kind of direct analogy is

not supported by the subsistence studies presented here. This means that the recent historic human strategies are not a good analogue for Pre-Hispanic subsistence strategies, as is also shown in recent paleoethnobotanical studies (Chiavazza & Mafferra, 2007). A similar late decline in $\delta^{13}\text{C}$ values has been observed in the neighboring region of central Chile (Falabella *et al.*, 2007, 2008) and other parts of the Americas, such as Ohio (Greenlee, 2006).

The differences between $\delta^{13}\text{C}_{\text{AP}}$ and $\delta^{13}\text{C}_{\text{COL}}$ ($\delta^{13}\text{C}_{\text{AP-COL}}$) values are presented and discussed considering the local isotopic ecology. $\delta^{13}\text{C}_{\text{AP-COL}}$ values have been used in isotopic palaeodiet studies as a measure of trophic level, where $\delta^{13}\text{C}_{\text{AP-COL}}$ increases with a decrease in trophic position – in other words, with a decrease in animal protein input to the diet (Schwarcz, 2006). Figure 5 compares the variation of $\delta^{13}\text{C}_{\text{AP-COL}}$ with reference to $\delta^{15}\text{N}$. The figure shows a weak trend where more depleted $\delta^{15}\text{N}$ individuals tend to have $\delta^{13}\text{C}_{\text{AP-COL}}$ greater than 5. Figure 6 shows the relationship between $\delta^{13}\text{C}_{\text{AP-COL}}$ and $\delta^{13}\text{C}$, indicating that $\delta^{13}\text{C}_{\text{AP}}$ explains better, but weakly, the variation in $\delta^{13}\text{C}_{\text{AP-COL}}$. The pattern is weak but to some degree shows that the enrichment of $\delta^{13}\text{C}_{\text{AP}}$ is associated with a slow diminution in $\delta^{15}\text{N}$ that could be interpreted as a

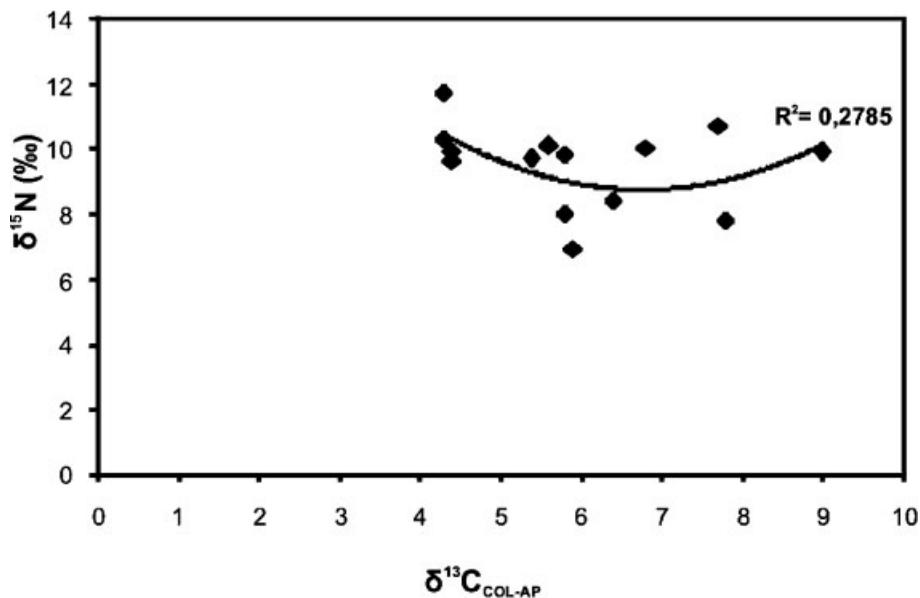


Figure 5. Relationship between $\delta^{15}\text{N}$ and dif $\delta^{13}\text{C}_{\text{COL-AP}}$.

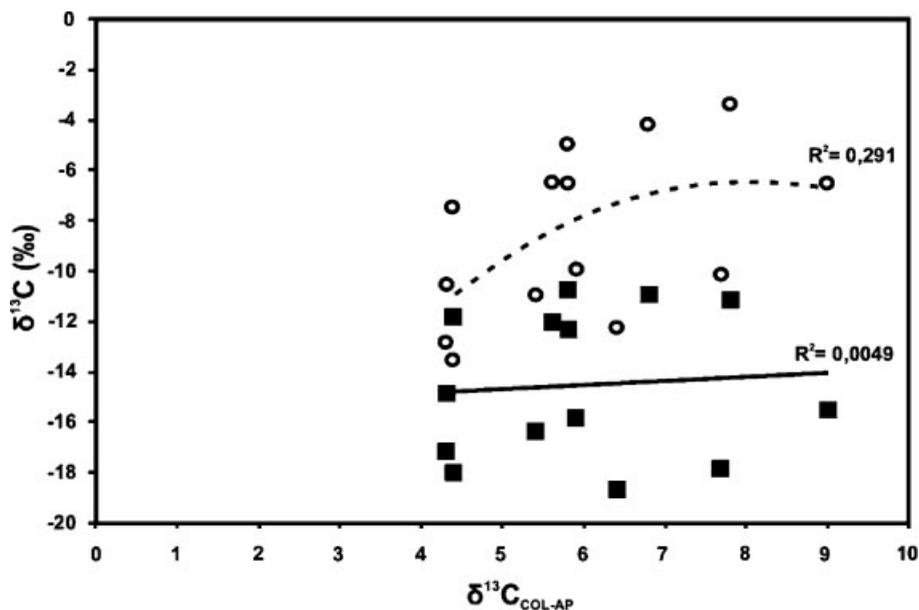


Figure 6. Relationship between $\delta^{13}\text{C}$ and dif $\delta^{13}\text{C}_{\text{COL-AP}}$.

diminution in the trophic level, as shown by $\delta^{15}\text{N}$. It is very tentative because the number of samples is small.

In terms of spatial variability the analysis was concentrated in the distribution of samples between lowlands and piedmont-highlands (Table 2). The sample size and its spatial and temporal distribution are far from ideal. Still, it shows some trends that provide future questions. The stable isotope data show an average enrichment in the highland samples, basically Uspallata, in comparison with the lowland samples (Figure 7). This result, which is not expected, is the opposite of the pattern for southern Mendoza (Gil, 2003; Gil *et al.*, 2006) where more enrichment is recorded in the lowlands. Again, no uniform spatial pattern is shown for $\delta^{13}\text{C}$ values, and this could indicate a significant dietary difference not considered at present.

The stable carbon isotope values between 32° – 33°S need to be discussed on a wider spatial scale including central Chile, southern Mendoza, and San Juan, where there are $\delta^{13}\text{C}$ values available for human samples (Gil *et al.*, 2006; Falabella *et al.*, 2007, 2008). A recent carbon isotope study in central Chile region has produced relevant information to compare with our results (Falabella

et al., 2007, 2008). The central Chile study presents stable isotope trends for the Late Holocene, mainly the last 2500 years. The most enriched average in the Chile human samples is recorded in the Aconcagua cultural complex, between 900–500 years BP, similar in chronology to the trends in northern Mendoza. Nevertheless, the average enrichment started earlier in the later case, between 1000–2000 years ago, and the abrupt average change was prior to that in Central Chile. On the other hand, the $\delta^{13}\text{C}$ isotope values in the neighbouring region of south Mendoza (Gil, 2003; Gil *et al.*, 2006) show a smaller consumption of C_4 resources and never reach the enrichment recorded in the north. In the Atuel valley of southern Mendoza the carbon isotope data show little enrichment after 2000 years ago and apparently also show a decrease the last part of the sequence, similar to northern Mendoza. Finally, the carbon isotope data for San Juan, north of Mendoza, show a different pattern. The San Juan samples show a trend for the last 4000 years when corn was significant, but less than in north Mendoza, and only after 1000 years ago (Gil *et al.*, 2006). This wider spatio-temporal trend shows a heterogeneous pattern in the introduction and trajectory of C_4 resources, basically



Figure 7. Difference in $\delta^{13}C$ values between lowland and highland regions.

maize. In all of these cases only for the last part of the Late Holocene was maize, on average, significant in the human diet.

Previous research indicates some relationships between maize consumption and the frequency of certain bioarchaeological proxies (Lukacs, 1989; Novellino *et al.*, 2004; Novellino & Gil, 2007). In the case presented here there is a low frequency of hypoplasia (8.5%) and a high frequency of

caries (38%). There is not a strong relationship between $\delta^{13}C$ and caries frequency, contrary to what is expected if the latter is influenced by the degree of corn consumption (see Novellino *et al.*, 2004). It is significant to mention a notable increase in the caries frequency in the latest time period (Figure 8), when $\delta^{13}C$ isotopic values were more depleted. One probable explanation for this Post-Hispanic increase in caries frequency is the

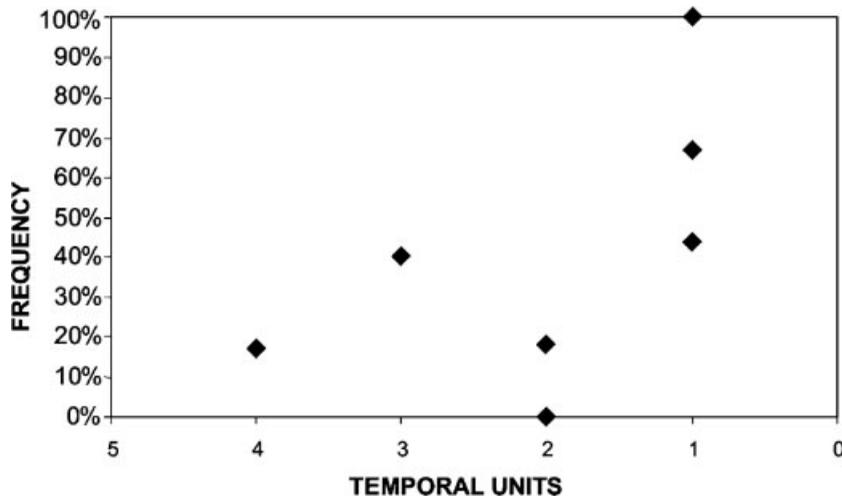


Figure 8. Temporal trends in the frequency of dental caries (average by archaeological site).

dietary incorporation of sugar cane. Nevertheless, $\delta^{13}\text{C}$ values do not support this scenario, as has been already shown.

The frequency of dental abscesses is low (28%) in the total sample, but the variation between archaeological sites is high (e.g. Barrancas Yacimiento = 0%, Uspallata Túmulo I = 67%). These values would be related to infections caused either by cariogenic processes and/or antemortem tooth loss at each site. However, we can not rule out that such variability may be due to differences in sample size at the different sites tested. Table 3 shows a low frequency of cribra orbitalia, a non-specific indicator of anaemia (Stuart-Macadam, 1992; Aufderheide & Rodríguez Martín, 1998; Wright & Yoder, 2003); the low frequency would indicate that the incorporation of iron in the diet is not deficient.

Final remarks

Subsistence and dietary research are useful topics of research for understanding changes in social systems (Binford, 2001). Corn consumption and its trends have been specifically associated with the development of complex societies (Finucane *et al.*, 2006) and generally associated with strong cultural change and reorganisation. The central western region of Argentina is the southern boundary for the farming of corn in the Pre-Hispanic record. This paper shows that human bone $\delta^{13}\text{C}$ values show a significant variation through time, but this variation is not linear and increasing through time, as archaeologists had previously thought. It is important to remark here that corn has been highly significant in human diets for the last 1200 years, and that this role in subsistence was variable from this time to Hispanic times. Therefore, historical information about human diet is not representative of the situation in Pre-Hispanic times.

Climatic conditions comprise one important variable to consider in the study of variation in corn use. Human strategies and diets are basically a response to the regional resource structure. The use of a given resource is related to its distribution and density across the landscape, and these variables are conditioned in turn by climatic conditions. The Late Holocene was not a stable

climatic period in the region (Zárate, 2002; Espizúa, 2005). Climatic fluctuations could have produced changes in primary productivity and in farming production, as has been recorded in historical times (Prieto, 1997–1998). Stable isotopes and world climatic databases provide a promising line of research in order to understand the role of different domesticates around the globe. On the agenda there is a necessity to explore the form and cause of 'contemporary' inter-individual diet variations and the decline in corn consumption during historical times. More research is needed, but available data clearly suggests that the role of corn was highly variable through time and space at its southern limit of dispersion.

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