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Isotopic study of geographic origins and diet of enslaved Africans buried in two Brazilian cemeteries

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A B S T R A C T

Brazil was the main destination of enslaved Africans during the eighteenth and nineteenth centuries in the New World. We have analyzed isotopes of carbon, nitrogen and strontium in the enamel and dentin of teeth derived from remains of 41 enslaved Africans excavated in Pretos Novos cemetery (Rio de Janeiro) and Sé de Salvador cathedral (Salvador) in order to investigate aspects related to the geographical origins and dietary habits in Africa in these two groups with differing histories.

Strontium isotope results indicate a wide range of geographical origin for the analyzed individuals of both cemeteries, being significantly wider in Pretos Novos. Carbon and nitrogen isotopes results suggest that the diet of most individuals was based on plants. Only 26% probably had access to a significant amount of animal protein. The results also show that while some individuals were consuming C3 plants such as yams and manioc, others had a diet based more on C4 plants such as sorghum, millet and maize.

Interpreted in conjunction with archaeological and historical evidence, the findings of this study, including the high variability of $^{87}Sr/^{86}Sr$, $\delta^{13}C$ and $\delta^{15}N$ values, contribute to the process of reconstructing the dramatic history of slavery in Brazil and in the Americas.

1. Introduction

The transatlantic trade of enslaved Africans is intimately linked to Brazilian history, primarily because slavery was present in the country between 1550 and 1888, a period much extended in comparison with other colonies. Moreover, throughout this era, Brazil was the main destination of slave ships in the Americas (Klein and Luna, 2010) and received approximately 40% of the 10.5 million slaves who arrived in the region (Florentino, 2002). Between 1700 and 1830, the main port of disembarkation of slaves was Rio de Janeiro, which received approximately 1,200,000 individuals, which accounted for 50% of the total slave trade in the country. During a similar period (1678–1830), the port of Salvador received around 790,000 slaves representing some 30% of the Brazilian slave trade. It is estimated that these two ports alone received one-third of all slaves traded in the Americas during that time (Florentino et al., 2004). At the end of the twentieth century, dozens of human remains associated with the period of slavery were discovered in the long-forgotten cemetery of Pretos Novos in Rio de Janeiro and in the churchyard of the former Sé de Salvador cathedral in Salvador.

In the present study, we have analyzed carbon ($\delta^{13}C$) and nitrogen ($\delta^{15}N$) stable isotopes and strontium isotopes ($^{87}Sr/^{86}Sr$) in the enamel and dentin of 41 individuals derived from the remains of enslaved Africans found in Pretos Novos cemetery and Sé de Salvador cathedral in order to investigate the geographical origins

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and dietary habits of the captives prior to their arrival in Brazil.

Isotope analysis has proven to be a valuable tool in elucidating the origins of ancient people and various aspects relating to their way of life (Schweissing and Grupe, 2003; Price et al., 2002). Such studies have provided important insights into the migration and diet of enslaved Africans buried in cemeteries in Campeche (Mexico) (Price et al., 2012), Barbados and Saint Martin islands (Caribbean) (Schroeder et al., 2009, 2012) and New York City (USA) (Goodman et al., 2004).

2. Historical backgound

2.1. Pretos Novos cemetery

The Pretos Novos cemetery is located in the port area of Rio de Janeiro, less than 500 m from Guanabara Bay and in the neighborhood presently known as Gamboa. The cemetery operated from 1769 until 1830 and was used to bury recently arrived captives from Africa who had died prior to being sold in the Valongo market (Pereira, 2007; Machado, 2006). The need to create a cemetery exclusively for enslaved newcomers can be explained by the increasing number of African captives arriving in Rio de Janeiro following the discovery of gold in the interior of Brazil at the end of the seventeenth century (Pereira, 2007), and by the need to control contagious diseases. As is common in other contemporary Christian cemeteries for the poor and indigent, the bodies that arrived at Pretos Novos were stacked in mass graves, often remaining unburied for days and sometimes burned. The exact number of slaves buried in this cemetery during its *ca*. 60 years of operation is not known but is estimated to be on the order of 20,000. According to the archives of the Church of Santa Rita, more than 1000 slaves were buried in the cemetery each year during the last six years of operation. An incessant stream of complaints from local residents led to the official closure of Pretos Novos in 1830 coinciding with the suspension of the legal slave trade in Brazil (Pereira, 2007). Although the slave trade continued illegally over the years, the cemetery was no longer used officially. The site was redeveloped in the ensuing decades as a residential area and details of its historic function were forgotten (Tavares, 2012).

Rediscovery of the Pretos Novos cemetery occurred in 1996 during renovation work on a private residence when test foundations dug at depths between 0.5 and 1.5 m revealed the presence of thousands of human bones. The owners of the residence reported the find to the Department of Cultural Heritage of Rio de Janeiro city, and the Brazilian Institute of Archaeology (IAB) was appointed to conduct an archaeological rescue excavation. Studies of historical documents and analyses of bones and teeth confirmed that the location was consistent with descriptions of Pretos Novos cemetery (Machado, 2006). Despite the emergency nature of bone removal and the lack of systematic excavation, it was possible to verify from the documents filed by IAB that the burial site consisted of two stratigraphic layers. The top layer, which ranged from 0.9 to 1.0 m in depth, was made up of landfill material containing some human remains, bones of domestic animals and construction waste, together with numerous artifacts including glass beads, crockery, iron tools and other items dating from the nineteenth century. The lower layer comprised beach sand corresponding to the substrate in which the first burials were reportedly performed (Machado, 2006; Bastos et al., 2011). Comingled human remains were collected from this site without spatial or stratigraphic tagging and most were highly fragmented, with many showing signs of burning. Nevertheless, Machado (2006) was able to examine 5563 bone fragments and teeth recovered from the accidental discovery and reported the predominance of young male adults and of teeth showing intentional dental modifications that were characteristic of some African groups (Fig. 1).

2.2. Catedral da Sé de Salvador

Construction of Sé de Salvador, the first cathedral to be built in Brazil, began in the upper part of Salvador city center around 1550, with successive extensions being added over the years. The cathedral churchyard served as a burial ground for all social strata of the city, including enslaved and freed African captives, from the mid-sixteenth century up until 1856 (Etchevarne et al., 1999). In accordance with contemporary custom, burials in the churchyard obeyed a certain hierarchy whereby rich folk were able to buy tombs nearer to the main altar.

In 1933, Sé de Salvador was demolished to make room for an extension to Salvador's tram system, and the bodies in tombs located in the inner portion of the cathedral were exhumed (Etchevarne et al., 1999; Tavares, 2006). In 1998 and 2001, archaeologists supervised by the team of the Archaeological Museum of the Federal University of Bahia (UFBA) carried out excavations at the original site of the cathedral. These investigations led to the identification of architectural structures, human remains, warfare materials, food remains, household objects and personal items such as saint medals, crucifixes and glass beads. Some of the personal items were associated with the remains and have been interpreted as grave goods (Etchevarne et al., 1999, 2001). Burial sites were located mainly in the cathedral churchyard with a few in the nave. However, some remains dating from the sixteenth century were located under the foundations of walls built during the construction of extensions to the cathedral. In 2006, Tavares (2006) investigated 421 entries in the cathedral's records of deaths in the eighteenth and nineteenth centuries and reported that 65% related to African individuals or their descendants (enslaved or freed).

Excavations revealed that the cathedral churchyard comprised a number of archaeological layers corresponding to successive landfills dating from the seventeenth, eighteenth and nineteenth centuries within which scattered human bones were found. Dozens of primary burial sites associated with the eighteenth century were found in the areas that were not part of the landfill at depths between 0.7 and 2.0 m, and some of these contained beads typical of the Niger region, reinforcing the African presence in the cemetery (Etchevarne et al., 1999, 2001). According to Liryo et al. (2011), of the 55 individuals in eighteenth century primary burial sites that could be examined in detail, 18 (32.7%) exhibited intentional modifications of the incisor teeth that were characteristic of African groups. Additionally, 40 loose incisors collected from the oldest landfills, including the churchyard of Sé de Salvador, exhibited some kind of intentional modification.

3. Isotopes in archaeology

3.1. Strontium isotopes

Information regarding the geographical origin of human remains may be gleaned from strontium signatures of body tissues. Among the four stable isotopes of strontium, ^{86}Sr and ^{87}Sr are reasonably abundant, but only the latter is radiogenic, being a product of the nuclear breakdown of rubidium (^{87}Rb) (Faure, 1986). Thus, old and Rb-rich rocks, in which radioactive decay of ^{87}Rb has occurred over a protracted period, exhibit $^{87}Sr/^{86}Sr$ ratios that are high in comparison with those of more recently formed rocks (Faure, 1986). Normally, $^{87}Sr/^{86}Sr$ ratios range between 0.703 and 0.750 depending on the nature and age of the rock, and values can be determined with high precision (up to five decimal places) using certain mass spectrometers (Price et al., 2006). Strontium isotopes do not undergo fractionation during the process of soil formation or

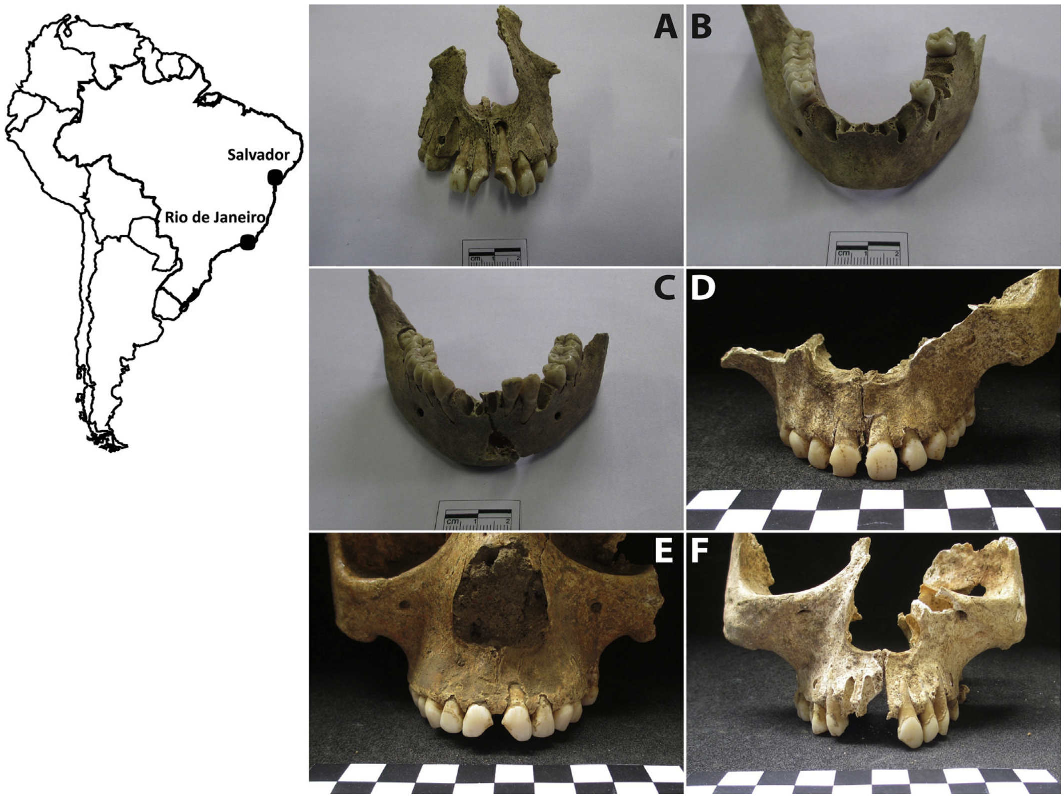

Fig. 1. Partial crania found at the cemeteries of Pretos Novos and Sé de Salvador. (A), (B), (C) Dental arches of individuals P16, P24 and P28, respectively, from Pretos Novos. (D), (E), (F) Dental arches of individuals S26, S93 and S280 from Sé de Salvador cathedral in Salvador. Map of South America indicating the cities of Rio de Janeiro and Salvador in the upper-left side.

when the element is introduced into the food chain, unlike lighter elements such as carbon and nitrogen (Sillen and Kavanagh, 1982). Thus, the strontium signature of plants and animals reflects those of the soil and water from which the element was derived (Faure, 1986; Miller et al., 1993; Bentley, 2006). Because the ionic radii and valences of calcium and strontium are similar, the latter tends to replace the former in crystals of hydroxyapatite deposited during the development of bones and teeth. Moreover, since enamel does not undergo remodeling, the strontium fixed during its formation is not replaced over time, providing a "signature of origin" related to the isotope profile of the region where the individual obtained his/her food and water during early life (Hillson, 1996).

3.2. *Carbon and nitrogen stable isotopes*

Measurement of the relative abundances of carbon ($\delta^{13}C$) and nitrogen ($\delta^{15}N$) stable isotopes present in different body tissues can also provide valuable information regarding the type of food ingested by an individual. Thus, diets that are rich in plants with the C3 photosynthetic pathway (e.g. wheat, rice and tubers) can be distinguished from those rich in plants with the C4 photosynthetic pathway (e.g. millet, maize and sorghum) or marine organisms. C4 plants and marine resources normally present less negative $\delta^{13}C$ values than C3 plants (Schwarcz, 1991; Ambrose, 1993). Moreover, $\delta^{15}N$ values normally increase by 2–6‰ at each trophic level and can be used to discriminate between diets rich in plants, terrestrial or marine animals (Hedges and Reynard, 2007; O'Connell et al., 2012). In general terms, human populations that feed on plants exhibit $\delta^{15}N$ values of up to 10‰, while those that consume large amounts of marine organisms present higher values, sometimes in excess of 20‰ (Schoeninger and DeNiro, 1984). Moreover, $\delta^{15}N$ values can vary between plants depending on the species and the environment (Ambrose, 1993; Makarewicz and Sealy, 2015).

Values of $\delta^{13}C$ and $\delta^{15}N$ measured in bones and teeth provide important information regarding the type of food ingested. Since bone tissue undergoes remodeling, isotopic analysis of the bones yields information mainly related to the dietary habits during the last years of life. In contrast, $\delta^{13}C$ and $\delta^{15}N$ values assessed in samples of dentin and $\delta^{13}C$ measured in dental enamel relate to the early life of the individual, from the time of gestation until the formation of third molars, varying according to the type of tooth (Hillson, 1996; Ambrose, 1993; Hedges et al., 2007). Furthermore, the $\delta^{13}C$ values of enamel hydroxyapatite are representative of the mean of all carbon sources ingested (i.e. carbohydrate, protein and lipids), while the $\delta^{13}C$ and $\delta^{15}N$ values of dentin collagen relate mainly from the protein fraction of the diet of an individual (Krueger and Sullivan, 1984; Howland et al., 2003). It is important to note that the $\delta^{13}C$ values of hydroxyapatite are 9–14‰ more positive than those of the diet because ingested carbon undergoes isotopic fractionation subsequent to assimilation into teeth and bones, while collagen $\delta^{13}C$ values are around 5‰ more positive (Lee-Thorp et al., 1989; Cerling and Harris, 1999; Tykot et al., 2009).

4. Materials and methods

A total of 41 teeth were selected from 41 individuals recovered from the Pretos Novos cemetery in Rio de Janeiro and the churchyard of Sé de Salvador cathedral in Salvador. None of the dental specimens included in the study exhibited anatomical anomalies or pathologies.

The 30 teeth collected from three different pits at the house renovation site in Pretos Novos were kindly provided by IAB

(Instituto de Arqueologia Brasileira). The selection criteria were (i) intact teeth with no visible signs of exposure to fire, and (ii) permanent teeth (excluding incisors and first molars) in order to avoid breast milk-related effects that could change the $\delta^{15}N$ values (Eerkens et al., 2011). Initially, the teeth were assembled into two distinct groups, articulated teeth (upper and lower jaw) and loose teeth. The type and position of the teeth in the jaws were determined and the lower left first premolars were selected preferentially. Since the remains at the cemetery site had not been excavated but merely removed as the pits were opened, it was necessary to estimate the minimum number of individuals (Buikstra and Ubelaker, 1994) represented by the dental specimens in order to ensure that teeth from the largest number of subjects would be included. The dentoalveolar arches and loose teeth (canines and second premolars) were compared to ensure that morphologies were not consistent with teeth previously selected.

Dental specimens found in the churchyard of Sé de Salvador cathedral were kindly provided by the Archaeological Museum of the Federal University of Bahia (UFBA). Only teeth obtained from eighteenth century primary burial sites of individuals that presented intentional modifications were selected for analysis since the historical records of the cathedral and the patterns of dental modification suggested that these individuals were born in Africa (Liryo et al., 2011; Handler, 1994). On this basis, 11 teeth comprising permanent premolars and molars from 11 individuals from Sé de Salvador were included in the study.

Dental specimens were cleaned using a toothbrush and scalpel and subsequently exposed to ultrasound for 20 min. Analysis of $\delta^{13}C$ and $^{87}Sr/^{86}Sr$ ratios in the inorganic fraction were performed on dental enamel because hydroxyapatite crystals are more resistant to post-depositional contamination than dentin or bone (Montgomery et al., 1999; Price et al., 2004; Hodell et al., 2004). Samples of enamel (15 mg) were removed from the buccal, lingual and/or interdental faces of the 41 teeth using a dental drill with diamond-coated bur. The resulting powders were immersed individually in 0.5 M acetic acid for 1 h to remove possible contaminating carbonates, rinsed with Nanopure® water (Barnstead® Nanopure System, Thermo Scientific, Waltham, MA, USA), dried overnight in an oven at 60 °C and stored until required for analysis.

Measurements of $\delta^{13}C$ and $\delta^{15}N$ in dentin protein (mainly collagen given the methodology used) were performed according to Ambrose (1990) on eight teeth from Pretos Novos cemetery and on all 11 teeth from Sé de Salvador churchyard. Fragments of root (200–300 mg) were cut from each tooth and suspended in 0.1 M NaOH for 24 h to neutralize any humic acids present in contaminant soil from the burial site. After rinsing, the samples were demineralized by suspension in 0.25 M HCl for 72 h followed by 0.1 M NaOH for 24 h. Lipid material was then removed by treatment with a mixture of chloroform: methanol: water (2:1:0.8), and the resulting collagen was rinsed and dried overnight in an oven at 60 °C.

Analyses of the enamel $\delta^{13}C$ values and $^{87}Sr/^{86}Sr$ ratios were performed at the Geochronology Laboratory of the University of Brasilia (Brasilia, DF, Brazil). The determination of inorganic $\delta^{13}C$ was performed using a Kiel IV carbonate device coupled with a MAT253™ stable isotope ratio mass spectrometer (Thermo Scientific). Repeated measurements of the reference carbonatite NBS18 (reference value of −5.0 ± 0.07‰; NIST, 2013) and limestone NBS19 (reference value of +1.95‰, NIST, 2012) were employed to calibrate the $\delta^{13}C$ results. Aliquots of reference materials analyzed in the same batch of the samples varied within less than 0.1‰. Isotope abundances were expressed relative to PDB (Pee Dee Belemnite).

In order to determine the $^{87}Sr/^{86}Sr$ ratio, an aliquot of each sample of powdered enamel (8–10 mg) was digested in 14 M HNO3 and submitted to chromatography over SR-B50-A resin (Eichrom, Lisle, IL, USA; particle size 100–150 μ) using 2.9 M HNO_3 as eluent. Evaluation of the $^{87}Sr/^{86}Sr$ ratio was performed using a Neptune MC-ICP-MS™ spectrometer (Thermo Scientific), involving 30 cycles in one block. During the course of sample measurements, repeated determination of Sr isotopes in a 100 ppm solution of NIST SRM 987 strontium carbonate ($^{87}Sr/^{86}Sr$ ratio of 0.71036 ± 0.00026; NIST, 2007a,b,c), yielded an average value of 0.71025 ± 0.00008 (2σ), n = 12.

Analyses of $\delta^{13}C$ and $\delta^{15}N$ values in collagen were performed at the University of South Florida (Tampa, FL, USA) using a MAT Delta Plus spectrometer (Thermo Scientific) coupled with an elemental analyzer. For each sample, the C:N ratio and the percentage of collagen in the dentin were also determined in order to assess the degree of preservation of collagen. Duplicate analyses of each collagen sample (1 mg each, in tin capsules) were performed in order to double-check analytical reproducibility. The analytical consistency was checked using the standard NIST 1577b, which was run during each batch of analyses to assess precision reported as ± 0.1 for $\delta^{13}C$, ± 0.2 for $\delta^{15}N$. NIST 8573 ($\delta^{13}C$ = −26.39 ± 0.09‰; $\delta^{15}N$ = −4.52 ± 0.12‰; NIST, 2007) and NIST 8574 ($\delta^{13}C$ = +37.63 ± 0.10‰; $\delta^{15}N$ = +47.57 ± 0.22‰; NIST, 2007) standards were used for calibration. Carbon and nitrogen isotope ratios were expressed relative to PDB and atmospheric air (AIR), respectively.

5. Results

The $^{87}Sr/^{86}Sr$ ratios in the dental enamel of individuals found in Pretos Novos cemetery varied from 0.70589 to 0.74985 (mean 0.72196 ± 0.00002), whereas those of teeth found in Sé de Salvador churchyard were between 0.70784 and 0.72400 (mean 0.71411 ± 0.00001) (Table 1). The low isotope ratios exhibited by individuals P22 and S261 (0.70589 and 0.70784) are usually found in inhabitants of regions with recent volcanic or carbonate rock formations. In contrast, the high isotope ratios of individuals P3 and P11 (0.74985 and 0.74782) are characteristic of inhabitants of geologically ancient regions or with very radiogenic rock. Even though the range of $^{87}Sr/^{86}Sr$ ratios determined in samples from Sé de Salvador was substantially (37%) lower than that established in Pretos Novos, it is clear that there was considerable diversity in the origins of individuals buried in the two locations. Also, it is quite possible that by sampling only persons from the cathedral who had dental modification to avoid including non-Africans and persons born in Brazil, we may have artificially reduced the strontium isotope variability by excluding regions and ethnic groups lacking dental modification that are included in the Pretos Novos sample.

Despite the wide range of $^{87}Sr/^{86}Sr$ ratios, some enamel results formed clusters suggesting the presence of individuals from the same region of Africa. The frequency histogram presented in Fig. 2 reveals that the majority (61%) of all teeth analyzed from both cemeteries had $^{87}Sr/^{86}Sr$ ratios in the range 0.710–0.720. However, the agglomeration of individuals with similar isotope ratios does not necessarily confirm a common origin since rocks from different places can present analogous $^{87}Sr/^{86}Sr$ ratios (Price et al., 2012; Faure, 1986), while the interval considered above is too broad to substantiate a single geographic region.

The inorganic $\delta^{13}C$ values in the dental enamel of individuals found in Pretos Novos cemetery ranged from −14.0 to −0.3‰ (mean −7.2‰ ± 0.02), whereas those from Sé de Salvador churchyard varied between −7.3 and −1.1‰ (mean −5.2‰ ± 0.02). Fig. 3 shows a cluster of teeth results from Pretos Novos with very negative $\delta^{13}C$ values (exemplified by P4, P7 and P12) that are typical of individuals who had consumed mainly C3 plants. A further cluster of teeth presented less negative values (exemplified by P3, P14 and P30) that could be associated with individuals who had

Table 1
Relative abundances and isotope ratios determined in teeth recovered from human remains found in Pretos Novos cemetery (PN) and Sé de Salvador churchyard (SS).

ID	Location	Specimen No	Sex	Age (years)	Tooth	$^{87}Sr/^{86}Sr$ ratio[a]	$\delta^{13}C$[a]	$\delta^{13}C$[b]	$\delta^{15}N$[b]	C: N ratio[b]	% Collagen[b]
P1	PN	B3: 2	–	–	PM1	0.71208	−1.7				
P2	PN	B4: 2	–	–	PM1	0.73628	−2.7	−8.8	8.1	3.4	10.6
P3	PN	B4: 1	–	–	PM1	0.74985	−1.2	−9.2	6.9	3.4	12.4
P4	PN	B4: Sna	–	–	PM1	0.71442	−14				
P5	PN	B4:SNb	–	–	PM1	0.73572	−8.4				
P6	PN	B4:SNc	–	–	PM1	0.72006	−2.3				
P7	PN	B1: 54	–	–	PM1	0.71862	−12.1				
P8	PN	B4: SNd	–	–	PM1	0.71963	−11.6	−18.7	8.1	3.5	13.1
P9	PN	B1: 101	–	–	PM1	0.71851	−10.8				
P10	PN	B1: 98	–	–	PM1	0.71038	−4.1				
P11	PN	B1: 97	–	–	PM1	0.74782	−4.3				
P12	PN	B1: 97	–	–	PM1	0.71625	−12.3	−19.9	14	3.5	18.9
P13	PN	B1: 99a	–	–	PM1	0.73501	−10.6	−17.6	7.9	3.4	13.9
P14	PN	B1: 99b	–	–	PM1	0.71621	−0.6	−8.1	10	3.3	19.5
P15	PN	B1: Mand 55	F	Adolescent	PM1	0.72094	−5				
P16	PN	B1: Mand 7,8	F	Adolescent	PM1	0.73017	−11.4				
P17	PN	B1: Mand 21	–	–	PM1	0.71037	−3.7				
P18	PN	B1: Mand 16,20,24	–	Child	PM2	0.71992	−10.6	−17.5	8.1	3.2	16.6
P19	PN	B1: Mand 3	M	Adult (>20)	PM1	0.70857	−1.4				
P20	PN	B1: Mand 5	F	Adult (>20)	PM1	0.71985	−11.4				
P21	PN	B1: Mand 1	F	Young adult	PM1	0.71607	−11.3				
P22	PN	B1: Mand 19	M	Young adult	PM1	0.70589	−11.1				
P23	PN	B1: Mand 34	M	Young adult	PM1	0.71513	−11.9	−18	7.5	3.2	12.8
P24	PN	B1: Mand 13	F	Adult (>20)	PM1	0.72437	−9.2				
P25	PN	B4: Mand 30	–	–	PM1	0.73384	−12				
P27	PN	B4: Mand 10	F	Adolescent	PM1	0.72874	−12.1				
P28	PN	B1: Mand 10	M	Adult (>20)	PM1	0.71014	−4.3				
P29	PN	B1: Mand 2	M	Adolescent	C	0.73505	−1.4				
P30	PN	B1: Mand 14,25	M	Young adult	C	0.71449	−0.3				
P31	PN	B14: Mand 6,8	M	Young adult	PM2	0.71389	−2.2				
S26	SS	AISE 26	–	–	M3	0.72400	−6	−12.3	8.5	3.3	10
S31	SS	AISE 31	M	Adult (>20)	PM1	0.71004	−5.1	−11.9	6.3	3.3	14.1
S93	SS	AISE 93		Young adult	M3	0.71274	−6.1	−12.3	7.2	3.3	4.6
S102	SS	AISE 102	F	Adult (>20)	PM2	0.71192	−4.9	−10.6	8.1	3.3	14.4
S122	SS	AISE 122	–	–	PM2	0.71797	−5.9	−13.5	7.4	3.3	13.3
S136	SS	AISE 136	–	Young adult	PM1	0.71214	−1.1	−9.5	10.6	3.2	10.3
S163	SS	AISE 163	F	Adult (>20)	PM2	0.71269	−6.3	−11.8	9.4	3.2	10.8
S220	SS	AISE 220	–	–	PM2	0.71181	−7.3	−11.2	7.5	3.2	7.8
S251	SS	AISE 251	–	–	M3	0.71739	−5.4	−10	11	3.2	10
S261	SS	AISE 261	M	Adult (>20)	M3	0.70784	−4.8	−9.7	11.5	3.3	9.1
S280	SS	AISE 280	M	Adult (>20)	PM1	0.71655	−4.5	−8.8	13	3.3	15

ID, laboratory identification of the individual; Mand, mandible; M, male; F, female; –, parameter undetermined; PM, premolar; M, molar; C, canine.
Carbon isotopes expressed as PDB, nitrogen isotopes expressed as AIR.
[a] Determined in enamel hydroxyapatite.
[b] Determined in dentin protein (collagen).

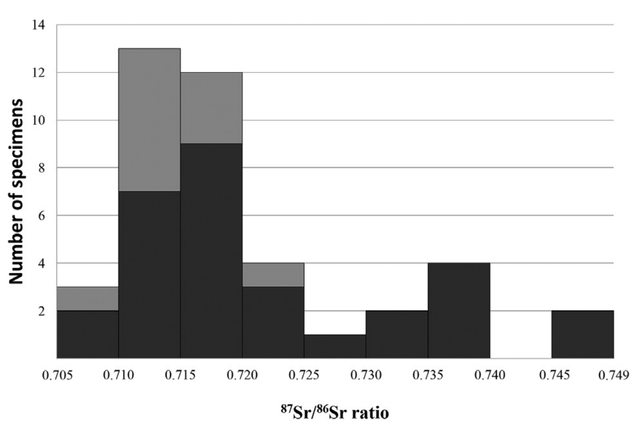

Fig. 2. Distribution of strontium isotope ratios ($^{87}Sr/^{86}Sr$) in teeth. Dental specimens were obtained from burial grounds at Pretos Novos cemetery (■) and Sé de Salvador churchyard (■).

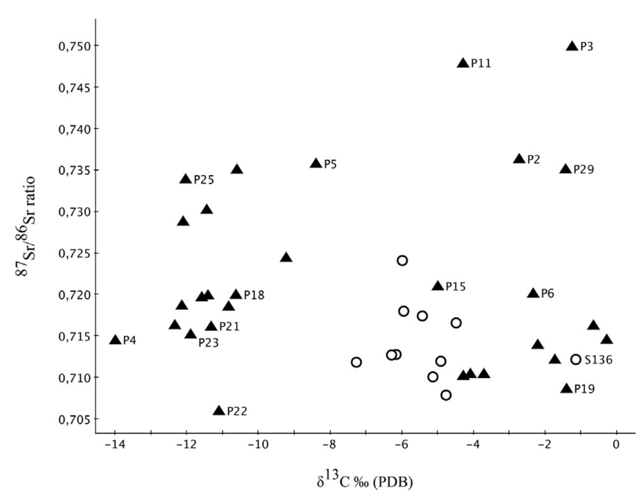

Fig. 3. Relative abundance of carbon-13 ($\delta^{13}C$) and strontium isotope ratios ($^{87}Sr/^{86}Sr$) in enamel hydroxyapatite of teeth. Dental specimens were obtained from former burial grounds at Pretos Novos cemetery (▲) and Sé de Salvador churchyard (○): identification codes refer to the ID values shown in Table 1.

consumed predominantly C4 plants or marine organisms. Additionally, some values (e.g. P5 and P15) appeared to be from individuals who consumed mixed diets. Regarding the analyzed teeth from Sé de Salvador, one (S136) exhibited a value suggesting a diet rich in C4 plants and/or marine organisms (Fig. 3). The remaining samples formed a cluster with intermediate values of around −6‰, possibly associated with individuals who had consumed a mixed diet comprising C3 and C4 plants as well as marine organisms.

Considering the inorganic $\delta^{13}C$ values and the $^{87}Sr/^{86}Sr$ ratios in dental enamel together (Fig. 3), it can be observed that teeth from Pretos Novos presenting the highest strontium isotopic ratios (i.e. P3 and P11) corresponded with individuals whose diets were rich in C4 plants. Some individuals from Pretos Novos that presented similar $^{87}Sr/^{86}Sr$ ratios (around 0.735) had different diets. While three of them (P5, P13 and P25) had $\delta^{13}C$ values compatible with a C3 plant based diet, two (P2 and P29) had values indicating a C4 plant based diet. It is also worthy of note that some individuals exhibited $\delta^{13}C$ values and $^{87}Sr/^{86}Sr$ ratios in dental enamel that were very similar, as for example P8, P18, P20, P21 and P23 from Pretos Novos. Such clusters suggest the possibility that the corresponding individuals originated from a common location, or neighboring localities.

The $\delta^{13}C$ and $\delta^{15}N$ values in dentin collagen of eight individuals from Pretos Novos cemetery ranged from −19.9 to −8.1‰ (mean −14.7‰ ± 0.1) and from 6.9 to 14.0‰ (mean 8.8‰ ± 0.2), respectively, while the corresponding values in 11 individuals found in the Sé de Salvador churchyard varied from −13.5 to −8.8‰ (mean −11.0‰ ± 0.1) and from 6.3 to 13‰ (mean 9.1‰ ± 0.2), respectively (Table 1). The C:N ratios in all 19 teeth were between 3.2 and 3.5, indicating that the collagen had been well preserved. Values of $\delta^{15}N$ in the range 6.3–10.0‰ recorded in seven individuals from each burial site, representing 74% (14/19) of all teeth analyzed, suggest that the corresponding individuals had consumed a low trophic level protein diet based predominantly on C3 and C4 plants. Four teeth (S136, S251, S261 and S280) corresponded to individuals that had probably ingested reasonable amounts of animal protein since their $\delta^{15}N$ values ranged between 10.6 and 13‰ (Fig. 4). Although their $\delta^{13}C$ values suggest the possibility of a marine diet, only the individual S136 have $^{87}Sr/^{86}Sr$ results compatible with inhabitants of coastal environments (0.71214). Finally, specimen P12 presenting $\delta^{15}N$ value of 14‰ is likely associated with individuals who had a high trophic level diet

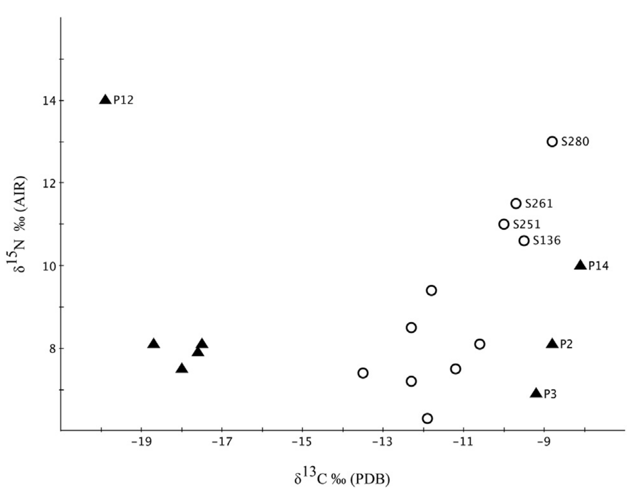

Fig. 4. Relative abundances of carbon-13 ($\delta^{13}C$) and nitrogen-15 ($\delta^{15}N$) in dentin collagen of teeth. Dental specimens were obtained from former burial grounds at Pretos Novos cemetery (▲) and Sé de Salvador churchyard (○): identification codes refer to the ID values shown in Table 1.

such as marine carnivorous fish or mammals. However, since carbon and strontium isotopes results of this individual are incompatible with high consumption of marine food, it is likely that his diet was based on freshwater fish (Yoder, 2010). On the other hand, there is also the possibility that this higher $\delta^{15}N$ value is related with the consumption of terrestrial resources from regions with elevated $\delta^{15}N$, such as arid environments (Ambrose, 1993).

6. Discussion

Records relating to the slave trade in Brazil show that Rio de Janeiro and Salvador were important entry points for captives originating from diverse ethnic and geographical origins. According to The Trans-Atlantic Slave Trade Database (2013), a total of 943,152 captives were shipped to Rio de Janeiro between 1765 and 1830, a period that coincided with the operation of the Pretos Novos cemetery. These captives boarded ships in at least 35 different African ports: 81% embarked in Atlantic Central Africa (mainly Luanda, Benguela, Cabinda and Ambriz), 17% in East Africa (Mozambique and Quelimane) and only 2% in West Africa. A similar number of captives (941,399) were shipped to Salvador between 1700 and 1810, and these boarded ships in 36 different African ports: around 68% embarked in West Africa (Elmina and Whydah), approximately 31% in Atlantic Central Africa (mainly Luanda and Benguela) and less than 0.5% in East Africa. The transport of significant numbers of slaves from East Africa (particularly Mozambique) to Brazil began in the nineteenth century after the opening of Brazilian ports to friendly nations and the imposition, by the British, of a blockade of slave trade activities north of the equator. These circumstances explain the arrival of a significant number of captives from East Africa in Rio de Janeiro in the nineteenth century and, consequently, their presence in Pretos Novos cemetery (Florentino, 2002; Lovejoy, 2011). In this context, Pereira (2007) analyzed the records of 3128 individuals buried in Pretos Novos during the period 1824 to 1830 and discovered that 29 and 28%, respectively, embarked in Benguela and Angola (Atlantic Central Africa), while 11% were shipped out from Mozambique (East Africa). A significant number of captives embarked in the ports of Cabida, Ambriz, Quiliname and Luanda, but only a few boarded ships in the ports of West Africa. Furthermore, 4% of the individuals buried in Pretos Novos cemetery were of African origin but were not young individuals, suggesting they possibly were not recent arrivals.

However, knowledge concerning the African ports from which the captives embarked is not sufficient to establish the origins of the individuals. The slave trade in Africa developed in various ways and underwent an internalization process over centuries of capture and commerce with Europeans. In West Africa, the main sources of slaves were prisoners taken during inter-tribal wars and sold to European merchants, who then confined them in coastal areas while awaiting shipment. Many of the slaves who arrived in Salvador, for example, were prisoners of wars between groups from West Africa such as the Afa-Fon-Ewe, Yoruba, Hassua and Nupe tribes (Klein and Luna, 2010; Florentino, 2002; Lovejoy, 2011; Ogot, 2010). In contrast, the majority of slaves in Atlantic Central and East Africa resulted from military action of the Portuguese colonizers. In this region, inter-tribal war was a secondary cause of imprisonment and slavery since such conflicts were not centralized as in West Africa (Florentino, 2002; Ogot, 2010). During the operation of the Pretos Novos cemetery in the eighteenth and nineteenth centuries, the slave trade routes in Atlantic Central Africa were extensive, reaching the kingdoms of Lunda and Luba in the heart of the continent and along the Congo River and its tributaries (Lovejoy, 2011).

The $^{87}Sr/^{86}Sr$ ratios of the individuals analyzed in the present study, when considered together with information regarding the slave-producing areas of the eighteenth and nineteenth centuries and the geological features of the African continent (Fig. 5), provide specific information regarding the regions from which individuals originated. Thus, teeth with high $^{87}Sr/^{86}Sr$ ratios (*ca.* 0.720 and above) were probably from individuals originating from areas of West and Atlantic Central Africa formed by Precambrian rocks that are typical of much of the African continent. However, individuals with the highest $^{87}Sr/^{86}Sr$ ratios, e.g. P3 and P11 presenting values of *ca.* 0.750, likely originated from areas characterized by Archaean rock that occur sparsely in Angola, Congo and Mozambique (Goldstein and Jacobsen, 1988; Schlüter, 2006). In contrast, teeth presenting low $^{87}Sr/^{86}Sr$ ratios, as exemplified by P19, P22 and S261 with values below 0.710, could be from individuals that inhabited recent volcanic areas that characterize much of Cameroon, some regions of Mozambique and small segments of Nigeria, Congo and Angola (Schlüter, 2006). Alternatively, these individuals could have inhabited the southernmost region of the Rift Valley, which was also a source of captives for the slave trade (Ogot, 2010). The individuals with $^{87}Sr/^{86}Sr$ ratios between 0.710 and 0.720 probably also had a diversified geographic origin. Sedimentary basins ranging from Mesozoic to Cenozoic are found in Nigeria, Congo, Angola and Mozambique and these regions could provide strontium results compatible with these individuals (Schlüter, 2006).

It is also possible that some slaves shipped to Brazil during the eighteenth and nineteenth centuries may have originated from coastal areas of Africa. Seawater has a $^{87}Sr/^{86}Sr$ ratio of 0.70918, and this influences the strontium signature of individuals who have consumed marine organisms or a diet based on local sources related to marine sediments (Faure, 1986; Wright, 2004). In this context, individuals P10, P17, P28 and S31 presented $^{87}Sr/^{86}Sr$ ratios close to that of the ocean, along with less negative dental enamel $\delta^{13}C$ values that are compatible with a diet rich in marine resources.

By comparing $^{87}Sr/^{86}Sr$ ratios determined in individuals found in the Pretos Novos cemetery and the Sé de Salvador churchyard with those discovered in burial sites related to enslaved Africans located in North America and the Caribbean (Price et al., 2006; Schroeder et al., 2009, 2012; Goodman et al., 2004), it is possible to notice that in all cases there was a great variety of geographic origins. As in Salvador, the Caribbean, Mexico and the United States received a large number of captives from West Africa (The Trans-Atlantic Slave Trade, 2013) and, thus, similar values of strontium isotopes would be expected for the enslaved Africans buried in these regions (Fig. 6). However, it is possible that the high $^{87}Sr/^{86}Sr$ ratios found in P3 and P11 from Pretos Novos are uncommon in West Africa, being present in older rocks such as those found in the Congo Craton (Schlüter, 2006) and, consequently, more frequent in enslaved Africans that were shipped to Rio de Janeiro.

The dietary profiles of slaves buried in the studied sites could be inferred from dental enamel $\delta^{13}C$ values together with dentin collagen $\delta^{13}C$ and $\delta^{15}N$ values. The main C3 plants cultivated in Africa during the time of slavery were species of yam (*Dioscorea rotundata*, *D. cayenensis* and *D. alata*), rice (*Oryza sativa* and *O. glaberrima*) and manioc (*Manihot esculenta*), while the predominant C4 plants were sorghum (*Sorghum bicolor*), millet (*Eleusine coracana* and *Pennisetum glaucum*) and maize (*Zea mays*) (Ogot,

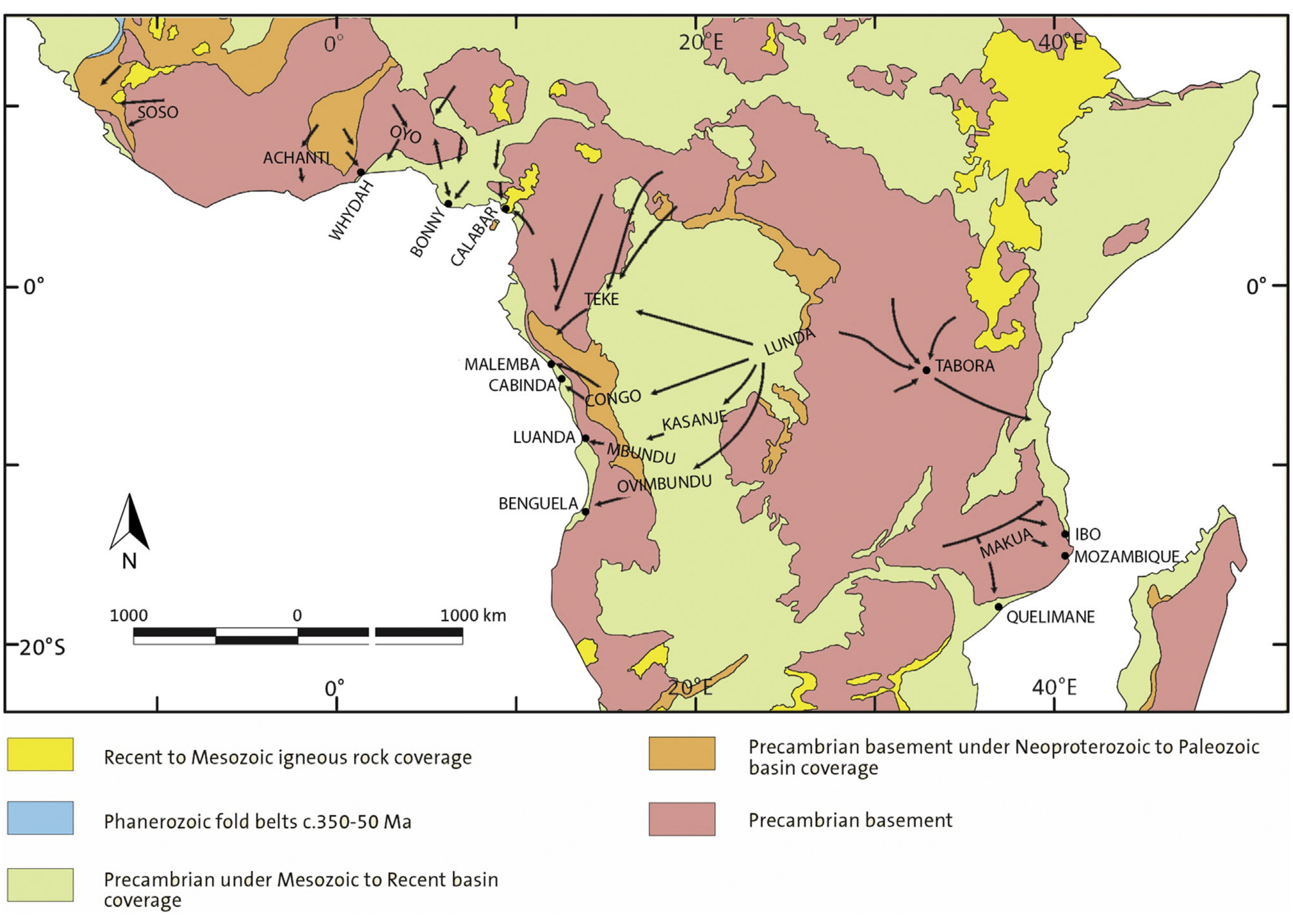

Fig. 5. Simplified geological map of part of Africa and main slave routes in the eighteenth and nineteenth centuries. Simplified geological map after Schlüter (2006); main slave routes (arrows) according to J. E. Inikori cited in Ogot (2010).

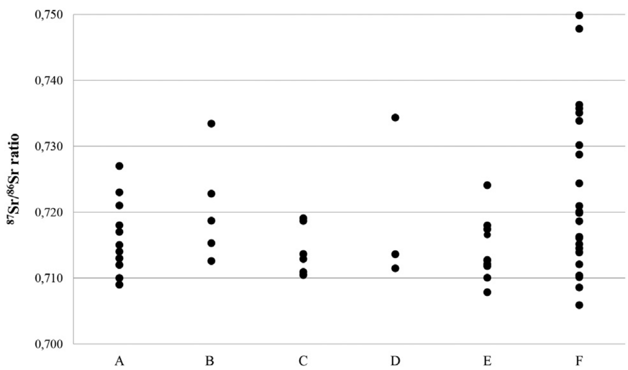

Fig. 6. Strontium isotope ratios ($^{87}Sr/^{86}Sr$) in dental enamel from presumably African-born individuals excavated from burial sites in the Americas. (A) New York African burial ground, New York, United States ($n = 18$) (Goodman et al., 2004); (B) Campeche colonial site, Campeche, Mexico ($n = 5$) (Price et al., 2012); (C) Newton plantation, Christ Church, Barbados, West Indies ($n = 7$) (Schroeder et al., 2009); (D) Zoutsteeg area, Philipsburg, Saint Martin, West Indies ($n = 3$) (Schroeder et al., 2012); (E) Pretos Novos cemetery, Rio de Janeiro, Brazil ($n = 30$); (F) Sé de Salvador churchyard, Salvador, Brazil ($n = 11$).

2010; Board on Science and Technology for International Development, 1996). However, not all of these cultigens were present in the diets of all African groups throughout the period. For example, rice was cultivated along the coast of West Africa in the region of Senegambia, comprising the countries Senegal and neighboring Gambia (Schroeder et al., 2009), which supplied few slaves to Rio de Janeiro and Salvador during the eighteenth and nineteenth centuries. The Akan, Yoruba and Igbo tribes that inhabited Ghana, Nigeria and Cameroon preferred yams, whereas the Fulani and Hausa people that inhabited the Sahel region, a zone of transition between the Sahara Desert to the north and the Sudanian Savanna to the south, planted mainly sorghum and millet (Ogot, 2010; Stahl, 1999). Manioc and maize were cultivated widely by the tribes of West and Atlantic Central Africa following introduction of the species by European colonizers, but subsequently became key crops even for populations in the interior of Africa, including the Lunda Empire (Isichei, 1997). The Bantu tribes of Atlantic Central and East Africa cultivated yam, sorghum and millet together with manioc and maize following their introduction to the African continent (Ogot, 2010). It is most likely that individuals exhibiting dentin collagen $\delta^{15}N$ values below 10‰, and these accounted for 74% of all samples analyzed, had their main source of protein from plants. Analysis of $\delta^{13}C$ and $\delta^{15}N$ in the dentin from enslaved Africans skeletal remains discovered in Barbados (Schroeder et al., 2009) and Mexico (Price et al., 2012) also point to a diversified diet, based mainly on C3 or C4 plants.

7. Conclusions

The results of the isotopic analyses of dental specimens carried out in this study are subject to a number of important limitations. Considering the sheer size and geological diversity of the African continent, as well as the scarcity of information regarding the distribution of $^{87}Sr/^{86}Sr$ ratios, the values obtained were not sufficient to identify with precision the geographical origins of the individuals buried in the Pretos Novos cemetery or the Sé de Salvador churchyard. Moreover, it was not possible to specify the types of foods most often consumed by these individuals whilst living in their homelands because of the multiplicity of African groups caught up in the slave trade. However, the $^{87}Sr/^{86}Sr$, $\delta^{13}C$ and $\delta^{15}N$ values determined in enamel and/or dentin samples showed that: (i) the 41 analyzed individuals were brought from a great variety of geological regions in Sub-Saharan Africa; (ii) the dietary habits of the buried individuals were predominantly plant based; and (iii) the individuals were from different agricultural populations, i.e. from groups that preferentially cultivated tubers (yam and manioc) or from those that cultivated grains (sorghum, millet and maize). Interpreted in conjunction with archaeological and historical evidence, such findings may contribute to the process of reconstructing the dramatic history of slavery in Brazil and in the Americas, as Rio de Janeiro and Salvador were major ports through which millions of African slaves arrived in the New World.

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