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Paleodietary analysis of the prehistoric population of the Canary Islands inferred from stable isotopes (carbon, nitrogen and hydrogen) in bone collagen

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A B S T R A C T

Nitrogen and carbon isotope compositions were measured in the bone collagen from a total of 86 prehispanic samples of the Canary Islands, and hydrogen in 70, all of them with enough amount of bone collagen, and adequate N and C content. These samples belong to prehistoric population of El Hierro ($n = 27$), Tenerife ($n = 18$), and Gran Canaria ($n = 41$). Isotope compositions were also obtained for prehistoric and modern food resources that were likely consumed by these people. Marked differences were observed among the three islands regarding the three isotopes analyzed: the δ^{15}N values were highest among the population of Gran Canaria (10.8‰ ± 0.9‰), who also showed the highest δD values (7 ± 8‰). The population of El Hierro showed the highest δ^{13}C values (−18.6‰ ± 0.7‰). These data suggest a high consumption of marine products by the population from El Hierro, and also an important consumption of terrestrial meat or marine, piscivore fish, by the population from Gran Canaria, together with domesticated C_3 plants (barley and/or wheat), fruits of *Ficus carica* and other wild species, and goat products. Additionally, marked differences were observed between men and women, which suggest that women consumed a more vegetal-based diet, a finding which is in agreement with the higher proportion of teeth with carious lesions among women.

In our study, a high δD is associated with a high δ^{15}N, suggesting a relation with animal protein (either marine or terrestrial) consumption.

1. Introduction

The Canary Islands are located in front of the North-west African coast, at a latitude 27–29° North (Fig. 1). Seven main islands and several small ones, all of them volcanic in nature, with a total area of 7250 km^2, constitute the Archipelago (Fig. 2). The climate of the Islands is extremely variable, due in part to the location of the Archipelago directly west of the Sahara desert, to the influence of the trade winds and the high mountains and huge ravines in a relatively small territory, which shape many different landscapes. In some areas aridity is prominent, whereas in others there are more humid and favourable conditions. In any case, rainfall is, in general, irregular and scarce, with a peak in fall and winter, and a prolonged dry season encompassing late spring and summer. Mountains reach considerable altitude in 5 of the seven islands (in all but Lanzarote and Fuerteventura, the two most easterly located). For instance, in Tenerife (1917 km^2), Teide peak reaches 3717 m; in La Palma, with an area of roughly 700 km^2, maximal altitude is 2432 m; Gran Canaria (1532 km^2) reaches 1949 m, and in El Hierro (270 km^2) and La Gomera (370 km^2), maximal heights are about 1500 m. These mountains act as barriers to the humid trade winds, which accumulate clouds and rainfall in the northern slopes, although the typical temperature inversion associated to trade winds in this latitude limits vertical growth of clouds, so humid conditions are restricted to an altitudinal fringe (between 600 and 1400–1600 m approximately).

1.1. Archaeological background. Economy and diet: preliminary studies

The Archipelago was inhabited in prehispanic times by people of North African origin who probably first arrived at the Islands towards the middle of the 1st millennium BC (Navarro Mederos, 1983). The probable North African origin of the first colonizers has been confirmed by recent data provided by genetic studies (Pinto

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Fig. 1. The Canary Islands in the Atlantic Ocean.

et al., 1996; Rando et al., 1999; Maca-Meyer et al., 2004). Due to still unclear reasons (Different arrival waves? Different adaptation to the geographical environment? Differences in social structure, already present before arrival?), archaeological remains differ from one island to another, although a high degree of similitude exists between neighbour islands, such as La Gomera and Tenerife or Fuerteventura and Lanzarote. Little is known about the early colonization of the Islands, but it seems that it was planned after an initial knowledge of the existence of a fertile land westwards. Primitive settlers arrived with goat and sheep, pigs, and domesticated plants, mainly barley and wheat, and colonized the different islands, probably in several arrival waves. Indeed, there are striking differences in the archaeological remains of the different islands, and even within the same island, some artefacts, such as pottery, show differences along different chronological strata.

Primitive settlers found a territory which lacked metal ores, and in which major wild sources of meat were scarce, represented only by birds, giant *Lacerta*, and, in Tenerife, by a rabbit-sized giant rat. In general these people were probably goat herders; they also practised fishing, undoubtedly, but they lacked a developed fishing technology, so they probably practised only coastal fishing, with the possible exception of Gran Canaria, in which archaeological remains suggest consumption of some marine species rarely reaching the coasts. By unknown reasons, contact between the islands was scarce, with the possible exception of some exchange between neighbour islands. Therefore, probably, the economy and social structure of the population of each of the different islands, although with a similar substrate, evolved in quite different ways. For instance, agriculture was strongly developed in Gran Canaria, and fishing was also important. Probably, these economic activities led to a considerable demographic concentration in this island. According to chroniclers who arrived with the Spanish conquerors during the 15th century (Morales Padrón, 1994), it was already inhabited by nearly 50 000 individuals with a population density of 30 inh/km^2. Several archaeological and ethnohistorical data support the existence of a strong hierarchical society, with a great reliance on agriculture, an economic activity which was less developed in the other islands. Indeed, recent reports suggest that as early as in 300 AD planned agriculture was performed by the islanders from Gran Canaria, not only including corn (*Hordeum vulgare*; *Triticum aestivum*) but also the exploitation of wild species, such as *Ficus carica.* Remains of fruits of these trees were especially abundant in some archaeological sites, even with quite antique dates (app. 1700 BP, La Cerera; Morales Mateo, 2009). Another important vegetal source of food was the fruits of the very abundant *Phoenix canariensis.* Scarce, scattered remains of *Lens culinaris* and *Pisum sativum* have been also recovered from some archaeological sites.

However, agriculture faces several problems in the Islands. In addition to the existence of arid or desertic areas, and to the sometimes torrential nature of rainfall, the proximity of the Islands to the Sahara desert and Sahel facilitated the arrival of locust plagues which devastated the fields and ruined the crop and *F. carica* plantations (repeatedly documented since short after Spanish conquest, Cola Benítez, 1996). This would almost certainly have been followed by widespread malnutrition. In support of this, we have shown a high prevalence of osteopenia among the inhabitants of Gran Canaria, assessed both by histomorphometric (Velasco-Vázquez et al., 1999) and radiological methods (González-Reimers et al., 2007), possibly explained by a poor nutritional status. Also, the proportion of adult individuals who died at young ages is strikingly high among the population of Gran Canaria (Velasco-Vázquez et al., 1999). Archaeological remains from Gran

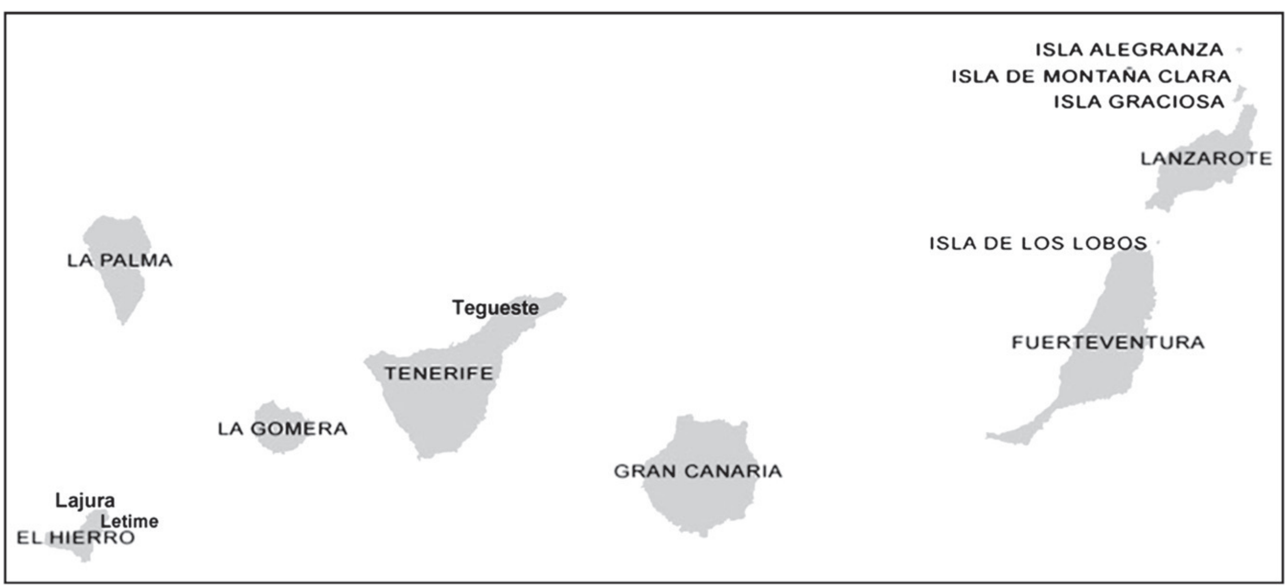

Fig. 2. The Canary Islands (Map scale 1:8 000 000).

Canaria, which huge silos located in easily defensible places, lend support to chroniclers' writings about the importance of agriculture and also stress the threads imposed by climate to this economic activity: in these silos, agriculture surplus should have been kept to be distributed by the landlords, but also constituted a reserve of corn in years of bad yield. Not only the trace element pattern suggests an important consumption of vegetables (González-Reimers and Arnay-de-la-Rosa, 1992), but this is also reinforced by the finding of a high prevalence of caries in the skeletons from this island (Delgado-Darias et al., 2006). Thus, archaeological data fit well with the results of the anthropological studies already commented.

Tenerife is the largest island of the Archipelago, but it was not as populated as Gran Canaria (about 15 000–20 000 inhabitants). A mountain barrier separates a fertile northern side from an arid southern part. Probably, the main economic activity was based on goat herding, although, undoubtedly, agriculture was also performed by their inhabitants. Preliminary data support the hypothesis that prevalence of osteopenia was less than among Gran Canaria, and, according to bone trace elements, dietary pattern was a mixed one, with less strontium than in Gran Canaria or El Hierro (González-Reimers et al., 1991). Similar results for Tenerife were also reported by other authors some years later (Aufderheide et al., 1992). Also, some studies have been made analysing carbon and nitrogen isotope composition of bone collagen on samples of Tenerife and carbon isotopes for bioapatite on some skeletal remains and mummies from Tenerife (Tieszen et al., 1995), and also including many plants and potentially consumed animal products.

In contrast with Gran Canaria and Tenerife, only 300 men should have survived in El Hierro at the time of the conquest by the Spaniards. Coastal fishing, shellfishing (there are huge shell middens in several parts of the island) and consumption of some wild vegetables, a rudimentary agriculture (wheat and barley) and goat herding were the main economic activities of these people (Jiménez Gómez, 1993). In contrast with Gran Canaria, prevalence of osteopenia is low among the prehispanic islanders from El Hierro (González-Reimers et al., 2004). As in other islands of the Archipelago, goats were, by far, the predominant domestic animals, reaching 85–90% of the bone remains in some archaeological sites, and also, scarce remains of sheep and a few pigs (only 2–3% of the total sample in some archaeological sites, Hernández Pérez, 2002).

Thus, available dietary information from the prehistoric population of the Canary Islands is fragmentary, based on dental pathology and bone trace element analysis. Therefore, further paleodietary research, such as that derived from stable isotopes, is needed, as well as comparative studies among the population of the different islands.

Mass differences between stable isotopes permit separation of the light isotopes from the heavy isotopes during chemical reactions which normally occur in living organisms, and also during physical processes such as diffusion (for instance, of carbon dioxide in the lungs) and vaporization (for instance, of sweat). This process is called isotope fractionation, and allows dietary reconstruction, knowing isotope composition of potential food sources, and assuming a given enrichment along the trophic chain. Although a step-wise enrichment in δ^{15}N of 3–3.4‰ between trophic levels is widely accepted (Schoeninger and DeNiro, 1984), the magnitude of the increase in δ^{13}C along the trophic chain is subjected to debate (Drucker and Bocherens, 2004).

Stable isotopes can be measured in the mineral phase of the bone – constituted by hydroxyapatite, with a significant proportion of carbonate salts – or in bone collagen. Collagen is a protein, thus formed by aminoacids, which contains nitrogen. Nitrogen necessarily derives from proteins, so nitrogen isotopes, determined in bone collagen, inform us about protein intake. On the contrary, carbon from bone collagen, or from carbonate salts in bone, and that part of oxygen present in the mineral phase, may derive from inhaled air, ingested water, carbohydrates, lipids, and proteins. However, the proportion of protein-derived carbon in collagen is greater, due to the presence of essential and semi-essential aminoacids. Isotope contents in both kinds of tissue have been widely used to estimate dietary patterns of prehistoric humans for several decades (DeNiro and Epstein, 1978, 1981; Schoeninger et al., 1983; Schoeninger and DeNiro, 1984; Ambrose et al., 2003).

Only recently, determination of δD in bone collagen has been incorporated to dietary studies. The rationale for its use is the following: 1) approximately 60% of the non-exchangeable hydrogen in bone collagen comes from food; 2) the marine system is about 45‰ higher in δD than terrestrial environment. If 60% of hydrogen comes from food hydrogen, than the effective difference between marine and terrestrial diets is about 60% $\times$ 45 $=$ 30‰. Therefore, a 33% marine component of a given diet would result in a 10‰ increase in the δD (Reynard and Hedges, 2008). Moreover, in one study in Great Britain, the δD values differed from carnivores/piscivores to herbivores/omnivores by about 90‰ (Birchall et al., 2005).

Nitrogen and carbon isotopes for the samples from Tenerife and El Hierro have been already reported (Yanes et al., in press), suggesting consumption of a mixed diet, but it is important to compare this information with that obtained for the population of other islands, and to put it in relation with the information derived from δD analysis. Therefore, based on this fact, and on the differences between archaeological remains, and, possibly, different economic pattern of the prehispanic society of different islands of the Canary Archipelago, such as Tenerife, El Hierro, and Gran Canaria, we performed the present study in order to compare collagen stable isotopes of carbon and nitrogen between skeletal remains of prehispanic individuals of these islands, and also to explore the relation between these two isotope values and hydrogen isotopes. This study, performed on remains of people who lived in a subtropical area of the Atlantic, may add to the general knowledge of stable isotopes in ancient population of different parts of the world. In addition, taking in consideration the relative paucity of studies dealing with the significance of δD in the inference of prehistoric diets, this study also pursues to deepen our knowledge about the role of δD in paleodietary analyses.

2. Material and methods

2.1. Sample

The samples analyzed include firstly, 18 bone samples belonging to adult individuals from Tenerife, which were found in several collective burials from Tegueste (Barranco del Agua de Dios). These collective burials were excavated about 150 years ago, and the anthropological collections reside at the Instituto Cabrera Pinto, in La Laguna city. Although radiocarbon dating on these samples is lacking, antiquity of other samples from Tenerife, buried in similar archaeological context, shows a range from 1800 to 700 BP (Galván et al., 1999). Secondly, 27 bone samples of individuals from El Hierro (La Lajura and Letime), excavated by one of us (Velasco-Vázquez et al., 2005). Data regarding carbon and nitrogen isotopes of the samples from Tenerife and 26 of the samples from El Hierro have been already reported (Yanes et al., in press). Radiocarbon data are available for individuals from El Hierro, yielding antiquities ranging from 1700 $\pm$ 40 BP to 1220 $\pm$ 40 BP (Velasco-Vázquez et al., 2005). The majority of analyzed bones are tibias, although pelvis and cervical vertebrae were studied for some individuals from El Hierro (Table 1). Thirdly, 41 samples from Gran Canaria, from several collective burial sites shown in Fig. 3, most of them

Table 1
Carbon and nitrogen isotopes in some species potentially consumed by the prehispanic inhabitants of the Canary Islands.

Species	Tissue	$\delta^{15}N$	$\delta^{13}C$	Source
Osilinus attratus[a]	Body tissue	6.7	−18.4	This study
O. attratus[a]	Shell organic matter	7.0	−16.5	This study
O. attratus[a]	Body tissue	7.9	−18.4	This study
Patella piperata[a](modern)	Shell organic matter	3.3	−14.5	This study
Patella sp[a]	Body tissue	5.1	−14.1	Tieszen et al., 1995
Thais haemastoma[a]	Body tissue	7.8	−15.0	Tieszen et al., 1995
Patella piperata[a] (modern)	Shell organic matter	4.4	−13.1	This study
Grapsus grapsus (crab)	Body tissue	8.7	−15,3	Tieszen et al., 1995
Sea urchin	Body tissue	9.5	−16,6	Tieszen et al., 1995
Hogfish[b]	Bone collagen	12.1	−15.0	Tieszen et al., 1995
Mycteroperca rubra[b] (Prehistoric)	Bone collagen	11.4 ± 0.23[c]	−11.1 ± 0.6[c]	Tieszen et al., 1995
Sparisoma cretensis[b] (Prehistoric)	Bone collagen	8.3 ± 0.10[c]	−13.1 ± 0.32[c]	Tieszen et al., 1995
Lacerta Goliath (giant extinct lizard)	Bone collagen	10.9	−20.5	This study
Canaryomis bravoi (giant extinct rat)	Bone collagen	9.6	−16.5	This study
Phoenix canariensis (modern)	Fruit	9.0	−27.5	This study
Barley (modern)	Seeds	3.4	−25	This study
Ficus carica (modern)	Leaves	8.7	−27.1	This study
Pteridium aquilinum (modern)	Rhyzoma	5.4	−25.5	This study
Wheat (Modern)	Seeds	2.0	−23.4	This study
Goat (Prehistoric)	Bone collagen	8.2	−18.5	This study

[a] Gastropods.
[b] Fish.
[c] Standard error.

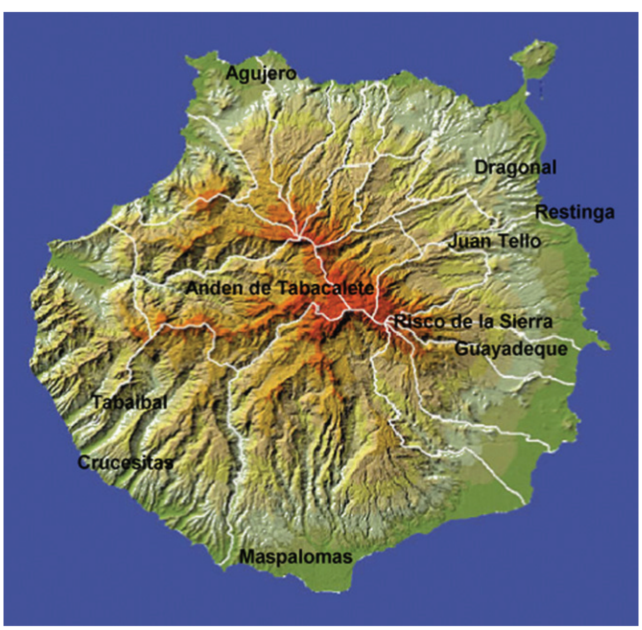

Fig. 3. The island Gran Canaria, with the archaeological sites in which the samples included in the study were found (map scale = 1:600 000).

excavated long ago (>100 years), currently deposited at the Museo Canario of the city of Las Palmas; radiocarbon dating performed on some of these samples yields antiquities ranging from 875 ± 60 BP to 1140 ± 100 BP.

Sex was estimated by pelvis inspection (Ubelaker, 1989), and also applying the discriminant functions which were obtained from the prehispanic population of Gran Canaria, when tibiae were available (González-Reimers et al., 2000). Sex determination was possible only for 8 individuals from Tenerife (3 males and 5 females), for 23 individuals from El Hierro (7 males and 16 females), and for 28 individuals from Gran Canaria (11 men and 17 women).

In 1995, Tieszen et al., and, later, Bocherens et al. (2003), carried out a study of carbon and nitrogen isotopes composition of theoretical potential food sources of the prehispanic population of the Islands; some of the species analyzed formed part of the diet consumed by the prehispanic inhabitants, but some others have never been documented in archaeological sites. In this study we have also selected some other (although not all) potential dietary items for isotope analysis based on published records of food resources consumed by these people, documented by archaeological findings (Jiménez Gómez, 1996; Rodríguez Santana, 1996). Many of the already reported results by Tieszen et al. (1995) and Bocherens et al. (2003), together with others performed for this study are shown in Table 1.

2.2. Stable isotopes

2.2.1. Bone collagen extraction

The collagen extraction used was established by Ambrose (1990) and Bocherens et al. (1991). Clean pieces of bone were ground in an agate mortar and pestled to a grain size less than 0.7 mm. About 200 mg of bone powder was weighed into a 2 mL Eppendorf centrifuge tube, and 1 M HCl was added to dissolve the mineral phase during 20 min. Samples were then centrifuged and the supernatant was poured off. The pellet was rinsed with distilled water and centrifuged three times. The remaining solid was plunged into 0.1 M NaOH for 20 h at room-temperature to remove organic contaminants. Samples were again rinsed with distilled water three times by repeated centrifugations. The residue was then placed into 0.01 M HCl (pH = 2) in closed tubes, at 57 °C for 17 h, to solubilize the collagen. After centrifugation of the samples, the supernatant (containing solubilized collagen) was freeze-dried overnight. Yield collagen was expressed as the mass of freeze-dried collagen relative to the original dry weight of bone.

2.2.2. Plant sample preparation and sea shell organic matter extraction

Modern cereal samples (wheat and barley) were first cleaned with distilled water by sonication and then oven-dried at 40–50 °C overnight. Samples were lipid extracted using 2:1 Chloroform:Methanol mixture for 20 h prior isotope analysis. Dry plant tissues were then grounded and homogenized. Lipids are depleted in $\delta^{13}C$ values (up to ∼3‰) compared to proteins and carbohydrates, and consequently, variations in the lipid content of organic tissues will significantly influence the $\delta^{13}C$ values (DeNiro and Epstein, 1977; Tieszen et al., 1983). Thus, the content of lipids in different organic tissues (within and among individuals) may vary and should be removed prior isotopic analysis in dietary and ecological studies (e.g., Bodin et al., 2006).

Sea shells and some body tissues of modern gastropod individuals were rinsed with distilled water while constant sonication. Clean shells were digested with 5 M HCl to eliminate completely the carbonate (between 1 and 5 days) until bubbling stopped. Samples were then centrifuged and the pellet (containing the shell

Table 2
Results of the human samples included in this study.

Signature	$\delta^{13}C$	$\delta^{15}N$	%N	% C	Collagen (%)	C/N	δD
Tenerife							
CP45	−19.4	10.6	10.7	27.98	1.7	3.08	12
Cp36	−20.1	9.5	9.01	24.17	1.60	3.13	−7
Cp64	−19.9	9.5	8.85	23.34	2.30	3.08	−24
CP53	−20.1	9.7	10.90	28.50	2.30	3.00	−19
CP49	−20.1	8.9	13.50	36.03	6.40	3.07	3
CP51	−19.7	10.0	15.70	40.70	6.40	3.00	−8
CPD2	−19.4	10.8	10.72	27.58	1.80	3.00	7
CP65	−20.3	9.6	10.90	28.20	3.40	3.00	−4
CP71	−20.2	8.6	12.00	30.90	2.40	3.00	−9
CP48	−19.5	10.2	11.90	30.80	2.10	3.00	1
CP52	−20.1	9.7	10.93	28.30	2.20	3.00	3
CP35	−19.9	9.8	10.36	27.55	1.40	3.10	11
CP62	−20.1	9.9	11.40	29.90	1.50	3.10	−7
CPD12	−20.3	9.6	11.46	30.90	1.70	3.10	8
CP34	−20.1	8.7	8.94	24.09	1.50	3.10	−18
CP11	−19.8	9.7	7.30	20.00	3.00	3.20	−16
Cp50	−19.1	10.7	12.81	34.30	3.00	3.09	4
CP7	−20.3	9.3	9.94	25.98	1.10	3.00	1
El Hierro							
29 H	−18.8	9.6	11.20	31.42	2.00	3.28	−20
31 H	−20.3	8.7	15.24	41.22	7.10	3.15	−29
10 H	−17.8	9.1	12.45	33.56	2.10	3.15	−15
35 H	−17.9	9.1	14.91	40.00	6.10	3.13	−15
7 H	−18.5	10.6	12.26	33.46	2.20	3.18	−8
15 H	−19.7	9.2	14.97	39.18	6.50	3.09	−15
20 H	−18.2	9.6	10.33	27.12	2.10	3.09	−18
34 H	−18.3	10.7	14.03	37.27	4.70	3.09	
1 H	−18.3	10.9	12.89	33.45	3.90	3.03	−17
1842 H	−19.1	9.9	13.69	36.73	3.10	3.15	−17
9 H	−18.6	9.4	7.30	19.54	2.20	3.09	
1556 H	−18.1	10.0	12.93	33.74	4.50	3.09	−14
25 H	−18.3	8.9	13.03	33.85	2.70	3.03	−20
26 H	−19.8	10.0	11.75	32.65	1.10	3.21	−13
233 H	−18.4	10.8	12.40	34.07	3.50	3.09	−15
11 H	−17.9	10.1	11.99	32.89	2.10	3.21	0
17 H	−17.9	11.4	10.72	30.34	1.50	3.33	1
2 H	−18.3	9.5	15.13	39.72	5.90	3.09	−7
12 H	−19.8	9.1	13.30	35.64	3.50	3.15	−13
30 H	−17.9	11.1	10.73	28.46	3.30	3.09	−7
1696 H	−18.7	9.2	11.61	30.38	2.50	3.03	−22
6 H	−18.9	9.0	11.72	31.54	2.80	3.15	−27
244 H	−18.4	8.8	9.86	26.28	1.70	3.15	−13
117 H	−18.1	9.2	10.31	28.56	1.20	3.27	−12
4 H	−18.6	8.9	9.41	26.73	1.30	3.27	−1
28 H	−18.0	11.0	11.28	29.74	1.60	3.03	8
1032 H	−18.2	10.2	14.17	39.19	2.60	3.03	−12
Gran Canaria.							
AGU 1168	−18.9	13.2	14.50	38.80	4.20	3.10	22
Cab2017	−20.3	10.4	12.80	35.20	4.30	3.20	2
Cas 1198	−19.7	11.5	8.00	23.70	2.00	3.50	−3
Cruc1156	−19.0	10.7	14.40	39.00	4.80	3.20	10
Drag2019	−19.6	10.5	14.50	39.70	7.00	3.20	22
RSie1060	−19.8	10.5	12.50	34.10	3.20	3.20	3
RSie1064	−19.2	11.7	15.60	44.00	6.10	3.30	6
RSie1063	−19.5	11.3	14.70	40.10	3.80	3.20	7
ATAB 104	−19.8	10.5	16.20	43.70	8.40	3.10	15
ATAB1049	−19.5	9.3	14.20	38.70	5.30	3.20	3
ATAB1051	−20.3	8.5	12.80	36.00	3.90	3.30	
GUA1001	−19.1	11.8	14.20	38.00	6.20	3.10	3
Gua 1002	−19.9	10.6	13.30	36.40	5.20	3.20	−3
GUA 1006	−19.9	10.0	15.00	42.40	10.50	3.30	9
GUA 101	−19.9	10.2	16.20	43.50	19.00	3.10	
GUA 1010	−19.4	12.0	14.50	39.50	6.50	3.20	13
GUA 1018	−19.5	9.9	14.10	37.80	5.60	3.10	7
GUA 1022	−19.5	10.8	16.20	46.10	10.30	3.30	−2
GUA-1071	−18.8	12.7	14.90	39.60	9.30	3.10	6
GUA-1078	−18.8	11.7	14.80	40.90	5.50	3.20	22
GUA-1083	−20.3	9.3	15.60	41.90	9.20	3.10	7
GUA-1087	−18.8	12.5	14.90	38.60	13.80	3.00	−1
GUA-1088	−19.8	9.9	13.30	35.30	4.10	3.10	−6
GUA-1092	−19.6	10.0	14.60	38.60	7.80	3.10	6
GUA-1097	−19.5	11.2	15.20	40.80	7.50	3.10	10
GUA-1101	−18.2	11.1	14.00	38.00	5.90	3.20	23
GUA-1145	−19.2	11.6	14.50	39.70	5.70	3.20	1
GUA-1201	−19.0	11.3	13.70	35.80	8.70	3.00	
GUA-1203	−19.3	11.1	16.10	42.00	14.40	3.10	2
GUA-2026	−19.6	10.4	13.30	36.40	4.80	3.20	
GUA-2097	−19.8	11.2	16.20	44.50	8.20	3.20	6
GUA-2099	−19.8	10.1	15.40	42.30	6.70	3.20	13
GUA-2101	−19.8	10.2	15.30	41.60	6.70	3.20	2
GUA 210	−19.9	11.0	15.90	43.10	8.00	3.20	
Tell1197	−19.6	10.5	14.40	38.00	5.10	3.10	9
Tell1198	−19.7	10.0	14.10	38.10	5.80	3.10	3
Ind1GC	−18.7	11.2	4.90	14.40	1.00	3.40	

organics) was first rinsed with DI water and then oven-dried at 40–50 °C overnight.

2.2.3. Stable isotope analysis

2.2.3.1. Analytical methods. Samples were analyzed in the stable isotope laboratory of the Savannah River Ecology Laboratory, University of Georgia, using a Finnigan Delta^{PLUS} XL continuous flow isotope ratio mass spectrometer (CF-IRMS).

All stable isotope results are reported in δ notation relative to the AIR for nitrogen, the international Vienna-Pee Dee Belemnite (VPDB) for carbon and oxygen and the Vienna-Standard Mean Ocean Water (VSMOW) for hydrogen. The δ values are defined as:

$$\delta^{15}N \text{ or } \delta^{13}C \text{ or } \delta D = \left[\left(R_{sample}/R_{standard}\right) - 1\right] \times 1000 (\text{in ‰ units})$$

where R = $^{15}N/^{14}N$ or $^{13}C/^{12}C$ or $^{2}H/^{1}H$

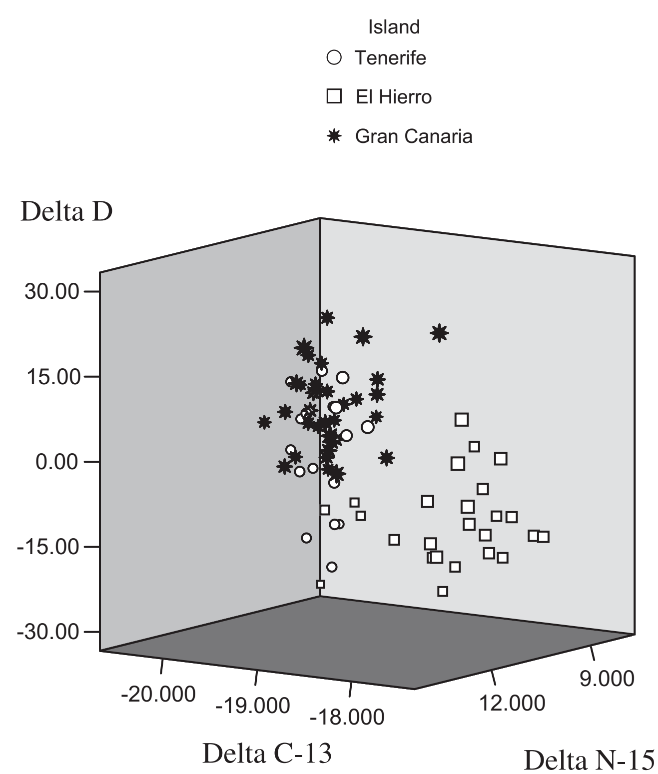

Fig. 4. Ternary diagram showing the data corresponding to human skeletal samples of the three islands. Note that samples from El Hierro cluster apart from the other two, and that samples from Gran Canaria show the highest δD values.

Table 3
Mean values of carbon, nitrogen, and hydrogen isotopes in the population of the different islands.

	$\delta^{13}C$ (‰)	$\delta^{15}N$ (‰)	δD (‰)
Tenerife (1)	−19.9 ± 0.4	9.7 ± 0.6	−3 ± 11 −2 (−11 to +5)
El Hierro (2)	−18.6 ± 0.7	9.8 ± 0.8	−13 ± 9 −14 (−18 to −8)
Gran Canaria (3)	−19.4 ± 0.5	10.8 ± 0.9	7 ± 8 6 (+ 2–+11)
ANOVA	$F = 40.92$; $p < 0.001$	$F = 17.98$; $p < 0.001$	KW = 37.73; $p < 0.001$
SNK	1 vs 2, 3; 2 vs 3	1,2 vs 3	1 vs 2,3; 2 vs 3

2.2.3.1.1. Nitrogen and carbon stable isotope analysis in bone collagen. About 1 mg of bone collagen, ~1 mg of shell organics and ~5 mg of grounded plant tissue and of soil organic matter powder were weighed into a pre-cleaned tin capsule, crimped and combusted in a Carlo Erba Elemental Analyzer (NC 2500). The CO_2 produced after combustion was analyzed using the CF-IRMS. Multiple in-house standards ($n = 20$) were analyzed as a check on the analytical precision of the analysis, which was better than ±0.1‰ (1σ standard deviation).

2.2.3.1.2. Hydrogen stable isotope analysis in bone collagen. About 0.8 mg of bone collagen was weighed into a pre-cleaned silver capsule, crimped and analyzed in the High Temperature Conversion/Elemental Analyzer (TC/EA) connected to the IRMS. The H_2 produced after pyrolysis was analyzed using the CF-IRMS. Multiple in-house standards ($n = 16$) were analyzed as a check on the analytical precision of the analysis, which was better than ±1‰ (1σ standard deviation).

The carbon isotope composition of modern food sources was corrected for the Suess effect (i.e., isotopic depletion of surface carbon reservoirs due to the burning of fossil fuels) by adding 1.6‰ to measured food values (Marino and McElroy, 1991; Ambrose et al., 1997). The following assumptions regarding metabolic fractionations and the Suess effect are employed in this study are: (1) $\delta^{13}C_{prehistoric\ tissues} = \delta^{13}C_{modern\ tissues} + 1.6‰$, (2) $\delta^{13}C_{diet} = \delta^{13}C_{human\ collagen} - 1‰$ and (3) $\delta^{15}N_{diet} = \delta^{15}N_{collagen} - 3‰$.

2.3. Dietary reconstruction via IsoSource

The quantitative contribution of potentially consumed food sources was computed using the *IsoSource 1.3.1* software (http://www.epa.gov/wed/pages/models/StableIsotopes/isotopes.htm) following Phillips and Gregg (2003), using a model proposed

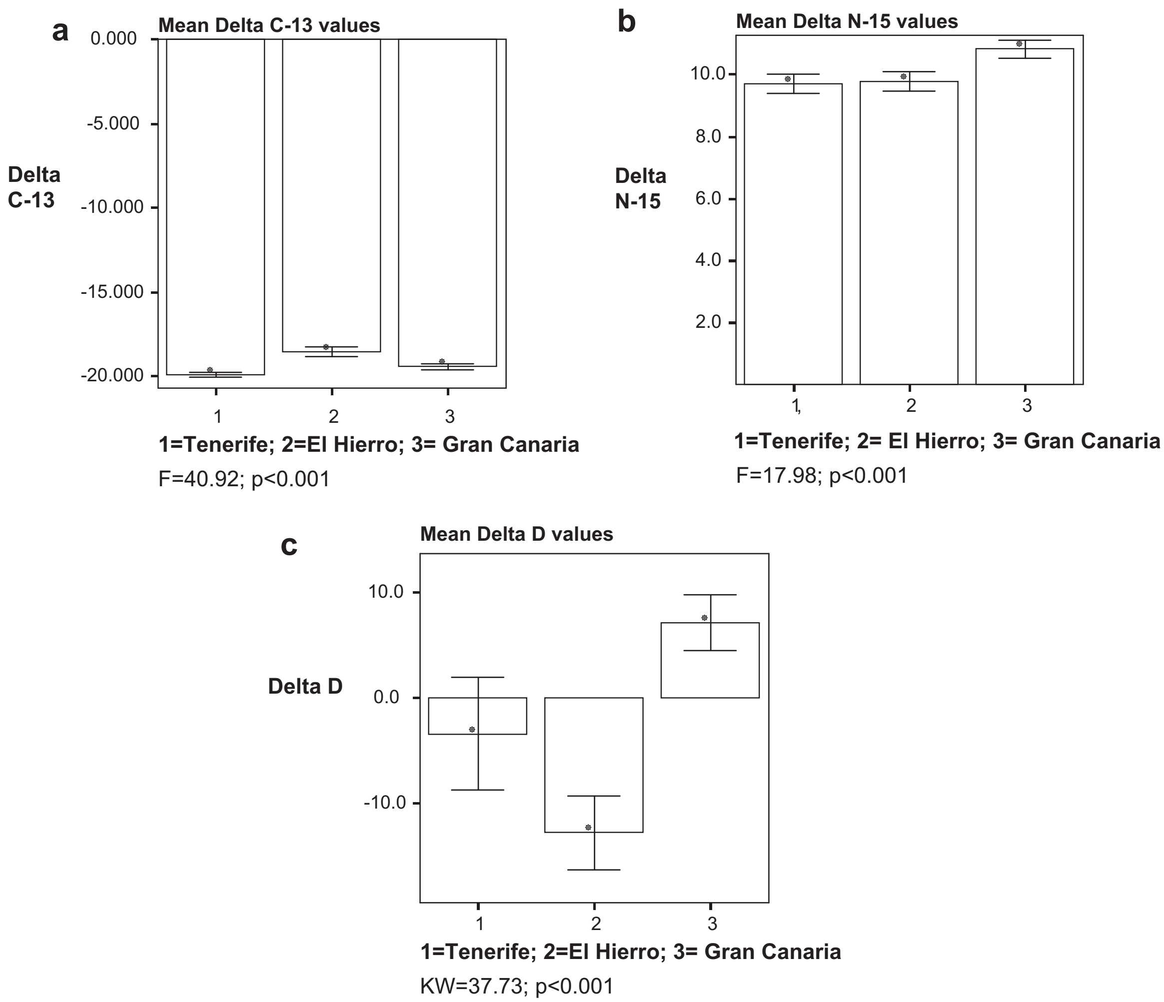

Fig. 5. a) Differences in $\delta^{13}C$ between the population of the different islands. b) Differences in $\delta^{15}N$ between the population of the different islands. c) Differences in δD between the population of the different islands.

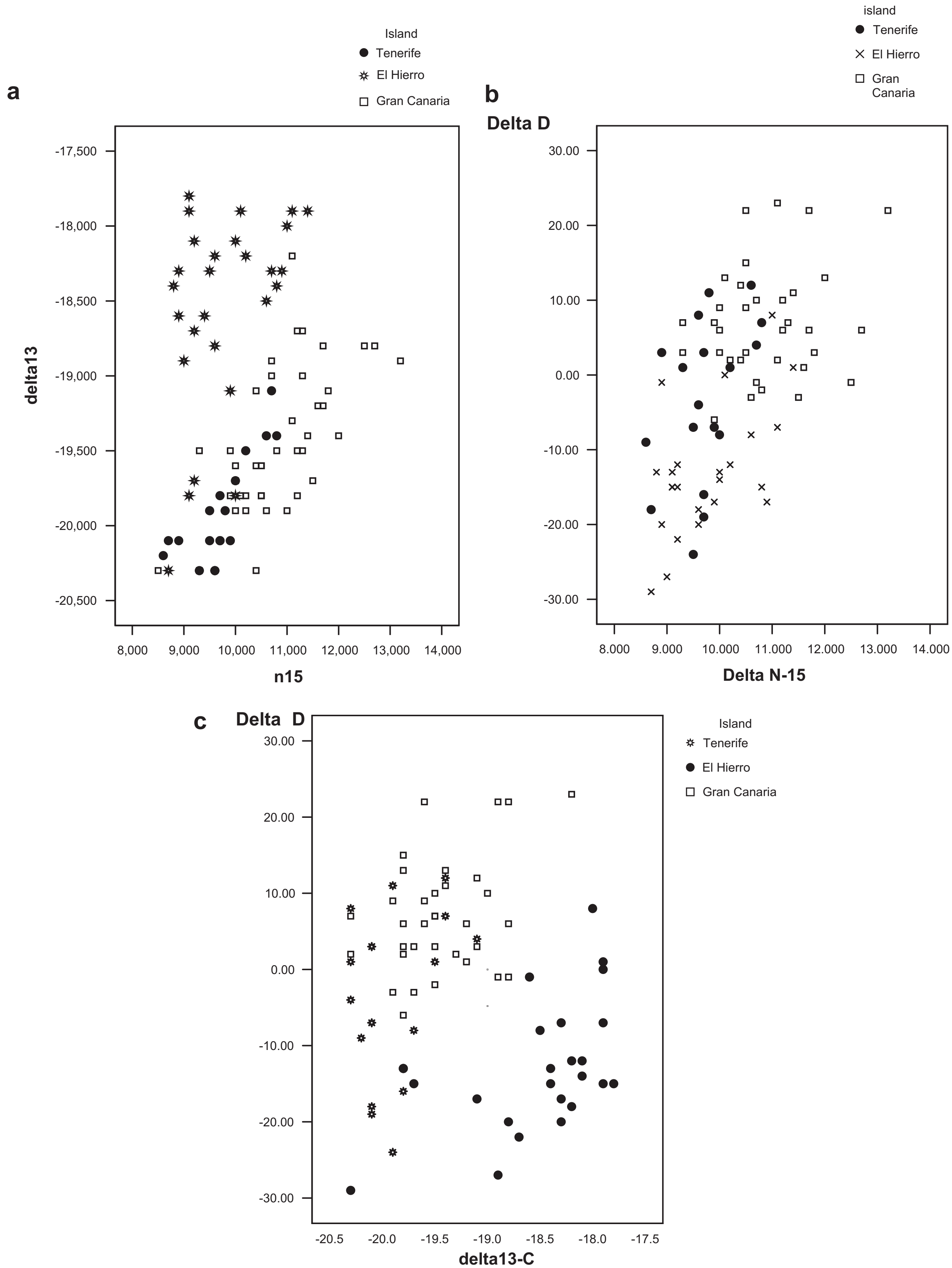

Fig. 6. a) Relationship between $\delta^{13}C$ and $\delta^{15}N$ in human samples of the three islands. b) Relationship between $\delta^{15}N$ and δD in human samples of the three islands. c) Relationship between $\delta^{13}C$ and δD in human samples of the three islands.

Table 4
Differences in δ^{13}C, δ^{15}N and δD between men and women.

		δ^{13}C (‰)		δ^{15}N (‰)		δD (‰)	
Gran Canaria	Men (11)	−19.2 ± 0.5	$T = 2.18$; $P = 0.039$	11.0 ± 1.1	$T = 1.03$; NS	10 ± 9	$Z = 1.31$; $p = 0.19$
	Women (17)	−19.6 ± 0.5		10.6 ± 1.0		5 ± 4	
Tenerife	Men (3)	−19.4 ± 0.4	$T = 4.80$; $p = 0.003$	10.4 ± 0.6	$T = 2.63$; $p = 0.039$	−2 ± 13	$Z = 0.15$; $p = 0.88$
	Women (5)	−20.2 ± 0.1		9.4 ± 0.5		−3 ± 7	
El Hierro	Men (7)	−18.3 ± 0.7	$T = 1.19$; NS	10.5 ± 0.8	$T = 3.18$; $P < 0.005$	−8 ± 10	$Z = 1.44$; $p = 0.15$
	Women (16)	−18.7 ± 0.7		9.5 ± 0.7		−15 ± 8	

by these authors, which computes the range of feasible source contributions to a mixture when there are too many sources to allow a unique solution through isotopic signatures. All possible combinations of each source contribution (0–100%) are examined in small increments and a small tolerance. We introduced in the program δ^{13}C and δ^{15}N values of terrestrial animals (*Lacerta goliath*); shellfish (*Osilinus attratus*; *Thais haemastona*, *Patella* sp.), crabs (*Grapsus grapsus*), sea urchin; fish (*Sparisoma cretense*, hogfish, *Mycteroperca rubra*); wild plants (dates of *P. canariensis*, leaves of *F. carica,* a partially domesticated tree); wheat and barley, and domestic animals (goat). Being certainly difficult to assess which proportion of each of these food components was really consumed (for instance, which species of fish, or shellfish), we calculated an approximate mean value for different groups of food, and introduced them in the program. So, after correction of δ^{13}C in the cases in which modern food samples were analyzed, we introduced δ^{13}C and δ^{15}N values of *Lacerta* as an indicator of consumption of meat of wild species, δ^{13}C and δ^{15}N of goats as an indicator of consumption of meat/milk of domestic species, δ^{13}C and δ^{15}N of −13.5‰ and 6.9‰, respectively, as indicators of shellfish, crabs and sea urchin consumption; δ^{13}C and δ^{15}N of −12.7‰ and 11.2‰, as indicators of fish consumption; δ^{13}C and δ^{15}N of −25.7‰ and 8.9‰, respectively, as indicators of *P. canariensis,* and *F. carica* consumption, and δ^{13}C and δ^{15}N of −22.7‰ and 3.4‰, as indicators of corn consumption (wheat and barley). All these values are derived from data obtained from our laboratory (Savannah River Ecology Laboratory, The University of Georgia, USA), and from those reported by Tieszen et al. (1995) or Bocherens et al. (2003), as shown in Table 1. In any case, data derived from the *IsoSource* program were only used as a complementary aid to estimate diet composition.

2.4. Statistics

Comparisons between the mean values of δ^{13}C and δ^{15}N and δD between the samples of the different islands were performed using ANOVA and further SNK test. Student's t test was used to detect differences between men and women in each island. Previous Kolmogorov–Smirnov test confirmed the parametric distribution of isotope values (something not fulfilled by δD). With the aid of the *IsoSource* program we calculated the proportion of each food item previously mentioned, grouping after the results in terrestrial meat (goat + lizard), marine products (fish + shellfish) and vegetal food (wild + domestic) consumed by each individual. A correlation analysis was then performed between δD values with δ^{13}C and δ^{15}N values, and also between δD values and the mentioned proportions of food (meat, marine food, vegetables) obtained with the *IsoSource* program. Statistics were performed with the aid of SPSS (Statistical Package for Social Sciences, Chicago, Ill).

Table 5
Dietary inference based on the application of the *IsoSource* program (%).

	Gran Canaria	El Hierro	Tenerife
Meat (Wild)	36–70	20–46	14–53
Shellfish	0–9	2–20	1–15
Fish	8–30	11–34	4–24
Vegetals (wild)	3–25	4–26	9–35
Vegetals (crop)	0–6	1–12	1–12
Goat	1–16	2–31	2–29

3. Results

3.1. Food sources stable isotope composition

In Table 1 we show the data of isotope composition of food sources which were certainly consumed by the prehispanic Islanders, specifying whether the results belong to this study or to those reported elsewhere. This is not a complete list, especially regarding fish species, since isotope composition of several others, documented in archaeological records, has not been analyzed as yet. However, Richards and Hedges (1999) compiled data from piscivore fish from several locations around the world, δ^{13}C and δ^{15}N values ranging −12.8‰δ to −17.2‰ and 12.8‰–14.5‰, respectively. Our data on *S. cretense*, and those reported by Tieszen et al. (1995) fully agree with the usual diet of these animals, consumers of marine plants and algae, whereas the δ^{13}C and δ^{15}N values for *M. rubra* and hogfish may support that these animals belong to a higher step in the food chain. Indeed, isotope analysis of these fish species shows a relatively high δ^{15}N, suggesting a fish-eating diet, in the range of the values reported by Richards and Hedges (1999). Also, especially in El Hierro, but also in Tenerife and Gran Canaria, there are enormous shell middens containing mainly *Patella*, some *Thais*, and some *Osilinus*, but also remains of crabs (*Grapsus*) and sea urchins. Limpets (*Patella*) showed δ^{13}C and δ^{15}N mean values compatible with algae grazing, whereas data for the carnivorous *Thais* show higher δ^{15}N values. Data of *Grapsus* and sea urchins – reported by Tieszen et al. (1995) – suggest a consumption of a mixed diet by these animals. The isotope values of prehistoric giant lizard (*Gallotia goliath*) suggest a diet that included C_3 plants but possibly some contribution of insects and animal protein. In archaeological sites from Tenerife – but not from El Hierro and Gran Canaria, where remains of these animals have not been recorded – there are some remains of *Canaryomis bravoi*, a giant rat with the size of a rabbit. Isotope composition of the bones of these animals shows relatively high values of δ^{15}N and, in the case of *Canaryomis*, and also a relatively high value of δ^{13}C, suggesting consumption of a mixed diet which also probably included animal protein.

Finally, the δ^{13}C values of domestic prehistoric ovicaprid bones averaged −20 ± 1.0‰, indicative of a primarily C_3 plant ingestion (Richards and Hedges, 1999), whereas the δ^{15}N value was indicative of a varied diet including plants and possibly other animal proteins. Both domestic plants (wheat and barley) and wild vegetal resources show very low δ^{13}C values, indicating a C_3 photosynthetic pathway. Interestingly, δ^{15}N values of fruits of *F. carica* and *P. canariensis* are significantly higher than those of domestic crop. In Table 1 we also provide δ^{13}C and δ^{15}N values of other potential wild

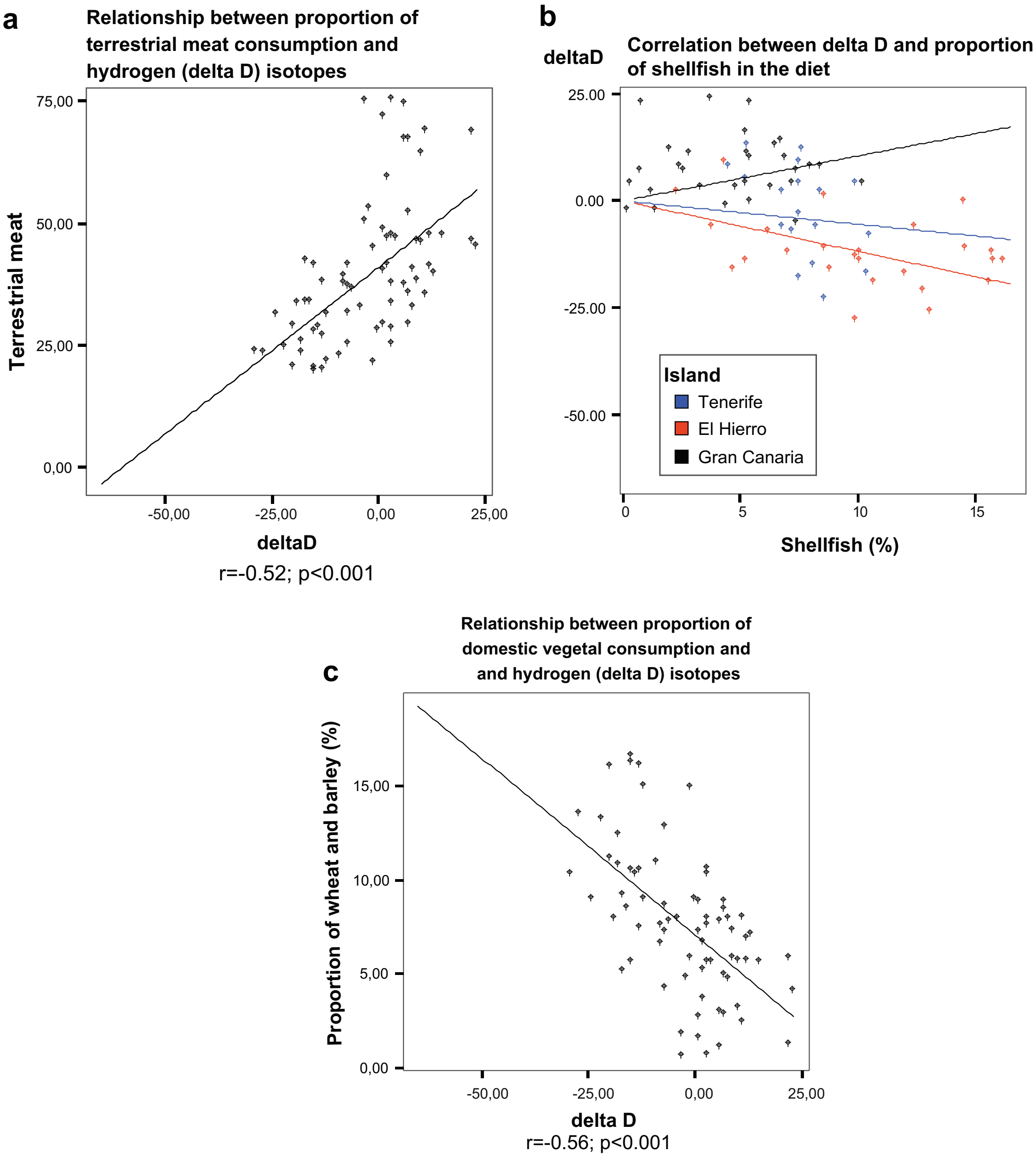

Fig. 7. a) Relationship between δD and proportion of terrestrial meat. b) Relationship between δD and proportion of shellfish consumption. Note that among the sample from Gran Canaria, correlation is direct (as a trend), whereas in those from Tenerife and El Hierro, correlations are inverse. c) Relationship between δD and proportion of wheat and barley consumption.

plant food sources, such as fruits of *Visnea mocanera* and rhyzoma of *Pteridium aquilinum*, reported by Tieszen et al. (1995) and Bocherens et al. (2003).

δD was determined only in 3 food items: *S. cretense* (a herbivorous, algae-grazing fish), showing a value of −41‰; pig (−40‰), and goat (−26‰).

3.2. Human samples

A total of 86 human bone samples were analyzed. When all data are pooled together (as summary data for the prehispanic population of the Canary Islands), $\delta^{13}C$ values of human bone collagen ranged between −20.3‰ and −17.8‰ (VPDB), with a mean value of −19.3 ± 0.7‰. Nitrogen stable isotope values ranged from 8.5 to 13.20‰ (AIR) across the total population, with a mean value of 10.3 ± 1.0‰, and δD ranged from −29‰ to + 23‰, mean = −1.9 ± 12.2‰, median +1.0‰, interquartile range = −13.0‰ to + 7.0‰ (Table 2, Fig. 4).

Marked differences were observed in $\delta^{13}C$ ($F = 40.92$, $p < 0.001$), which values were much higher among the population of El Hierro than among the population from the other islands (Table 3); statistically significant differences were also observed between the populations of Gran Canaria and Tenerife (Fig. 5a).

Also, marked differences were observed in $\delta^{15}N$ values, highest among the population from Gran Canaria, which were statistically significantly different of those from Tenerife and El Hierro ($F = 17.98$; $p > 0.0001$; Fig. 5b).

Results regarding δD collagen were even more striking: the lowest values correspond to the population of El Hierro (−12.84‰), which a median of −14.00‰ and a range from −29‰ to +8‰, and the highest, to that of Gran Canaria (7.03‰, range −6‰ to 23‰), differences being clearly significantly between the population of the islands analyzed (KW = 37.82, $p < 0.001$; Fig. 5c). Overall, relationship between $\delta^{13}C$ and $\delta^{15}N$ was only of marginal statistical significance ($p = 0.051$, Fig. 6a). A significant correlation was observed between $\delta^{15}N$ and δD ($\rho = 0.58$, $p < 0.001$, Fig. 6b), but not between $\delta^{13}C$ and δD ($\rho = -0.15$, Fig. 6c).

Significant differences were observed regarding $\delta^{13}C$ and $\delta^{15}N$, but not δD values, between men and women in each of the three islands; men always showed a trend to higher values than women (Table 4).

Using the *IsoSource* program as indicated, utilising a 2% increment and a 1% tolerance values for all the islands, we observed that consumption of marine products was important, ranging 34% (range = 13–54) for the population of El Hierro, 33% for Gran Canaria (range 13–53), and 22% for Tenerife (range 5–39%). Goat herding was also important, highest values being observed among El Hierro (app. 17%) and Tenerife (16%), whereas consumption of vegetals ranged from 17% for Gran Canaria to 23% for Tenerife (Table 5). We pooled together the proportion of terrestrial meat (both with and without goat, which could be better considered as a source of milk), marine diet (fish and shellfish) and vegetables in the diet of each individual, and further calculated the relation between the proportion of these dietary sources and δD. We found a significant, direct relationship between δD values and the proportion of meat in the diet ($\rho = 0.61$, $p < 0.001$; Fig. 7a), and inverse ones with proportion of marine diet ($\rho = -0.29$, $p = 0.013$), especially shellfish ($\rho = -0.58$, $p < 0.001$, Fig. 7b) and wheat and barley ($\rho = -0.52$, $p < 0.001$, Fig. 7c) whereas no relation was found between δD values and fish consumption. However, among the 30 cases from Gran Canaria in which δD was also determined, a direct (although non-significant) trend was observed between consumption of marine products and δD ($\rho = 0.33$, $p = 0.07$).

4. Discussion

4.1. Dietary reconstruction based on $\delta^{13}C$ and $\delta^{15}N$

As said before, bone collagen isotope analysis records mainly the protein fraction of the diet in ca. 5–10 years prior to death (Dürrwächter et al., 2006). Collagen shows a relatively fixed composition, with a carbon/nitrogen ratio of 2.9–3.6, a crucial aspect in paleodietary analysis (Valentin et al., 2006), because this range is considered to be characteristic of unaltered collagen (DeNiro, 1985). In this study, in all the samples included, we have obtained a C/N ratio fully in the range of the normal collagen composition, so that they are useful for reliable paleodietary inference.

In several studies (DeNiro and Epstein, 1981; Ambrose et al., 1997; Hedges and Reynard, 2007) it has been shown that $\delta^{15}N$ increases from diet to consumer in a step-wise manner, figures ranging from 2‰ to 5‰. In this sense, our results would support a highest consumption of animal proteins by the population of Gran Canaria, since differences of $\delta^{15}N$ are highly significant when compared with the results of the populations of El Hierro and Tenerife, who showed relatively low $\delta^{15}N$ values, suggestive of vegetal consumption. Consumption of both wild vegetal species and also corn constituted an important food source among the prehispanic population of the Canary Islands. Regarding El Hierro, chroniclers speak about consumption of a certain kind of corn, identified as barley (*H. vulgare)* by recent archaeological data (Ruiz González, 2008), but there is no reference to consumption of C-4 plants, at least domesticated ones (Abreu Galindo, 1940). In this study we have obtained $\delta^{13}C$ values for modern samples of wheat and barley between −23.4 and −25‰, fully in the reported range for C_3 plants (Katzenberg, 2000). Delta 13 of C_3 plant-eaters is around −20‰ (Richards and Hedges, 1999), lower than the findings obtained for the population of El Hierro, but similar to those from Tenerife (−19.9). On the other hand, $\delta^{13}C$ values of marine food ranges between −12.3 and −19.3‰ (Richards and Hedges, 1999), that of shellfish, −15.9‰, and that of crustaceans, −15.7‰. Therefore, based on these results, consumption of a mixed diet composed of shellfish and fish and some C_3 vegetables could explain the results obtained on the population of El Hierro, since it is assumed that $\delta^{13}C$ in collagen increases about 1–1.5‰ between trophic levels (Drucker and Bocherens, 2004; Richards and Hedges, 1999). Following the same reasoning, and considering the lower $\delta^{13}C$ values of the ancient population of Tenerife, we could infer that marine component of the population from Tenerife was by far less than that from El Hierro. Interestingly, δD values for the population of Tenerife were significantly higher than those of El Hierro. It is known that δD increases with the trophic level; despite the more intense reliance of the population of El Hierro on marine resources than that of Tenerife, the results of δD do not disagree with this hypothesis: it is important to keep in mind that in El Hierro there are huge shell middens mainly containing shells of *Patella* sp., a herbivorous gastropod; and also that the fish mainly consumed was *S. cretense*, an algae-grazing fish, which δD was −41‰. Probably, consumption of terrestrial meat, derived from *L. goliath*, or perhaps from goat (with a δD of −26‰) can explain the differences with El Hierro and the apparent contradiction between higher δD in the face of a more intense vegetal consumption. Indeed, applying the *IsoSource* program it seems clear that consumption of marine products was more intense among the population of El Hierro compared to that of Tenerife, who consumed more terrestrial meat than that of El Hierro. These results fit with the finding relative to the prevalence of dental caries, recorded following well-defined methods (Hillson, 2001), which were much more abundant among the population from Tenerife than among El Hierro: indeed, among 49 individuals from Tegueste the proportion of teeth affected by carious lesions was 18.60%, whereas this figure reaches only 15.31% among the population from El Hierro (13.2% after application of Luckac's correction factor) (Velasco-Vázquez et al., 2001).

Data from Gran Canaria yield $\delta^{13}C$ values similar to those from Tenerife. As said before, agriculture was strongly developed in Gran Canaria, and distribution of corn was hierarchically organized. Surplus of good years was kept in caves located in easily defensible places, and distributed to the population during years of bad yield. The low $\delta^{13}C$ values are in accordance with this hypothesis, but the significantly higher $\delta^{15}N$ values also suggest a higher consumption of animal/marine protein.

Applying the *IsoSource* program we obtained a similar result, suggesting a high consumption of terrestrial meat. However, archaeological remains do not support the consumption of such large amounts of meat of terrestrial origin; instead, agriculture was strongly developed in this island – by far more than in Tenerife or El Hierro – and there are also chroniclers reports stressing the paramount importance of fishing as a main economic activity performed by these people. In this sense, a detailed study by Rodríguez Santana (1996) shows that remains of several species of fish, including piscivore fish, such as *Muraena*, Serranidae (*Epinephelus guaza*, *M. rubra*), or Belonidae were widely distributed in different archaeological sites of Gran Canaria. Bocherens et al. (2003), in their compilation, report $\delta^{15}N$ around 15‰ for piscivore fish species; as shown in our table, none of these was analyzed in this study, nor in others previously reported on the Canarian ichthyofauna. It is possible that the inclusion of more species of big, piscivore fish species would displace the relative weight of marine elements in the *IsoSource* program, stressing the importance of fish consumption. In this sense, it is remarkable that the dietary items introduced in the *IsoSource* program, which includes the vast majority of dietary sources consumed by the population of the Islands, do not allow dietary inference of 4 individuals from Gran Canaria, even with a 1% tolerance. These individuals show δ^{15}N ranging from 12.5 to 13.2. It is also worth of note that some of these individuals were buried in coastal tumuli, and that individuals buried in these tumuli showed a high proportion of auricular exostoses – related with marine activities – and also a low Ba/Sr ratio (Velasco-Vázquez et al., 2000), which suggests an important consumption of marine resources.

Using only the data reported in this study and those derived from Tieszen's study on several potential food sources, dietary analysis for the population of El Hierro and Tenerife fits more closely with archaeological remains. For instance, in El Hierro, huge middens contain thousands of shells belonging to *Thais*, *Osilinus*, and, especially, *Patella piperata*, *Patella candei*, and *Patella ulyssiponensis*; in addition, it is possible to observe remains of crabs (*G. grapsus* and *Plagusia depressa*) and sea urchins in these shell middens (Hernández Pérez, 2002). The predominance of shellfish in the diet accords with the finding of the *IsoSource* program, which shows that shellfish consumption was very important among the population of El Hierro. Moreover, giant lizards were abundant in El Hierro – they are still not extinct in this island – and they were probably consumed as an important part of the diet. Other source, which was not analyzed, but surely formed part of the diet, were seabirds, which consumption could also contribute to a enrichment in δ^{15}N.

In Tenerife, shellfishing and fishing were probably not as important as in the two other islands. In Tenerife existed another wild source of animal protein, derived from the giant rat, *C. bravoi*, which reached the size of rabbit and probably occupied the same ecological niche. Abundant remains of *Canaryomis*, mixed with *Lacerta*, have been dug out in recent excavations in the Northern coast (Galván et al., 1999). A smaller species, *Canaryomis tamarani,* existed in Gran Canaria, but it is unclear whether it was consumed, and in which amount, by the prehispanic population.

4.2. Interpretation of δD results

However, dietary inference based only on δ^{15}N values may be problematic, due to the presence of several confounding factors (Hedges and Reynard, 2007). Recently, a work by Birchall et al. (2005) in Britain fauna showed marked differences in δD in relation with trophic levels, differences between carnivores/piscivores differing by about 90‰ from herbivores/omnivores, living in a similar environment, such as the British Isles. This is a very important issue, since climatic differences may profoundly affect δD composition: δD values of different North American lakes vary from −9‰ in Southern Californian lakes to −147‰ in subarctic regions (Sauer et al., 2001). The ample variation of δD values in carnivores and herbivores confers this isotope a potential interest in paleodietary analysis; indeed, very recently, δD isotopic analysis has been incorporated to paleodietary studies (Reynard and Hedges, 2008). As in our study, a significant correlation was observed between δD and δ^{15}N, but, in contrast with the aforementioned study, we failed to find a relationship between δD and δ^{13}C. The changes in δ^{13}C with trophic level are slight, only 0.5–2‰. On the other hand, although marine animals should show an enrichment in δD, this is not the case in our study. Indeed, we analyzed a parrotfish, which showed a very low value of −41‰, *S. cretense* was one of the most important fish species consumed by the prehispanic population, mainly because its abundance in ponds and puddles formed during the low tide. However, surely, fishing systems were probably different among Gran Canaria than in the other islands. Although there are no prehispanic ship wrecks, in Gran Canaria consumption of several species of the open sea has been documented, in contrast with Tenerife, an island in which *Sparisoma* was proportionally more frequently consumed. Perhaps this fact and the very low δD values for *Sparisoma* also explains the inverse relation between marine diet and δD among Tenerife and El Hierro, but not in Gran Canaria, in which the relation is a direct one, at least as a trend. However, it is also important to consider that δD increases in parallel with an increase in terrestrial meat proportion. We only analyzed δD of two potential meat sources, values being quite low (goat (−26‰) and pig (−40‰)). As said before, being the Canary islanders a pastoralist population, goat was utilized more as a milk source than as a meat source. There are, indeed, scarce bones of sheep and many of goats in several archaeological sites of the islands, in which also some remains of pigs can be found, but in a very low proportion. Probably, the higher δD values observed for the population of Gran Canaria depend on a more heavy consumption of fish-eating fishes. Indeed, in Birchall's (2005) study, δD of aquatic piscivores, such as pike, was 43.6‰. Interestingly, samples from El Agujero, in the coast of Gran Canaria, showed the highest δD values (22‰) and also the highest δ^{15}N values (13.2‰), compatible with consumption of a marine diet. This interpretation is in accordance with the high prevalence of auricular exostoses, described in those interred in coastal tumuli (Velasco-Vázquez et al., 2000), and with a very low Ba/Sr ratio in these people.

In our study we also observed differences between men and women regarding isotopes, especially δ^{15}N and δ^{13}C, but also, as a trend, in δD values. Translating these data into a dietary pattern, these data suggest, as a whole, more consumption of meat by men and more consumption of vegetal food by women. Applying the *IsoSource* program, these data also suggest a trend to a greater consumption of shellfish by women and of fish by men. All these results are consistent with the observation of a more intense dedication of women to agriculture and gathering (Delgado-Darias et al., 2006) and a more intense fishing activity, and perhaps hunting, by men.

5. Conclusion

Therefore, we conclude that marked differences exist in the carbon, hydrogen, and nitrogen isotope fingerprints between the population of the three islands analyzed, which suggest striking differences in dietary pattern between Gran Canaria and the two other islands. Probably, the difference resides in the consumption by the population of Gran Canaria, of a higher proportion of some marine fish species which were not so commonly eaten by the population of Tenerife and El Hierro. When food sources are different for different populations – as probably happened between Gran Canaria and the other islands of the Archipelago – dietary interpretation based on *IsoSource* program may be less useful or even misleading.

Additionally, marked differences were observed between men and women, which suggest that women consumed a more vegetal-based diet, a finding which is in agreement with the higher proportion of teeth with carious lesions among women.

In our study, a high δD is associated with a high δ^{15}N, suggesting a relation with animal protein (either marine or terrestrial) consumption.

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