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Human Diet and Residential Mobility in the Central Western Argentina Colony: Stable Isotopes (^{13}C, ^{15}N, ^{18}O) Trends in Archaeological Bone Samples

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Abstract Change or continuity of the human diet after the Spanish settlement in America is a topic mostly addressed in historical written documents with little use of the archaeological record and bioarchaeological or culture material. To counteract this weakness, this paper presents a study of the diet in individuals living in central-western Argentina between the seventeenth, eighteenth, and nineteenth centuries. The paper, focusing on historical bioarchaeology using stable isotopes ($\delta^{13}C$, $\delta^{15}N$, $\delta^{18}O$) from bone samples of human skeletal remains found in Mendoza, Argentina. The aim is to reconstruct the human diet and its residential mobility. Our results show little inclusion of maize in these populations' diets, significantly less than those for the same region during pre-Hispanic times. The data do not indicate a historic continuity in dietary practices between pre-Hispanic and post Hispanic human population.

Keywords Colony · Central Western Argentina · Stable isotopes · Human diet · Residential mobility

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Introduction

Cultural change, collapse, and the establishment of new organization systems have been distinctive processes originated by the Spanish Conquest of the Americas. Most of the knowledge about this time period is based on written documents. Today, many archaeological studies complement this information from different regions of Latin America. The central- western region of Argentina (Fig. 1) is an interesting case study because it provides a unique example on the establishment of colonial cities in a region where small-scale groups of farmers and hunter-gatherers coexisted (Bárcena 2001; Gambier 2000). Within this framework, several research programs in central-western Argentina have attempted to develop a better understanding of how the Spanish settlement affected the previous local population. Recently, these studies have debated the ethnic structure, diet, and subsistence patterns during the historic time (after 1561 CE) (Bárcena 2001; Chiavazza 1999, 2001, 2010, 2013; Chiavazza and Mafferra 2007; Durán and García 1989; García 1999, 2011; García Llorca 2004; Lagiglia 1976; García Llorca and Cahiza 2007; Michieli 1998; Parisii 1991–92). Central points in this discussion have been the role of agriculture as an economic practice, and the relevance of maize for these populations' diets. It has been generally accepted that once agriculture and the consumption of domestic resources were established, approximately 2000 years BP, farming practices were continuous until the historic period. This view implies a long-term farming base for the region (García 2011). An alternative model has been proposed (Chiavazza and Mafferra 2007; Gil et al. 2009; Mafferra 2010) which argues that once maize was incorporated into agricultural production it did not become important until 1000 years ago. In addition, the importance of maize varied

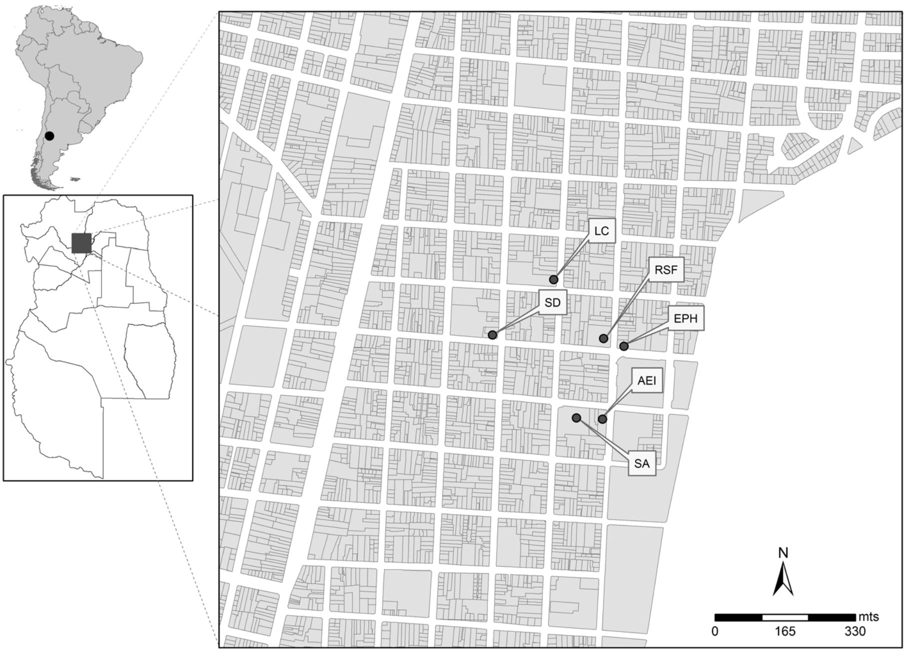

Fig. 1 Location of archaeological sites mentioned in the study; San Francisco, (RSF), Alberdi and Ituzaingo (AEI), Plaza Huarpe Building (EPH), Santo Domingo (SD), San Agustín (SA) and La Caridad (LC)

highly within contemporary populations and among different areas from northern Mendoza (Chiavazza 2013; Gil et al. 2009, 2010, 2011). Chiavazza and Mafferra (2007) propose a similar model using historical data from the fifteenth century for the area of Mendoza city. Chiavazza and Mafferra (2007; also see Mafferra 2010) propose a low significance for American domestic plants during Hispanic times, supported by the lack of American domestic plants in the archaeobotanical record. Therefore, the native domestic plants would not have been significant after the Spanish arrival. Chiavazza and Mafferra's (2007) paper was strongly questioned and discussed by García (2011; see answers in Chiavazza and Mafferra 2011). García (2011) affirms that the evidence does not permit any doubt about the engagement of agricultural practices by the historic-period Huarpes. García (2011) confirms the traditional model arguing about the existence of a local economy based on extractive and productive activities that persisted through the last 2000 years.

The objective of this article is to improve the characterization of human diets from central-western Argentina, mainly from northern Mendoza (see Fig. 1). Focus is placed on the importance of maize as a dietary resource during historic times and on mobility patterns. In order to discuss the models explained above, we present the results of the first stable isotope ($\delta^{13}C$, $\delta^{15}N$ and $\delta^{18}O$) studies on human bone from historical times for the region.

It has been clearly proven that the archaeological record of macrobotanical remains does not directly reflect subsistence and that an archaeological record has the potential to indicate processes on different spatial and temporal scales (Schiffer 1987; Ugan and Coltrain 2012). Records from archaeological deposits usually show a history of formation and temporal and spatial resolutions different to that indicated by chemical bio-indicators on human remains. Within this framework, the potential of stable isotopes to reconstruct human diets is a useful tool for understanding trends on a more fine-grained, individual scale.

Human Samples and Their Contexts

This study uses human bones remain recovered in colonial contexts from Mendoza city. The sample consists of human bones from excavations of Catholic churches: ruins of San Francisco (RSF), Santo Domingo (SD), La Caridad (LC) and San Agustín (SA) (see Fig. 1). The sample includes adults, both male and female, dated in a temporal interval of ca. 250 years, from the beginning of the seventeenth to the middle of the nineteenth centuries. Since the colonial churches were destroyed—as well as the rest of Mendoza city—by an earthquake on March 20, 1861, the integrity of the record and the temporal resolution is low. Chronological discriminations are difficult to make because of the great amount of debris generated in the successive demolitions. In addition, churches were confined places that received citizens' remains continuously for about 250 years. The space crisis is visible in the movements of bones and the relocation of deposits to generate space for future inhumations. In this context there is yet another distortive process for most of the cases considered: the churches were rebuilt from humble buildings made of earth (adobe and/or tapia walls) during the seventeenth century to brick structures in the eighteenth century (Chiavazza 2008). Furthermore, churches became part of the settlements at a later stage. Early colonial and even pre-

Hispanic domestic contexts can usually be found in different stratigraphic levels below the church floors or in contact with graves.

The sample from the Jesuit church (1608–1767), which then became San Francisco (1789–1861), has three building stages: a first temple (ca. 1611–1716) placed where the transept of the second building was raised (1716/1731–1861). In this setting, corpses from victims of the earthquake were documented as being buried around the ruins (Chiavazza 2005). The cases from Santo Domingo and San Agustín correspond to individuals buried under the main naves of the churches built during the eighteenth century. The sample of the individual from La Caridad is difficult to ascribe to a burial from the Jesuit or the Franciscan Order, because the Franciscans built the church and then gave it to the other brotherhood of La Caridad when the Jesuits were expelled (Mansegosa and Chiavazza 2010). This subject is relevant because not only the position establishes the social origin of the dead person on religious grounds, but also with the order entrusted with the funeral rites and disposition of the body (see the documentary study for Santo Domingo in Bárcena (2009). The temporal differences of the studied individuals were defined by their contextual associations and by the materials within stratigraphic levels (Chiavazza and Cortegoso 2001; Chiavazza and Zorrilla 2005).

What Does the Recent Archaeological Record Tell Us About Human Diet?

The study of archaeological middens at these sites (Chiavazza 2010, 2013; Chiavazza and Mafferra 2007) shows a pattern in which the colonial occupations in contact with native populations consumed a wide variety of both animal and plant products (Tables 1 and 2). A rapid incorporation of European subsistence elements, mostly Euro-Asiatic domestic vegetables, can be seen. From the fifteenth- and sixteenth-century contexts, both wild-native and domestic-foreign resources stand out (Chiavazza 2013). Urban sites (AEI, EPH, and RSF, see Fig. 1, Tables 1 and 2) present a record dominated by non-American domesticates. Other contemporary archeological sites, further away from this urban sector (PA70, see Fig. 1, Tables 1 and 2), present a minor presence of these non-local resources. In the non-urban archaeological site (PA70), there is a high importance of fish and low significance of camelids. In addition, the record of native domestic plants (such as maize) is not prominent.

Stable Isotopes, Diet and Mobility

Stable isotope analysis has become a solid line of evidence that has been applied to a variety of subjects such as palaeodiet, palaeoecology, and human mobility, among others (Koch 1998; Panarello et al. 2010). The use of stable isotopes to study palaeodiet began in the 1960s (Bender 1968). Van der Merwe and Vogel (1978) was the first high-impact example of an attempt to use this methodology to discuss the importance of maize in the human diet. Today, stable isotope analysis is a well-established practice in archaeological research (Ambrose 1993; Schwarcz and Schoeninger 1991). The method is based on the property of differential

Table 1 Zooarchaeological record on the piedmont and eastern plain in Mendoza (percentages) (sources: Chiavazza 2010, 2013; López et al. 2011)

	Sites			
	AEI	EPH	RSF	PA70
Indeterminate ≥*50 kg*	–	–	–	4.0
Reptilia	–	–	–	1.0
Birds	3.1	1.5	5.1	7.1
Rheidae	–	–	–	2.8
Rhea americana	0.2	–	–	–
Ardea cocoi	–	–	–	0.1
Gallus gallus	6.4	9.6	3.6	0.0
Bos taurus	23.2	30.4	1.5	–
Equus caballus	8.4	6.7	0.7	–
Sus scrofa	14.8	2.2	8.0	3.5
Caprininae	16.6	13.3	48.2	0.4
Lama guanicoe	3.1	16.3	11.7	7.6
Felis sp.	4.7	–	–	–
Canis sp.	7.4	0.7	–	–
Pseudalopex griseus	0.2	–	0.7	–
Dasypodidae indet.	–	–	–	0.1
Zaedius pichyi	0.2	0.7	0.7	0.1
Chaetophractus villosus	–	–	–	0.1
Tolypeutes matacus	–	–	–	0.1
Rodentia	1.2	0.7	12.4	49.1
Microcavia australis	–	–	–	3.7
Mus musculus	–	–	–	0.4
Osteichthyes	–	–	–	16.5
Percichthys trucha	10.7	17.8	7.3	2.5
Odontesthes sp.	–	–	–	0.6

isotope discrimination. For instance, in the case of carbon, this discrimination ($^{13}C/^{12}C$) enables to differentiate vegetables with different photosynthetic mechanisms (C_3, C_4 and CAM). Since maize is a C_4 plant, it can be easily discriminated in ecological contexts where resources have other photosynthetic pathways. Isotopes from other elements such as N ($^{15}N/^{14}N$) and O ($^{18}O/^{16}O$) allow researchers to discuss topics as trophic chains and residential mobility (Panarello et al. 2010).

It is difficult to measure the absolute abundance of a determined isotopic species. Analysts therefore have chosen to use the ratio between the number of molecules containing the heaviest isotope and the number of molecules containing the lightest isotope. In the case of carbon, with stable isotopes ^{12}C and ^{13}C, this ratio called R^{13} is equal to $^{13}C/^{12}C$. Because the values of this ratio are very small, they are expressed in a simpler way based on isotopic deviation (δ). The δ indicates how much the isotope

Table 2 Archaeobotanical record in the urban sector (AEI, RSF y EPH) and eastern plain of Mendoza (PA70) (percentages) (sources: Chiavazza 2010; Chiavazza and Mafferra 2007)

	AEI	EPH	RSF	PA70
Prosopis sp.	–	2.1	–	74.2
Zea mays	–	2.1	–	–
Hordeum sp.	2.2	2.1	0.5	–
Triticum sp.	68.2	17.0	80.1	–
Secale sp.	4.4	–	0.2	–
Avena sp.	1.6	–	0.3	–
Prunus sp.	–	36.2	0.1	–
Vitis sp.	–	27.7	0.5	0.2
Olea sp.	–	2.1	0.8	0.1
Marrubium sp.	–	4.3	5.8	–
Unidentified	23.7	6.4	13.0	25.5

ratio of the sample under study departs from that presented by an already defined international standard (Newton 2010; Panarello et al. 2010)

$$\delta = 1000(\mathrm{RM}{-}\mathrm{RR})\Big/\mathrm{RR}‰$$

where RM is the isotope ratio from the sample and RR is the same ratio but from the international standard. This same equation is applied to $\delta^{15}N$ for the $^{15}N/^{14}N$ ratio and to $\delta^{18}O$ for the $^{18}O/^{16}O$ ratio. The international standards to which these ratios refer are V-PDB for carbon, AIR for nitrogen, and V-SMOW for oxygen (Panarello et al. 2010).

The distribution of C isotope values in C_3 plants has a mode of −27‰ and a range between −34 and −22‰ (Heaton 1999). The distribution of values of carbon in plants with a C_4 photosynthetic pathway ranges from −16 to −7‰ with a mode value of −13 ‰ (Tessone 2011; Pate 1994). This is why it is accepted for central-western Argentina that bone collagen from an individual whose diet was based on C_3 resources will have $\delta^{13}C$ values of around −21.5‰ V-PDB, with a range from −17 to −23‰ V-PDB (Gil 2003; Gil et al. 2010). Those whose diet was based on C_4 resources will have a bone collagen value of about −7.5‰ V-PDB and a range from −14 to −7‰ V-PDB, with values for mixed human diets falling in between. These values of $\delta^{13}C$ are obtained in relation to pre-established international standards (Ambrose 1993; Tykot 2006). According to experimental advances (Ambrose and Norr 1993), the $\delta^{13}C$ values based on bone collagen mainly reflect the protein fraction of the diet. On the other hand, the inorganic fraction (hydroxyapatite or just apatite) reflects the fraction of the diet that provides energy and metabolizes. $\delta^{13}C$ from hydroxyapatite is in isotopic equilibrium with bicarbonate in blood (and also with dissolved CO_2) that indicates the macronutrients that are being metabolized. The values obtained from bones show an isotope fractionation in ^{13}C related to diet, which is named as the difference between substrate and base. In the case of collagen, an enrichment of around 5‰ is estimated, although this value may differ according to species and types of diets (Tessone 2011). The fractionation of the inorganic component (hydroxyapatite) is still under discussion

but the generally stipulated value of 12‰ is adopted, although it may present values as far as 9‰ (Ambrose and Norr 1993; Tykot et al. 2009). This figure has been recently questioned and some authors argue that the relationship between diet and mineral vs. collagen is more complicated (see Kellner and Schoeninger 2007 for a detailed discussion). Other consideration places the temporal resolution as related to the analyzed tissue. In the case of bone, it is presumed that the value obtained is an average of the food ingested and assimilated within the last 7–10 years, but recently it has been suggested that the time span can be even more extensive (Hedges et al. 2007).

Nitrogen stable isotope analysis has been generally used to discriminate differences in the trophic levels between individuals (Hedges and Reynard 2006), but several researchers suggest that the values shown by those isotope values may reflect different ecological, climatic, nutritional, and metabolic variables (Ambrose and De Niro 1986; Hedges and Reynard 2006; Petzke et al. 2010; Sealy et al. 1987). On the other hand, the relationship between the increases in $\delta^{15}N$ values directly associated to trophic levels is well founded and does not seem to be challenged (Hedges and Reynard 2006).

Another stable isotope recently incorporated into archaeological studies, particularly in Argentina, is $\delta^{18}O$. In archaeology, oxygen isotopes ($^{18}O/^{16}O$) are used to investigate mobility and patterns of residence (Buzon et al. 2011; Dupras and Schwarcz 2001; Knudson 2009; Sanhueza and Falabella 2010; Sponheimer and Lee-Thorp 1999; Turner et al. 2009). These isotopes are registered in phosphate and carbonate from hydroxyapatite and mainly reflect the isotopic composition of bodies of water chiefly determined by the water ingested during bone and teeth formation (Longinelli 1984; Longinelli and Nuti 1973; Luz et al. 1984; Sponheimer and Lee-Thorp 1999; Turner et al. 2009; White et al. 2004). The water ingested varies in a regular way with respect to latitude, altitude, rain patterns, and other environmental factors (Dansgaard 1964; Gat 1996; White et al. 1998, 2004). Therefore, if variations in ^{18}O from water from a region are found, there is potential to explore human mobility and patterns of residence (Dupras and Schwarcz 2001; Turner et al. 2009; White et al. 2000, 2002, 2004). In order to understand human values, $\delta^{13}C$, $\delta^{15}N$ and $\delta^{18}O$ are collected from fauna, plants, and water of the same region, generating aspects of/for isotopic ecology (Martínez Del Rio et al. 2009).

Environment, Resources, and Isotopic Ecology

The current city of Mendoza (see Fig. 1) is located on the western border of the oriental plain, close to the piedmont that joins it with the Cordillera de los Andes. Mendoza city lies in the Monte desert. Most of the rain falls in the summer with an estimated mean annual average of 250 mm. The Río Mendoza, which originates in the Cordillera de los Andes during the melting season, is the main water resource. Several springs, brooks, and swamps are associated with it.

In order to adjust and discuss the results from stable isotope analyses, it is necessary to know the isotopic values of potential resources as well as surface water and rainfall. The isotopic values from resources improve the interpretation of isotopes values in human bone samples, allowing more accurate estimates for paleodiets. Values generated from water samples inform the $\delta^{18}O$ and enabled us to adjust the results from the same isotope on human samples, both in terms of residential mobility and/or

hypothetical geographic origin of the analyzed individuals. This isotopic information on resource and water contributes to the elaboration of a regional isotopic ecology.

Figure 2 shows the regional tendency of the $\delta^{13}C$ and $\delta^{15}N$ values available for the most commonly exploited resources during the late Holocene in the center west of Argentina (Durán et al. 2014; Gil et al. 2010). Although the variability of resources is lower than the potentially exploited one, significant trends can be observed in Fig. 2. On the one hand, $\delta^{13}C$ values for maize show a significant segregation of this species from the other resources. This allows the expectation for populations that based their diet on this resource to be clearly differentiated from those who did not. This species shows a significant enrichment of $\delta^{13}C$ and also of $\delta^{15}N$. With regard to this latter isotope, maize resembles the tendency shown by *Cucurbita maxima* (squash) the other domestic plant included in Fig. 2. Other significant vegetal resource, algarrobo/ mesquite (*Prosopis sp.*), also differentiated itself by presenting very low values of both isotopes. The fauna presents more uniform values. Its $\delta^{13}C$ values point to a mixed composition of C_3 and C_4 resources, together with a $\delta^{15}N$ mean value of around 7‰ (see Fig. 2).

Many researchers have used stable isotopes of oxygen ($^{16}O/^{18}O$) to determine mobility and residence patterns of human populations (Buzon et al. 2011; Dupras and Schwarcz 2001; Knudson 2009; Sanhueza and Falabella 2010; Sponheimer and Lee-Thorp 1999; Turner et al. 2009). The isotopes are registered in phosphate or hydroxyapatite from tooth and/or bone show water composition at the time the tooth

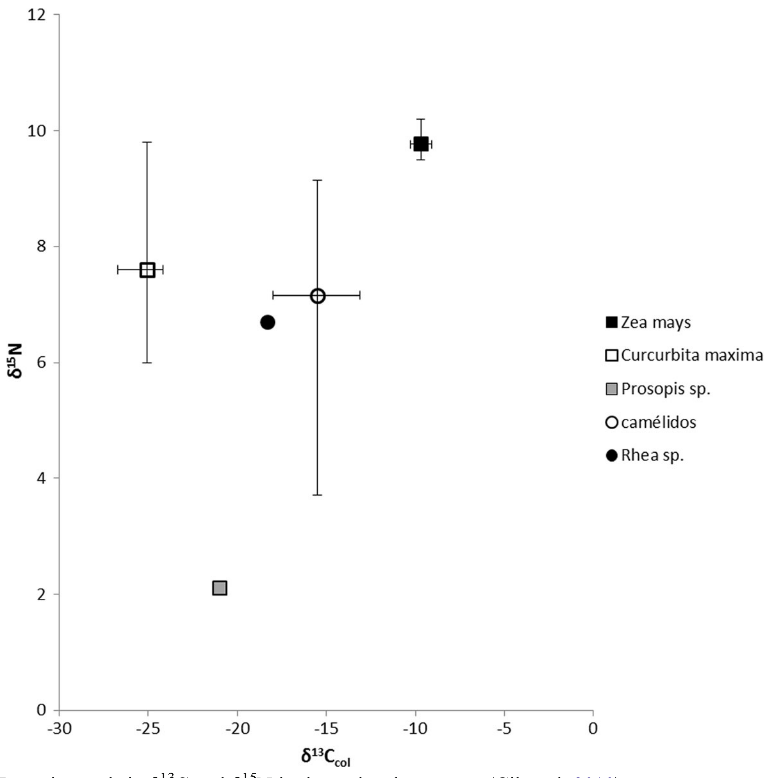

Fig. 2 Isotopic trends in $\delta^{13}C$ and $\delta^{15}N$ in the regional resources (Gil et al. 2010)

and/or bone were formed. In human beings, the isotopic composition of water in the body is mainly but not exclusively defined by the water they drank (Longinelli 1984; Longinelli and Nuti 1973; Luz et al. 1984; Sponheimer and Lee-Thorp 1999; Turner et al. 2009; White et al. 2004). Drinking water itself, in turn, varies according to latitude, altitude, rainfall pattern, and other environmental variables (Dansgaard 1964; Gat 1996; White et al. 1998, 2004). Thus, if the region presents a pattern of variation in ^{18}O, the value of this isotope in bone and teeth can indicate where the individual consumed water. This variation can be used to evaluate mobility and residence of both individuals and populations (Dupras and Schwarcz 2001; Turner et al. 2009; White et al. 2000, 2002, 2004).

For $\delta^{18}O$ isotopic trends from water, the data available comes from samples from the Río Mendoza (Hoke et al. 2009), groundwater, and rainfalls on its basin (Hoke et al. 2013). Data from nearby areas helps to contextualize this information and define it on a macro-regional scale (Gil et al. 2011; IAEA/WMO 2006; Panarello and Dapeña 1996; Sanhueza and Falabella 2010; Ugan et al. 2012; Vogel et al. 1975). Previous research propose an altitudinal relationship with $\delta^{18}O$ from river waters: the Río Mendoza, central to the basin, presents estimated values of −19‰ V-SMOW at 4000 masl, diminishing 3‰ every 1000 m according to Vogel et al. (1975) or 4.8‰ according to Hoke et al. (2009). According to these gradients, in the city of Mendoza, the Río Mendoza is expected to present $\delta^{18}O$ values between 8 and 10‰ V-SMOW. Besides, data from groundwater indicates depleted values for the plain, showing its association with the Río Mendoza. Vogel et al. (1975) obtained values of −18‰ V-SMOW, confirming that the Río Mendoza is the recharging source of the aquifers and is not rainfall. Rainfall samples in this area present values of −4‰ V-SMOW (Hoke et al. 2009).

Methodological Aspects

This paper analyzes the $\delta^{13}C$ and $\delta^{15}N$ stable isotope values of the human bone collagen and $\delta^{13}C$ and $\delta^{18}O$ values obtained from the carbonate fraction of these same bones. The $\delta^{13}C$ and $\delta^{18}O$ values of apatite were calculated using the V-PDB standard and $\delta^{15}N$ using AIR. Bone collagen and hydroxyapatite were obtained from laboratory procedures carried out at the Museum of Natural History of San Rafael following the protocol described in Coltrain and Leavitt (2002) and presented below. $\delta^{13}C$, $\delta^{15}N$ and $\delta^{18}O$ measurements were made at the University Of Wyoming's Stable Isotope Facility.

Specimens were selected after the bioanthropological description (Mansegosa and Chiavazza 2010). From a visual perspective, the bone specimens presented good conditions regarding preservation, without signs of thermal alteration or advanced weathering. Approximately 1 g of bone was obtained from each individual. Samples processed at MSR follow the laboratory procedures as describe below and were measured at the University of Wyoming's Stable Isotope Facility. Collagen extraction started with 1 g of cortical bone cleaned of surface contaminants. Samples were demineralized whole in 0.6N HCl at 4 °C and progress was recorded daily. After demineralization, the collagen pseudomorph was rinsed to neutrality, treated with 5 % KOH to remove organic contaminants, and soaked 24 h in a 2:1:0.8 mixture of

methanol, cloroform, and water to remove residual lipids. The acid and base extracted collagen pseudomorph were again rinsed to neutrality, then lyophilized and weighed to obtain a collagen yield. Approximately 100 mg of lyophilized collagen were gelatinized in 5 ml of acidified water (pH 3) for 24 h at 120 °C. Water-soluble and -insoluble phases were separated by filtration and the water-soluble phase lyophilized. Collagen^{13}C and ^{15}N were determined by flash combustion to produced CO_2 and N_2 and measured on a Costech 4010 Elemental Analyzer coupled to a Thermo Delta Plus XP IRMS (analytical precision 0.3‰). Both stable isotope measurements and sample weight percent carbon and nitrogen were obtained from single sample combustion. Collagen preservation was evaluated by atomic carbon to nitrogen ratios (atomic C:N). The samples all fall within the 2.9–3.6 range, indicative of adequately preserved bone collagen (Ambrose 1990).

To obtain the isotopic values from carbonate hydroxyapatite, 100 mg of bone were processed, ground, and weighed and then were transferred to an Eppendorf tube. This sample was placed in 3 % hydrogen peroxide for 15 min to remove organic components. Then the sample was washed three times to neutrality and dried. It was then washed in acetic acid 0.1 M for 15 min to remove labile carbonates and washed again to neutrality and dried. Finally, the sample of ground bone was sent to the University of Wyoming's Stable Isotope Facility (Gas Bench online with a Finnigan Delta Plus XP) for analysis. The values of stable isotopes for carbon and oxygen were determined there and reported in values related to the V-PDB standard (analytical precision 0.3‰).

Results

Twenty human bones samples from the seventeenth, eighteenth, and nineteenth centuries were processed (Table 3). From those samples, 13 results based on bone collagen (δ^{13}Ccol and δ^{15}N) and 19 on bone hydroxyapatite (δ^{13}Cap and δ^{18}O) were obtained. Table 3 shows the basic variables of the human bones and the results from the isotopic analyses obtained from each sample. Table 4 summarizes the basic statistics. Our set has a mean value of −16.9‰ for $\delta^{13}C_{col}$. When the estimation is made on the temporal groups already mentioned, these tendencies vary from −17 to −16.4‰, showing a slight enrichment of δ^{13}C from bone collagen toward more recent occupations. The difference between the groups is not statistically significant (one way ANOVA F=0.37, p=0.698; Table 4). These values point out that the contributed protein comes mainly from a mixture from C_3 and C_4 resources, with a slight predominance of C_3. This same isotope, when measured in hydroxyapatite, presents an average value of −12.2‰ and similar values (between −11.9 and −12.5‰) when it is estimated on temporal groups, although with a tendency to deplete (see Table 4). In this case, the results indicate that the energy fraction of the diet would come almost exclusively from C_3 resources with a low to null supply of C_4 resources. Only one individual shows values departing from this trend, (ca. −8‰ NC5 from San Francisco Ruins site), which implies an important energetic supply from C_4. The range of variation is greater in δ^{13}C values from collagen (2.9‰; between −18 and −15.1‰) than from hydroxyapatite (1.5‰; between ca. −12 and −13.5‰). The values from hydroxyapatite are significantly homogeneous except for the individual NC5, already mentioned (Fig. 3, also see Table 4). When analyzing according to sex, proteins sources (inferred from δ^{13}Ccol) seem to have been

Table 3 Stable isotope values ($\delta^{13}C$, $\delta^{15}N$ and $\delta^{18}O$) obtained from analyzed individuals

Site	Individual	Sex	Age	Chronology	N%	C%	MSR	$\delta^{13}C$	$\delta^{15}N$	MSR	$\delta^{13}C$	$\delta^{18}O$	Atomic C/N
San Francisco	AS1	M	20–49	19th c–1861	–	–	58	–	–	145	−12.8	−10.6	–
	NC1	F	35–49	19th c–1861	14.5	40.3	59	−17.2	10.7	146	−13.2	−9.9	3.2
	NC2	M	35+–50	19th c–1861	14.8	40.7	60	−16.1	12.0	147	−11.8	−9.4	3.2
	NC12	F	35–49	17th c	–	–	64	–	–	151	−11.0	−14.0	–
	NC15	M	18-	17th c	14.9	40.9	66	−17.3	10.8	–	–	–	3.2
	NC10	–	18-	17th c	–	–	63	–	–	150	−11.6	−7.9	–
	NC14	F	18	17th c	13.3	36.5	65	16.6	10.6	152	−12.1	−11.0	3.2
	NC11	M	20–34	17th c	–	–	72	–	–	159	−11.8	−12.2	–
	C11	F	20–34	17th c	13.9	38.4	69	−17.0	10.8	155	−129	−11.9	3.2
	C12	F	20–34	17th c	–	–	70	–	–	156	−12.3	−13.2	–
	C8	F	18–20	17th c	13.0	36.1	68	−17.0	10.7	154	−11.9	−11.9	–
	C13	F	18–20	17th c	–	–	71	–	–	157	−11.8	−12.0	–
	NC5	M	20–34	18th c	15.3	41.9	61	−17.9	11.1	148	−8.1	−11.0	3.2
	C3	F	35–49	18th c	12.4	34.2	67	−17.0	12.3	153	−13.3	−10.1	3.2
	NC6	F	20–49	18th c	14.9	40.9	62	−15.1	13.3	149	−13.2	−9.6	3.2
	AN1	F	20–34	18th–19th c	14.9	41.0	57	−18.2	10.8	144	−12.9	−10.0	3.2
La Caridad 2008	LC2	M	42–50	18th–19th c	14.9	40.9	56	−17.5	10.9	143	−13.4	−11.7	3.2
Santo Domingo	SD2	M	31–35	–	15.3	42.0	54	−17.4	10.7	141	−13.7	−9.6	3.2
	SD1	F	35–49	19th c	13.8	38.0	53	−15.9	9.6	140	−12.3	−13.9	3.2
San Agustin	B36II4	F	45–50	18th c	–	–	55	–	–	142	−12.4	−11.2	–

Table 4 Basic descriptive statistics of analyzed samples

		N	Min	Max	Average	DS
δ^{13}Ccol	Total	13	−18.2	−15.1	−16.9	0.8
	17th c	4	−17.3	−16.6	−17.0	0.3
	18th c	3	−17.9	−15.1	−16.6	1.4
	19th c	3	−17.2	−15.9	−16.4	0.7
δ^{15}N	Total	13	9.6	13.3	11.1	0.9
	17th c	4	10.6	10.8	10.7	0.1
	18th c	3	11.1	13.3	12.2	1.1
	19th c	3	9.6	12.0	10.8	1.2
δ^{13}Cap	Total	19	−13.7	−8.1	−12.2	1.3
	17th c	8	−12.9	−11.0	−11.9	0.5
	18th c	4	−13.3	−8.1	−11.7	2.5
	19th c	4	−13.2	−11.8	−12.5	0.6
δ^{18}O	Total	19	−14.0	−7.9	−11.1	1.6
	17th c	8	−14.0	−7.9	−11.7	1.8
	18th c	4	−11.2	−9.6	−10.5	0.7
	19th c	4	−13.9	−9.4	−10.9	2.0

isotopically similar between male and female. But females present greater internal variability, whereas for carbohydrates and fat (inferred from δ^{13}Cap) the greater variation is found in males. In average, however, they present similar trends. The correlation between δ^{13}C for bone collagen and apatite (see Fig. 3) shows a weak correlation of −0.20 (Spearman correlation p=0.54). This indicates a weak and non-significant relation associating the enrichment of one with the depletion of the other. These results indicate that C_4 resources, such as maize, were not a central source either of energy or of proteins. Besides, it shows that the isotopic sources of protein have varied more than the sources of carbohydrates and fat (energy). Individuals from the

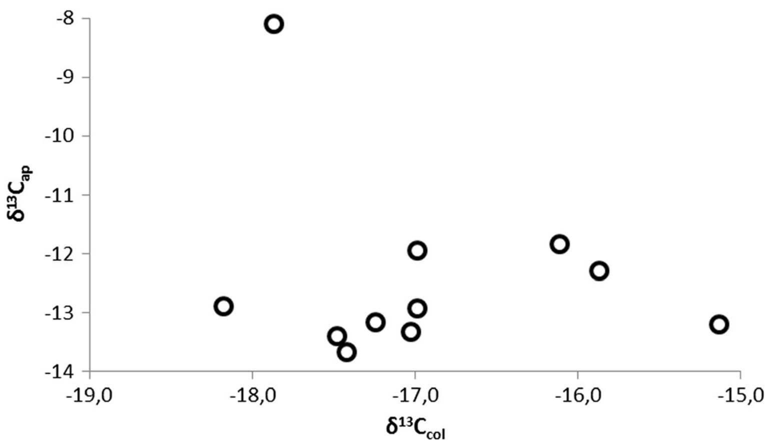

Fig. 3 Relation between the δ^{13}C values of bone collagen and apatite

seventeenth century present a greater homogeneity in values both from bone collagen and hydroxyapatite (*DS*=0.29 and 0.10 respectively) than those from eighteenth and nineteenth centuries (see Table 4). However, statistically significant variations between these two isotopes were not detected for temporal sets; that is, as regarding isotopes, there would be no significant variation in the average diet during those ca. 300 years.

The $\delta^{15}N$ values show an average of 10.7‰, indicating a high trophic level in the food chain. There are no statistical significant variations when analyzing this isotope according to temporal sets, although average samples from the seventeenth century are more enriched (12.2‰) and this set presents the smallest variability (*DS*=0.1). No significant variation was found between the sexes.

The isotopic composition of oxygen in hydroxyapatite from mammalian bones is directly related to corporeal water composition, which reflects the isotopic composition of the oxygen that enters the body. The isotopic composition of oxygen in turn is defined by a complex relationship between climate, diet, and physiology (Longinelli 1984; Luz et al. 1984; Sponheimer and Lee-Thorp 1999). The main sources of bodily oxygen are atmospheric O_2, consumed water, and oxygen found in food. From these three sources, the drinking water has the most significant role in determining human corporeal values in $\delta^{18}O$.

The analyzed samples indicate an average of −11.1‰ with a range between −8 and −14‰, that is, a variation between individuals of 6‰. No statistical differences were detected among temporal sets, although samples from the eighteenth century present smaller variability (*SD*=0.75) than the other two temporal sets (SD between 1.8 and 2 respectively; see Table 4).

Discussion

The $\delta^{13}C$ values from bone collagen indicate a mixed composition of C_3 and C_4 resources in human diet but a significantly higher composition of C_3. Bone collagen fraction mainly indicates the source/s origin of the proteins on the diet (Ambrose and Norr 1993). But hydroxyapatite, the component that indicates the source origin of the energy fraction on the diet, presents even more depleted values than bone collagen. This reflects a diet almost exclusively based on C_3 resources as the energy source/s. Only one individual presents values that contradict this trend (NC5). These data support the low importance maize had among human diets during the seventeenth, eighteenth, and nineteenth centuries. However, it does not mean that the people did not know this resource, which is mentioned in documents and is found in archaeological records dating after about 500 years BP.

To improve the meaning of this trend, these isotopic data were compared with those available from other pre-Hispanic human samples from the same region (Gil et al. 2009, 2010, 2011). To do it, the Froehle et al. (2012) model was applied. This is a new version based on Kellner and Schoeninger (2007), where the model defines the diet composition of each sample according to the origin of the energy and proteins based on δ^{13}Cap and δ^{13}Ccol values. The bivariate carbon model (δ^{13}Cap vs. δ^{13}Ccol) provides detailed information on the isotopic signatures of whole diet and dietary protein but is limited in its ability to distinguish between C_4 and marine protein. Here, using cluster analysis and discriminant function analysis, Froehle et al. (2012) generate a

multivariate diet reconstruction model incorporating δ^{13}Cap, δ^{13}Ccol, and δ^{15}N holistically. Inclusion of the δ^{15}N data prove to be useful in solving protein-related limitations of the bivariate carbon model, and splits the sample into five distinct dietary clusters (Froehle et al. 2012). Five clusters with different diets had been identified statistically by Froehle et al. (2012). Each cluster indicates a diet characterized in terms of C_3, C_4, and marine/terrestrial resources. We include the human samples presented in this paper as "CWA Historic" and use two group of archaeological human samples ("CWA Group I" and "CWA Group II") from pre-Hispanic times and recorded in the same region (data from Gil et al. 2009) as comparative strategies. In Fig. 4 "CWA Group I" diet (human samples with chronology between 2000 and 1000 years BP) falls almost entirely into Cluster 4, which barely overlaps Cluster 1. Therefore, "CWA GROUP I" is a result of an overall diet that was about 70 % C_3, as well as getting at least 65 % of their protein from C_3 sources (definition of each cluster in Froehle et al. 2012). In other words, both their overall diet and protein were overwhelmingly C_3, with a smaller contribution from C_4 sources. "CWA Historic" (human samples presented in this paper) falls mostly in the Cluster 1 and Cluster 4 overlapping area. Thus, they either ate a 100 % C_3 diet, or a 70 % C_3 diet similar to that of "CWA GROUP I" (definition of each cluster in Froehle et al. 2012). CWA GROUP II, with chronology between 1000 and 500 years BP, falls mostly in Cluster 2 and seems to have obtained a large portion of their overall diet and their protein from C_4 sources (definition of each cluster in Froehle et al. 2012). "CWA Historic" group diet is much more similar to "CWA GROUP I" than to "CWA GROUP II," and maize was not a significant part of the diet in "CWA Historic," at most it would have made up 30 % of the diet, but possibly it was not eaten at all.

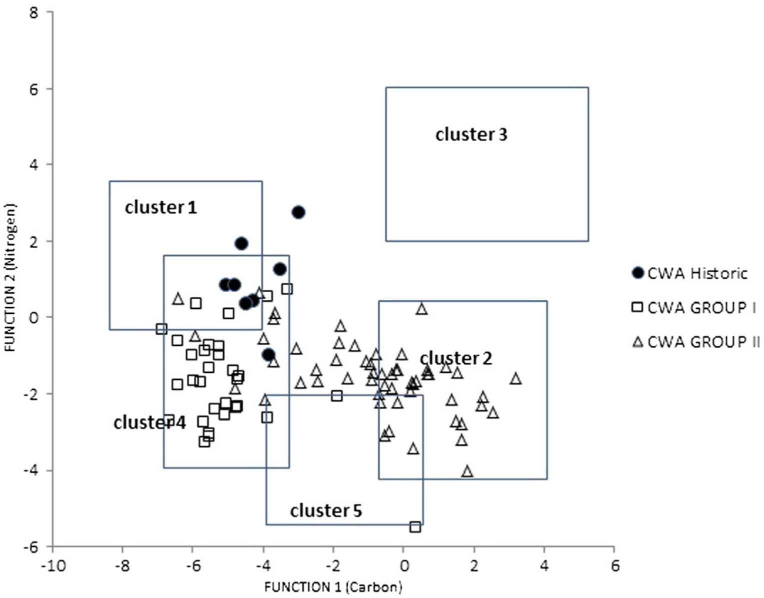

Fig. 4 Relation between the δ^{13}Ccol, δ^{13}C, δ^{15}N values in samples from the center west of Argentina using the Froehle et al. 2012 (human data from "CWA Group I" and "CWA Group II" based on Gil et al. 2009), including the results presented here ("CWA Historic")

In the samples analyzed, it has been found that $\delta^{18}O$ values have an important range of variation. In order to compare the values obtained from humans bone samples with those from water samples, the formulae presented in Knudson (2009; also see Gil et al. 2014a, b) was used. The values from humans converted to V-SMOW indicate they range from −19 to −11‰ V-SMOW, with an average of −15.5‰. The 8‰ of variation in the $\delta^{18}O$ values is a substantial range, suggesting that these individuals consumed different water sources during the last decade of their lives. This indicates differences in residential mobility and/or geographic origin between individuals. On the other hand, these values are isotopically more depleted than those expected for individuals who drank water from the Río Mendoza in the city area (expected value −8‰ V-SMOW). However, the values in human bone samples are expected to be in this region at altitudes ranging from 5500 to 2000−1500 masl, or alternatively are similar to results obtained from groundwater aquifers near the city of Mendoza (−18‰ V-SMOW, Vogel et al. 1975). In this regard, data would point to a significant use of local groundwater or, less likely, the migration of individuals from other sectors such as the highland in the Cordillera de Los Andes. This last possibility is rather unlikely due to the limited temporal availability of this sector, which can only be inhabited during the summer. Figure 5 compares the $\delta^{18}O$ obtained for human bone samples on pre-Hispanic and historic times from the lowlands and the highlands in central-western Argentina (ca. 30–32° SL; Gil et al. 2014a). Figure 5 shows a statistically significant difference, the values of the samples studied in the present paper are significantly lower than the others mentioned above (Gil et al. 2014a). The data show a change in the water source of supplies and/or geographic origin of the historical individuals from pre-Hispanic times.

Another significant topic concerns the analysis of individuals as either indigenous or Spanish or “Criollos” (creoles). The correlation between different cultural identities and cultural consumption patterns is difficult to assess from the

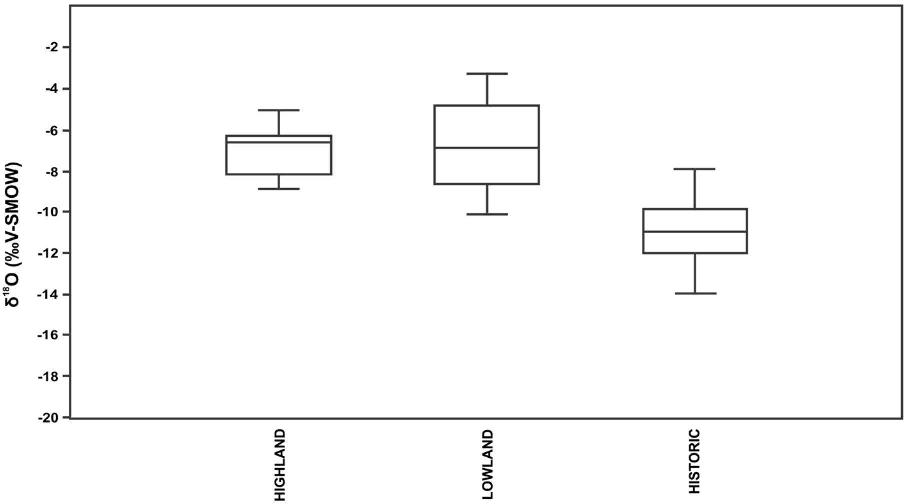

Fig. 5 Comparative trends in $\delta^{18}O$ values obtained from human samples from the North of Mendoza from the last 2000 years separated in Highland, Lowland (Gil et al. 2014a, b) and the samples presented in this paper (Historic), corresponding to this region for the last 300 years (see Gil et al. 2014a)

archaeological record. The topic is relevant but interpreting the information from the written documents is also formidable. Thus, the intention of this paper is not to focus on the ethnic association of diet patterns. We assume that if a person was buried in a temple that he or she adhered, at least formally, to the ideology of Western society as expressed in the seventeenth-nineteenth centuries. A change in their diet and consumption pattern may or may not be inferred. In general, historic funerary documents provide information about cultural identity and geographic origin of individuals (Indian, African, mulatto, creole), but lacks spatial information about the individuals' burial locations. The historic record itself is fragmentary and generally has low spatial resolution. Based on this observation, we avoid the ethnic assignation of individuals, but assume they ascribed to a Western lifestyle.

Conclusion

The results presented in this paper support the arguments of a human diet with low emphasis on maize during historical times (seventeenth-nineteenth centuries) in central-western Argentina. These trends are basically confirmed in colonial contexts recorded in Mendoza city. Agricultural practices centered on maize became important during part of the late Holocene (Gil et al. 2014b). Counter intuitively, during colonial times maize did not play such a central role to the urban population. The preliminary isotopic analysis of human individuals in rural/non urban contexts close to Mendoza city shows a similar pattern (Gil et al. 2009, 2014a, b). Maize was a highly significance resource during pre-Hispanic times, at least until 1400 CE (Gil et al. 2014b). Maize could be displaced by the early incorporation of animal (cattle, poultry) and plant (wheat and barley) products in the Mendoza valley. The zooarchaeological and archaeobotanical records in Mendoza-colony contexts are consistent with the isotopic data obtained in this study. It is debated today whether this dietary change was the result of Spanish invasion alone and/or a consequence of a new environmental structure associated with climatic change that preceded it, called the Little Ice Age (Gil et al. 2014b).

The incorporation of new, foreign products may not have taken place on a preexistent economic basis from the Huarpe ethnic group as proposed by the written documentation. The residential mobility of populations during colonial times is being debated. The $\delta^{18}O$ results are not as would be expected for a population consuming water from the Río Mendoza in the city. This river, running along canals and ditches, has always been thought to be the main source of the city's water. However, toward the end of the eighteenth century, the installation of a system of aqueducts and fountains provided water from a pre-Andean spring (El Challao) to the inhabitants of the city. In the historic reconstruction, the records from sources of drinking water have not been sufficiently analyzed. Yet, consuming water from the Río Mendoza has been taken for granted. The lack of evidence of water storage in wells or by other means provides analytical lines of research in historical documents for more concrete information about the origin of water consumed by the inhabitants of the City of Mendoza between the seventeenth and nineteenth centuries.

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