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Eating out or dining in: modeling diverse dietary strategies in the Middle Period, San Pedro de Atacama, Chile

William J. Pestle[1] · Christina Torres-Rouff[2,3] · Mark Hubbe[3,4] · Erin K. Smith[5]

Abstract The Middle Period of the Atacama oases, North Chile, has been characterized as a time of peace, uniform abundance, and widespread access to exotic materials. In the present work, we test this notion through a comparison of Middle Period human isotopic data ($\delta^{13}C_{co}$, $\delta^{15}N_{co}$, and $\delta^{13}C_{ap}$) representing two distinct *ayllus*, Solcor and Tchecar, in the San Pedro de Atacama oases. We employ Bayesian mixture modeling of individual-level isotopic data to quantify and compare dietary composition within and between the cemetery populations of these two contemporary locales. Ultimately, our research shows that dietary diversity, which we take as a proxy for differential levels of participation in long-distance exchange or the access to the products thereof, was unequally distributed, and that the supposedly uniform richness of the Middle Period was similarly discontinuous. While average isotopic values for the two *ayllus* were similar, variance within each differed significantly, as did variance in dietary composition arrived at through modeling. By all measures, the individuals interred in Solcor 3 had more varied diets, particularly in terms of carbohydrate-rich plants, than their contemporaries interred at Tchecar Túmulo Sur, suggesting that more individuals from Solcor 3 had greater participation in/access to long-distance exchange networks. Besides providing novel insights into the lived experience of the Middle Period residents of far northern Chile, this work also demonstrates the power of Bayesian mixture modeling for the reconstruction of individual paleodiet.

Introduction

The San Pedro de Atacama oases, at the confluence of the San Pedro and Vilama Rivers in the hyper-arid Atacama Desert of northern Chile (Fig. 1), are the site of long-standing human activity (Llagostera 2004; Núñez 1991). Life in the region is interpreted to have reached its prehistoric pinnacle during the Middle Period (AD 400–1000), which the common narrative describes as a period of unparalleled prosperity and peace, with burgeoning intra- and interregional interaction. This period of prosperity is assumed to be linked to the rising tide wrought by spheres of interaction and long-distance exchange, phenomena that lifted all boats, to a greater or lesser degree. However, distribution of the impact of this interaction across local individuals in the oases has not been properly tested, despite the importance of understanding unequal access to resources to the reconstruction of the social dynamics of past Atacameño society. Here, we present initial analyses that address questions of inequalities in diet and we test the hypothesis that the prosperity observed during the Middle Period was equally accessible to all local individuals.

By the Middle Period, the oases featured stable permanent settlements with a local populace that practiced camelid

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Fig. 1 Map showing location of sites/*ayllus* mentioned in text. *Inset map* showing location of San Pedro de Atacama
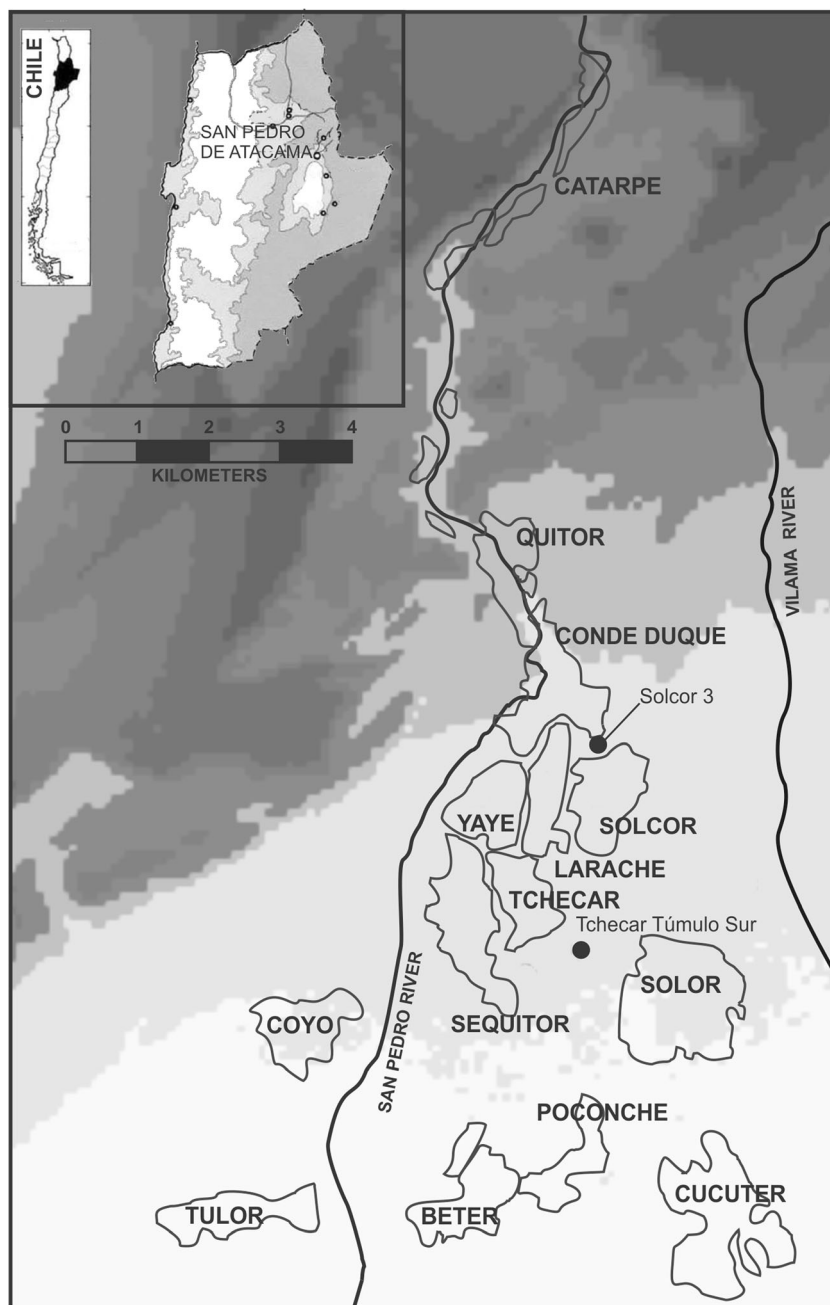
pastoralism and small-scale agriculture (Llagostera and Costa 1999; Núñez 2007). The Middle Period is also associated with the earliest evidence for surplus production, which was bolstered by incipient craft specialization, the growth of agriculture, and individuals who focused their energies on trade and exchange (Llagostera and Costa 1999; Núñez 1991; Pimentel et al. 2007). The growing prominence and affluence of the oases at this time is reflected in notable increases in the quantity and quality of grave goods and a substantial network of interregional interaction (Berenguer and Dauelsberg 1989; Llagostera and Costa 1999). This interaction is evident in the local archeological record and Atacameño material culture

is also found at distant locales (Llagostera 1996; Torres and Conklin 1995; Uribe 2002). Despite the well-established interregional exchange that characterized the period, the material culture found in Atacameño oases cemeteries suggests the predominance of local styles and goods (e.g., Llagostera 2004, Stovel et al. 2005). The distinctive suite of material culture in the mortuary context at this time included black polished ceramics, textiles with only minor decoration, an array of weapons and tools, and the regular, if not common, presence of snuffing paraphernalia (Bravo and Llagostera 1986, Llagostera 2004, Uribe and Agüero 2001). While any number of foreign variants of these same items are found in local

cemeteries, their presence is minor in comparison to the wealth of local material.

One apparent driver and/or consequence of the growing inter-regional interaction was the emergence, during the Middle Period, of institutionalized social inequality. Based on settlement pattern data and artifactual and bioarchaeological analyses, archeologists contend that the Middle Period witnessed the appearance of a local elite, who developed and maintained their social position by access to the aforementioned networks of exchange (Hubbe et al. 2011; Llagostera 1996, 2004; Núñez 1991, Núñez 2007). While surplus production and long-distance exchange are clear features of the Atacameño Middle Period, what remains unclear is how widely the benefits of these phenomena were distributed. We have previously argued (e.g., Pestle et al. 2016; Torres-Rouff et al. 2015) that diverse diets in the Atacameño Middle Period are a consequence of participation in and/or access to far-flung networks that would have brought diverse foodstuffs to the Atacaemeño oases not otherwise available locally. The linkage between social status and access to diverse and exotic foods has deep roots in archeological and anthropological studies of food (Curet and Pestle 2010; Douglas and Isherwood 1996; Smith 1987). Starting from this association, we examine individual diets at two contemporary San Pedro cemeteries in an attempt to assess how uniformly food, and potentially status, were distributed in the Middle Period.

Isotopic background

As is well evidenced in the present volume, stable isotope analysis is the best available archeological means for reconstructing the diets of ancient individuals. Forty years of archeological applications have built a corpus of well-tested methods enabling the accurate reconstruction of broad aspects of human paleodiet (Ambrose 1993; Lee-Thorp 2008). In brief, the isotopic composition of carbon and nitrogen in consumer bone collagen and hydroxyapatite (expressed using the δ notation, the ratio of the heavier to lighter isotope as compared to an international standard), having been corrected for fractionation, are compared with the isotopic values of the range of locally available foodstuffs (the food web). Comparison of consumer and source/food web values allows for determination of the relative importance of broad classes of different foodstuffs (e.g., marine versus terrestrial proteins, C_3 versus C_4 plants) to individual consumer diet.

Assuming sufficient preservation of target biomolecules and accurate knowledge of local food webs and fractionation, stable isotope analysis can be used to reconstruct broad aspects of individual paleodiet (major versus minor contributors, for instance) with a high degree of accuracy. The basics of this method have remained effectively unaltered since the earliest archeological applications of the technique (Hall 1967; van der Merwe and Vogel 1978), and their real power of the method remains in the scalability of the data it generates, which

permits inference of everything from individual to societal diets. Given the incredible preservation of skeletal biomolecules in the Atacama Desert and the relative simplicity (e.g. lack of freshwater foods) of the local food web, stable isotope analysis is particularly well suited for paleodiet reconstruction in the region.

Recent decades, however, have witnessed the development of powerful new tools for the interpretation of isotopic data, in particular mixing models, which open the door to informed quantification of source contribution (Fernandes et al. 2014, 2015; Lubetkin and Simenstad 2004; Moore and Semmens 2008; Newsome et al. 2004; Parnell et al. 2010, 2013; Phillips 2001; Stock and Semmens 2013). Such models greatly improve the explanatory power of bioarchaeological reconstructions of paleodiet because they use a range of user-stipulated inputs to modeled bounded source contributions to a given consumer's diet, rather than relying on basic visual comparisons of plotted source and consumer data, or making simplistic assumptions (e.g., hydroxyapatite isotope values reflect plant diet).

While the earliest linear mixing models (Phillips 2001; Phillips and Gregg 2003) could deal with only a limited number ($n + 1$) of food sources, later developments (Parnell et al. 2010; Moore and Semmens 2008) expanded calculations to non-determined systems and provided means for dealing with uncertainty in input parameters based on Bayesian approaches. Most recently, models such as Food Reconstruction Using Isotopic Transferred Signals (FRUITS) (Fernandes et al. 2014) have been built to accommodate the input of consumer, food web, macronutrient composition, and routing parameters, as well as user-specified priors, to determine probabilistically bounded source contributions while accounting for uncertainty in all input data. These recent Bayesian approaches "offer a powerful means to interpret data because they can incorporate prior information, integrate across sources of uncertainty and explicitly compare the strength of support for competing models or parameter values" (Moore and Semmens 2008, p. 471). Crucially, these approaches are model-bound and therefore infer the probability of possible alternatives fitting the observed data following Bayesian principles. The substantial potential of these methods for addressing questions of significant paleodietary interest has resulted most recently in several applications in the South-Central Andes (e.g., Andrade et al. 2015; Pestle et al. 2016).

Materials

In the present work, we consider the remains of 45 individuals from two Middle Period San Pedro cemeteries, Solcor 3 ($n = 19$ of 132 burials) and Tchecar Túmulo Sur ($n = 26$ of 202 burials). These two cemeteries are associated with

different oases and distinct *ayllus*, the term given to the ascriptive descent groups that form the fundamental unit of Andean social organization (Abercrombie 1998; Bastien 1978; Rasnake 1988). As such, the individuals drawn from the two cemeteries likely represent different social units that may have experienced the prosperity of the Middle Period in distinct ways. The individuals included in the present study were selected in consultation with museum staff as to represent the full range of burial treatments observed within the two cemeteries. We acknowledge from the outset that the sample sizes are small and that expansion of the sample of refinement of model parameters could impact the conclusions reached here.

The remains from Solcor 3 were excavated in the 1980s by Dr. Agustín Llagostera and a team from the Museo Arqueológico R.P. Le Paige; Father Gustavo Le Paige, the local Jesuit priest and a pioneer in Atacameño archeology, excavated Tchecar Túmulo Sur in the 1960s, only retaining skulls from the graves he excavated. Direct radiocarbon dating of human remains from both cemeteries confirm their contemporaneous use, primarily in the second half of the Middle Period, between roughly AD 750 and 1000 (Hubbe and Torres-Rouff 2011; Torres-Rouff and Hubbe 2013).

At least some of the individuals buried in the Solcor 3 cemetery appear to have occupied advantageous positions within Middle Period Atacameño society, as the cemetery contains a number of tombs with Tiwanaku-style artifacts and local high status goods (Bravo and Llagostera 1986, 1988). This is not to suggest that all the individuals buried there were of high status, as there were also more modest tombs; however, the cemetery stands out as one with abundant foreign material culture. The remains from this cemetery have been studied extensively (e.g., Bravo and Llagostera 1986; Hubbe et al. 2012; Llagostera et al. 1988; Nado et al. 2012). In contrast, the remains from Tchecar Túmulo Sur are little studied; limited analysis of the material culture indicates that the cemetery is largely bereft of luxurious or exotic goods, with only one non-local object (a vessel) found among the tombs there (Torres-Rouff 2008).

Methods

Age and sex of the individuals were estimated following standard osteological protocols (Buikstra and Ubelaker 1994; Buzon et al. 2005). Sampling for isotopic analysis took place at the Museo Le Paige. Samples of dense cortical bone (1–2 g target weight) were removed using a diamond cutoff wheel mounted on a handheld rotary tool. In the case of Tchecar Túmulo Sur, as only crania had been retained following excavation, samples necessarily were selected from cranial elements (typically parietal/zygomatic), whereas for Solcor 3, ribs were the preferred skeletal element. During sampling, the rotational speed of the tool was kept as slow as possible

to limit any possible denaturation of proteins. Following extraction, samples were bagged in sterile sample bags. Cutoff wheels were cleaned between uses with dilute bleach and distilled water and subsequently air-dried.

Extractions of target biomolecules (collagen and hydroxyapatite) were performed in the Archeological Stable Isotope Lab at the University of Miami. Collagen extraction followed a modified version of that established by Longin (1971) and previously detailed elsewhere (Pestle 2010). Weighed 0.5 g aliquots of coarsely ground (0.5–1.0 mm) cortical bone were placed in 50 ml centrifuge tubes, to which was added 30 ml of 0.2 M HCl. The tubes were capped and placed in a constantly spinning rotator for 24 h, at which time the degree of demineralization was assessed, with neutral buoyancy taken as the hallmark of complete demineralization. Samples requiring another 24 h to demineralize had their acid refreshed at this time. After demineralization, samples were rinsed to neutral and treated with 30 ml of 0.0625 M NaOH for a period of 20 h. After this removal of humics, samples were again rinsed to neutral, and then gelatinized for 24 h at 90 °C in 10^{-3} M HCl. The resulting gelatin was filtered using 40-μm sterile single-use Millipore Steriflip® vacuum filters, allowed to condense at 85 °C, frozen, and then freeze-dried. Collagen yield data were collected after extraction and freeze-drying to assess the state of sample preservation.

Extraction and purification of bone hydroxyapatite followed the protocol of Lee-Thorp (1989) and Krueger (1991), with minor modifications (Pestle 2010). Briefly, weighed 0.1 g aliquots of a fine-ground (0.125–0.25 mm) fraction of cortical bone were placed in 50 ml centrifuge tubes. This material was first oxidized for 48 h using 30 ml of a 50 % solution of commercial bleach (sodium hypochlorite), with a reagent change after 24 h. After all sample organics were oxidized, samples were rinsed to neutral and labile carbonates were removed using 30 ml of 0.1 M acetic acid. Acid treatment lasted 4 h, with a 5 min vacuum treatment at the 2 h mark. Following this, samples were rinsed to neutral, frozen, and freeze-dried. Hydroxyapatite yield was recorded subsequent to extraction and lyophilization.

Isotopic analysis of both collagen and hydroxyapatite was performed in the Marine Geology and Geophysics' Stable Isotope Laboratory at the University of Miami's Rosenstiel School of Marine and Atmospheric Science. Collagen samples were analyzed using a PDZ Europa ANCA-GSL elemental analyzer interfaced to a PDZ Europa 20:20 isotope ratio mass spectrometer (IRMS). This process produced data on both sample elemental composition (carbon and nitrogen yield, from which atomic C/N can be computed) as well as the isotopic measures of $\delta^{13}C_{co}$ and $\delta^{15}N_{co}$. Hydroxyapatite samples were analyzed using a Kiel-IV Carbonate Device coupled to a Thermo-Finnigan DeltaPlus IRMS, producing $\delta^{13}C_{ap}$ values for the analyzed samples. Precision for replicates of bone collagen and hydroxyapatite was better than

0.1 ‰ for $\delta^{13}C_{co}$ (collagen), $\delta^{15}N_{co}$ (collagen), and $\delta^{13}C_{ap}$ (hydroxyapatite). All isotope results were calibrated using acetanilide and glycine for collagen and an in-house carbonate standard calibrated to NBS-19 for hydroxyapatite. Standards were run in every sample run bracketing analyzed samples. As all samples were extracted and analyzed using the same protocols and instrumentation, concerns of inter-laboratory variability are obviated (Pestle et al. 2014).

Individual isotopic data were analyzed using the Bayesian multi-source mixture modeling software FRUITS v2.1.1 (Food Reconstruction Using Isotopic Transferred Signals [Fernandes et al. 2014]). This analysis allows for probabilistic and uncertainty-integrated quantification of dietary inputs. FRUITS was chosen because of its capability for incorporating food macronutrient, elemental, and isotopic composition data, as well as source and consumer uncertainty, in its calculations. As the authors note, "FRUITS is a novel Bayesian mixing model that efficiently handles knowledge on dietary routing mechanisms and provides a platform for the simple introduction of expert prior information to arrive at an accurate diet reconstruction, complete with uncertainty estimates, based on chemical and isotopic dietary proxies," (Fernandes et al. 2014, p. 8). In the present case, the input parameters (described in detail below) include measured consumer (human) isotope values, food web macronutrient and isotope composition, stipulated routing of dietary macronutrients to consumer tissues, and physiological boundaries for protein intake.

For the purposes of this analysis, we determined the consumer-foodstuff offset (and error) for $\delta^{13}C_{co}$ using the linear regression method described in Pestle et al. (2015a). The offset (fractionation) factor in $\delta^{13}C_{ap}$ was stipulated as 10.1 ± 0.4 ‰ (Fernandes et al. 2012). Finally, for $\delta^{15}N$, we employed a trophic fractionation value of 3.6 ± 1.2 ‰, as recommended by several experimental studies of omnivorous animals (Ambrose et al. 2000; DeNiro and Epstein 1981; Hare et al. 1991; Howland et al. 2003; Sponheimer et al. 2003; Warinner and Tuross 2009).

Food web isotope values comprised the edible portions of 119 southern Andean plant and animal samples drawn from previous work in the region (DeNiro and Hastorf 1985; Miller et al. 2010; Pestle et al. 2015b; Schoeninger and DeNiro 1984; Tieszen and Chapman 1992). Any modern data included in this reference sample had $\delta^{13}C$ values corrected by +1.5 ‰ to account for the fossil fuel burning effect (Keeling et al. 1979). Macronutrient composition of each food group was determined by reference to a range of comparable foodstuffs in the USDA National Nutrient Database for Standard Reference (Agriculture 2013). Elemental composition (particularly %C) of each foodstuff/macronutrient group was based on formulae provided in Morrison et al. (2000). Isotopic offsets between measured bulk food isotope values and the isotopic values of specific dietary macronutrients were derived

from Tieszen (1981). Digestibility was determined following Hopkins et al. (1981). To account for differential elemental routing, all nitrogen in bone collagen was stipulated as coming from dietary protein (the only macronutrient that contain nitrogen), the carbon in hydroxyapatite was stipulated as reflecting (an average of) all dietary carbon, and the carbon composition of bone collagen was set as reflecting a 3:1 ratio of dietary protein to energy (Fernandes et al. 2012).

Final food group isotope, macronutrient, and elemental concentration values used in the FRUITS simulations are presented in Table 1. We chose to include legumes, alongside the more commonly discussed terrestrial mammals and local protein-poor C_3 and C_4 plants, as a potential food source despite the fact that archeological evidence for their local presence is equivocal. While legumes have been recovered archeologically in the Atacama (Arriaza et al. 2015; Latcham 1938; Núñez et al. 2009; Thomas et al. 1995), the same cannot be said for sites in the oases themselves, although this lack of local archeological visibility could result from the paucity of local paleobotanical studies. Marine foodstuffs, common in Atacama coastal populations, were not included as a potential source given the lack of archeological evidence for their presence in the San Pedro oases. Consumption of protein was limited to less than 45 % of protein as energy (using the FRUITS a priori data option), reflecting the upper limit of possible human protein intake (WHO 2007). All FRUITS simulations were performed using 10,000 iterations.

Comparisons of subgroup (site, sex) isotopic and modeled dietary data were made using Levene's tests for homogeneity of variances and, depending on the results of that test, Student's or Welch's t tests for equality of means. In addition, Stable Isotope Bayesian Ellipses in R (SIBER, Jackson et al. 2011) was used to characterize intra-group variation using a Bayesian framework. Given small sample sizes, however, this attempt was restricted to visual depictions of standard ellipse area (the bivariate equivalent of standard deviation) rather than calculation of the various within-group metrics being used more frequently in ecological (e.g.. Layman et al. 2007a, b; Syväranta et al. 2013) and, more recently, archeological isotopic studies (Szpak et al. 2014).

Results

Quality of sample preservation was assessed using chemical (collagen yield) and elemental (carbon and nitrogen yield, atomic C/N ratio) measures, all of which are routinely generated in the course of sample extraction and elemental analysis. Only those samples meeting widely accepted standards (collagen yield >0.5 wt%, carbon and nitrogen yields of greater than 4.5 and 0.9 wt%, respectively, and atomic C/N ratios between 2.9 and 3.6) were included here (Ambrose 1990; Pestle and Colvard 2012). Samples with sufficient collagen

Table 1 Food group isotope, macronutrient, and elemental concentration values used in FRUITS dietary simulation

Food grouping Group	n	Macronutrient concentration (%)				%C				Tissue $\delta^{13}C$ (‰)					Tissue $\delta^{15}N$ (‰)	
		Protein	Fat	Carbohydrates	Energy	Protein	Fat	Carbohydrates	Energy	Bulk	Protein	Fat	Carbohydrates	Energy	Bulk	Protein
Terrestrial mammals	30	83±12	16±12	1±3	17±12	43±12.7	12±12.1	0±4.2	13±12.7	−18.3±3.9	−20.3±3.9	−25.3±3.9	−18.8±3.9	−25.1±3.9	7±1.7	9±1.7
C_3 plants	59	11±5	5±4	84±7	89±5	5±6.9*	4±6.7	37±8.5	41±6.9	−23.9±1.4	−25.9±1.4	−29.9±1.4	−24.4±1.4	−24.9±1.4	6.2±3.5	6.2±3.5
C_4 plants	12	11±5	5±4	84±7	89±5	5±6.9*	4±6.7	37±8.5	41±6.9	−10.2±1.1	−12.2±1.1	−16.2±1.1	−10.7±1.1	−11.2±1.1	8.2±3.6	8.2±3.6
Legumes	18	28±2	2±1	71±3	72±2	13±5.6*	1±5.3	31±5.8	33±5.6	−23.4±1.4	−25.4±1.4	−29.4±1.4	−23.9±1.4	−24.1±1.4	1.9±1.6	1.9±1.6

*Assumes 87.4 % digestibility of plant protein as compared to animal protein

preservation were assumed to also have well-preserved hydroxyapatite. Details of the state of preservation are presented in Table 2. Overall, 93.3 % (42 of 45) of the analyzed samples possessed sufficient unaltered collagen for isotope study. The average collagen yield for the 45 samples was 16.0 ± 5.5 wt%.

Considering the two cemeteries separately, 84.2 % (16 of 19) of the samples from Solcor 3 were sufficiently well preserved for analysis, whereas all 26 samples from Tchecar Túmulo Sur yielded quality collagen. The average collagen yield for the 16 well-preserved samples from Solcor 3 was 17.3 ± 6.0 wt%, with an average atomic C/N ratio of 3.2 ± 0.1, whereas the 26 Tchecar Túmulo Sur samples averaged 15.2 ± 5.2 wt%, with an average C/N ratio of 3.3 ± 0.1. All in all, the samples were exceedingly well preserved (Pestle et al. 2015b), as is almost always the case for inhumed materials from the hyperarid Atacama (with some exceptions, see Pestle et al. 2016). There were no significant differences in collagen preservation (as judged by collagen yields, elemental yields, and atomic C/N ratios) between the two sites under consideration.

Isotopic data from the 42 well preserved individuals from Solcor 3 and Tchecar Túmulo Sur are presented in Table 2, with summary data in Table 4. Considering data from all analyzed individuals together, $\delta^{13}C_{co}$ averaged −14.0 ± 1.4 ‰, $\delta^{15}N_{co}$ + 11.5 ± 1.0 ‰, $\delta^{13}C_{ap}$ − 8.8 ± 1.5 ‰, and $\Delta^{13}C_{ap\text{-}co}$ 5.3 ± 0.8 ‰. For the 16 Solcor 3 individuals, $\delta^{13}C_{co}$ averaged −13.9 ± 1.7 ‰ (range 5.3 ‰), $\delta^{15}N_{co}$ + 11.4 ± 1.3 ‰ (range 5.4 ‰), $\delta^{13}C_{ap}$ − 9.1 ± 1.9 ‰ (range 8.9 ‰), and $\Delta^{13}C_{ap\text{-}co}$ 4.8 ± 0.7 ‰ (range 1.9 ‰). Of these values, only $\Delta^{13}C_{ap\text{-}co}$ was determined to differ significantly from those observed for the 26 individuals from Tchecar Túmulo Sur, where the average was −14.1 ± 1.2 ‰ (range 7.5 ‰) for $\delta^{13}C_{co}$, +11.5 ± 0.9 ‰ (range 5.2 ‰) for $\delta^{15}N_{co}$, −8.5 ± 1.1 ‰ (range 5.0 ‰) for $\delta^{13}C_{ap}$, and 5.6 ± 0.8 ‰ (range 3.0 ‰) for $\Delta^{13}C_{ap\text{-}co}$ Inter-group comparisons (t tests) of these values yielded non-significant p values for $\delta^{13}C_{co}$ ($p = 0.67$), $\delta^{15}N_{co}$ ($p = 0.8$), and $\delta^{13}C_{ap}$ ($p = 0.3$), and a $p < 0.01$ for the comparison of the sites' $\Delta^{13}C_{ap\text{-}co}$ values.

For all three of the primary isotopic measures ($\delta^{13}C_{co}$, $\delta^{15}N_{co}$, and $\delta^{13}C_{ap}$), the observed variance was higher for the Solcor 3 samples than those from Tchecar Túmulo Sur (Table 4). Levene's F test comparisons indicated significantly higher variance among the Solcor 3 samples for both carbon isotope values, with a p value of 0.05 for $\delta^{13}C_{co}$ and 0.01 for $\delta^{13}C_{ap}$. The overall difference in intra-*ayllu* variability is evident in Fig. 2, in which $\delta^{15}N_{co}$ has been plotted against $\delta^{13}C_{ap}$.

Considering the results of FRUITS modeling (Tables 3 and 4), the "average" diet of an individual from the 42 analyzed samples comprised roughly 31 % C_3 plants, 27 % C_4 plants, 24 % terrestrial mammal meat, and 19 % legumes, but such average values fail to convey the extreme variability of diets in the populations under study. Modeled mean C_3 plant

Table 2 Contextual, osteological, chemical, elemental, and isotopic data for analyzed Solcor 3 and Tchecar Túmulo Sur individuals. Individuals with insufficient collagen preservation noted in italics

Site	Lab no.	Burial no. museum no.	Sex	Collagen yield (wt%)	Apatite yield (wt%)	wt% C	wt% N	Atomic C:N	$\delta^{13}C_{co}$ (‰)	$\delta^{15}N_{co}$ (‰)	$\delta^{13}C_{ap}$ (‰)	$\Delta^{13}C_{ap\text{-}co}$ (‰)
Solcor 3	*G-80*	*T84, 3883*	–	*0.8*	*52.5*	–	–	–	–	–	–	–
Solcor 3	G-81	T8, 1161 A	F	14.3	48.9	43.0	15.6	3.2	−14.7	10.3	−9.8	4.9
Solcor 3	G-82	T70, 2513	F	20.5	50.9	44.3	16.0	3.2	−14.4	11.4	−9.0	5.4
Solcor 3	G-83	T117, 13.156	M	19.7	45.7	44.4	16.1	3.2	−13.3	11.0	−7.6	5.7
Solcor 3	G-84	T60, 2342	M	17.6	52.5	42.6	15.5	3.2	−15.9	9.7	−11.9	3.9
Solcor 3	G-85	T54, 2071	M	4.3	55.2	30.4	10.8	3.3	−16.5	9.6	−11.6	4.9
Solcor 3	G-86	T60, 2341	F	20.5	48.3	43.9	15.9	3.2	−14.6	11.5	-9.5	5.1
Solcor 3	*G-87*	*T50, 1948*	–	*1.3*	*60.6*	*6.9*	*1.5*	*5.2*	–	–	–	–
Solcor 3	G-88	T112, 13.111	M	18.8	44.2	42.5	15.4	3.2	−13.9	11.4	-9.2	4.7
Solcor 3	G-89	T16, 3061	F	21.6	42.7	44.7	16.2	3.2	−15.5	11.7	−10.6	4.9
Solcor 3	G-90	T44, 1871	–	21.9	36.4	44.3	16.1	3.2	−11.2	15.0	−7.9	3.3
Solcor 3	G-91	T101, 3597	–	19.1	49.1	42.2	15.3	3.2	−11.5	10.9	−6.6	4.9
Solcor 3	H-10	T70, 2514	M	17.3	52.0	44.3	16.1	3.2	−14.5	12.8	−10.5	4.0
Solcor 3	*H-11*	*T68, 2459*	–	*23.7*	*65.6*	*4.4*	*0.4*	*12.0*	–	–	–	–
Solcor 3	H-12	T107, 13.118	M	20.1	45.1	42.7	15.4	3.2	−13.9	11.5	−8.7	5.2
Solcor 3	H-13	T132, s/n	M	18.4	44.7	43.4	15.6	3.2	−11.5	10.9	−5.8	5.7
Solcor 3	H-7	T27, 1629	M	20.4	54.9	42.6	15.4	3.2	−15.1	12.0	−11.3	3.9
Solcor 3	H-8	T93, 3.083	M	1.5	70.6	17.4	5.7	3.6	−11.4	12.1	−5.8	5.5
Solcor 3	H-9	T30, 1683	F	21.4	48.3	43.5	15.9	3.2	−14.7	10.6	−9.9	4.8
Tchecar	I78	863, 11,177	F	19.7	39.4	41.3	15.1	3.2	−14.4	11.6	−8.2	6.2
Tchecar	I79	1173, 11,283	M	18.1	62.6	39.1	13.9	3.3	−14.7	12.0	−9.3	5.4
Tchecar	I80	687, 11.281	–	18.4	37.5	42.2	15.3	3.2	−14.4	12.2	−8.4	6.0
Tchecar	I81	1151, 11.130	M	16.8	37.6	43.4	15.8	3.2	−13.9	11.0	−9.5	4.4
Tchecar	I82	692, 11.123	–	17.8	40.6	42.7	15.4	3.2	−13.9	11.2	−8.1	5.8
Tchecar	I83	814, 11.106	M	17.6	44.2	43.4	15.6	3.3	−15.6	10.4	−9.6	6.0
Tchecar	I84	1161, 11.247	F	14.3	55.2	40.9	14.8	3.2	−12.9	12.0	−6.4	6.6
Tchecar	I85	801, 11,324	–	21.7	51.0	41.6	14.8	3.3	−13.6	12.2	−8.4	5.1
Tchecar	I86	680, 11,244	–	12.0	53.5	40.8	14.7	3.2	−13.9	10.8	−9.3	4.5
Tchecar	I87	1222, 11,143	F	21.3	49.6	41.0	14.7	3.2	−14.6	11.8	−9.1	5.4
Tchecar	I88	1105, 11,257	F	15.6	61.7	25.8	8.9	3.4	−13.8	11.7	−7.7	6.1
Tchecar	I89	1158, s/n	–	9.9	47.5	39.7	14.0	3.3	−14.2	12.2	−7.8	6.4
Tchecar	I90	1155, 11,304	F	9.1	50.1	40.6	14.4	3.3	−14.5	11.3	-8.8	5.7
Tchecar	I91	844, 11,116	–	19.3	47.1	42.2	15.2	3.2	−10.3	11.6	−5.5	4.9
Tchecar	I92	678, 11,160	M	13.6	50.9	42.4	15.3	3.2	−14.0	11.2	−8.5	5.4
Tchecar	I93	691, 11,499	M	18.4	50.2	42.6	15.2	3.3	−13.6	11.5	−8.1	5.5
Tchecar	I94	666, 11,308	F	20.1	40.9	43.1	15.6	3.2	−14.3	11.7	−8.6	5.7
Tchecar	I95	686, 11,189	–	3.1	55.9	32.7	11.0	3.5	−17.8	9.0	−10.5	7.4
Tchecar	I96	815, 11,307	F	17.0	42.2	41.8	15.1	3.2	−14.1	11.2	−9.1	5.1
Tchecar	I97	824, 11.263	–	12.3	42.7	43.2	15.5	3.3	−13.2	10.9	−8.1	5.1
Tchecar	I98	694, 11.141	F	13.4	41.9	43.5	15.8	3.2	−13.6	11.6	−8.9	4.8
Tchecar	J70	1158	–	9.7	54.3	42.8	15.2	3.3	−13.9	12.0	−7.0	6.8
Tchecar	J79	815, s/n	F	17.7	39.3	42.1	15.1	3.3	−14.3	11.2	−9.6	4.7
Tchecar	J80	686, s/n	–	1.5	59.3	37.4	12.4	3.5	−15.9	11.4	−9.8	6.1
Tchecar	J81	680, s/n	F	15.3	50.3	43.6	15.7	3.2	−14.0	10.7	−8.8	5.2
Tchecar	J82	807, s/n	–	20.4	39.0	44.5	16.1	3.2	−13.4	14.2	−9.0	4.4

Fig. 2 Scatterplot of $\delta^{13}C_{ap}$ and $\delta^{15}N_{co}$ values of analyzed Solcor 3 and Tchecar Túmulo Sur individuals. Specific Solcor 3 individuals discussed in text labeled by tomb number
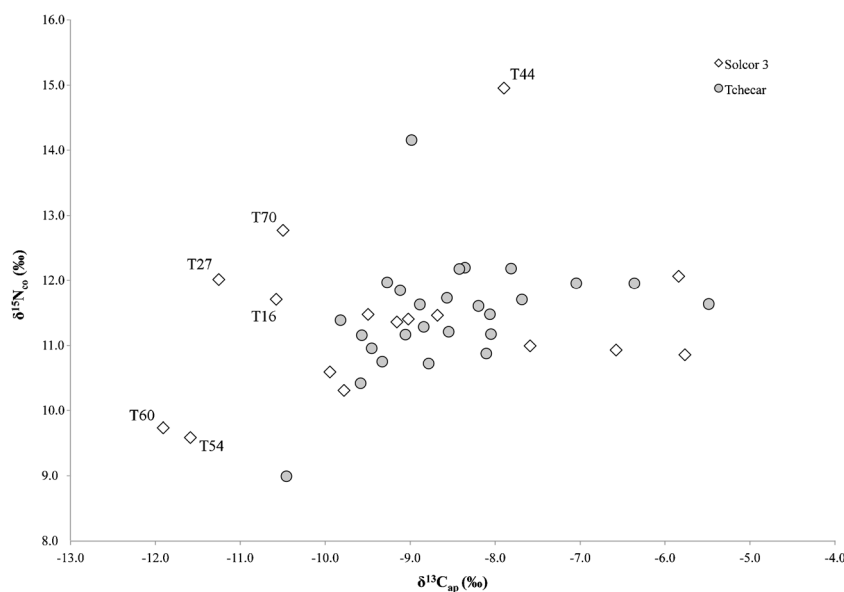
contributions for the populations under study ranged from 16 to 51 %, C_4 plants 6–54 %, terrestrial mammal meat 18–31 %, and legumes 9–34 %. On the scale of individual sites, the average mean modeled diet of an individual from Solcor 3 consisted of 32.7 ± 9.8 % C_3 plants (range 34.4 %), 24.2 ± 14.4 % C_4 plants (range 44.6 %), 24 ± 4.2 % terrestrial mammal meat (range 12.7 %), and 18.9 ± 6.3 % legumes (range 24.7 %). At Tchecar Túmulo Sur, the mean modeled contributions to the diet of an average individual were 29.4 ± 5 % C_3 plants (range 20.9 %), 28.2 ± 8.3 % C_4 plants (range 39 %), 24.1 ± 3 % terrestrial mammal meat (range 12.6 %), and 18.3 ± 4.5 % legumes (range 21.1 %).

As was generally observed with the raw isotopic data, while none of the inter-*ayllu* differences in mean modeled foodstuff contribution were significant, with Student's or Welch's t test p values ranging from 0.22 (C_3 plants) to 0.98 (terrestrial mammals), variance was always higher among the Solcor 3 individuals, and for two of the foodstuff categories (C_3 and C_4 plants), significantly so (Levene's F test p values <0.01; Table 4). As a means of presenting the modeled dietary data in a more readily recognizable manner, in Fig. 3, we have reduced the mean modeled contributions of each of the four dietary inputs to two axes, with the more proteinaceous foods (legumes and terrestrial mammals) on the x-axis and carbohydrate-rich plant foods (C_3 and C_4 plants) on the y-axis. From this representation, it is clear that the dietary combination found at Solcor 3 was far more varied, particularly in terms of carbohydrate-rich plant consumption, than that observed among the individuals from Tchecar Túmulo Sur.

Factoring in individual sex, where possible, better resolves some of this patterning (Table 4 and Fig. 4). Comparing females from the two cemeteries with one another, females of Tchecar Túmulo Sur were found to have significantly higher $\delta^{13}C_{ap}$ and $\delta^{13}C_{co}$ values (Student's t test $p = 0.02$ for both

comparisons) than their female counterparts from Solcor 3, resulting in a significantly higher modeled average consumption of C_4 plants (Student's t test, $p = 0.01$). Variances for the two groups of females were largely equal (standard ellipse areas of 0.75 and 0.57 for Solcor 3 and Tchecar Túmulo Sur females, respectively, see Fig. 4), with only $\Delta^{13}C_{ap\text{-}co}$ and modeled terrestrial mammal consumption showing significant differences (Levene's test p values of 0.05 and 0.03, respectively). Interestingly, the Tchecar females exhibited greater variance for the former and the Solcor females were more varied in the latter. Thus, while there were some apparent differences in average plant consumption between the two groups of females, the observed intra-group variance did not vary consistently.

The same cannot be said when males from the two cemeteries were compared with one another (Table 4), in that while central tendencies were similar, variances were uniformly higher at Solcor 3. While comparison of isotopic and dietary composition for males of the two cemeteries yielded no significant differences (Student's or Welch's t test p values ranging from 0.22–1.0), Solcor 3 males had more varied isotopic and dietary composition than their Tchecar Túmulo Sur counterparts for all measures save terrestrial mammal meat consumption. For $\delta^{13}C_{ap}$ and C_3 and C_4 plant consumption, the observed differences in variance were statistically significant (Levene's test p values of 0.03, 0.01, and 0.05, respectively). This pattern is very evident in the much larger standard ellipse area of the isotopic data for the Solcor 3 males (SEA of 5.28), as compared to the other three site/sex groups (Solcor 3 females, 0.75, Tchecar Túmulo Sur females 0.57, and Tchecar Túmulo Sur males 1.33) represented in Fig. 4.

Among the Tchecar Túmulo Sur individuals, not only were there no significant differences by sex in isotopic values or modeled dietary contribution (Student's or Welch's t test,

Table 3 Results of FRUITS dietary simulation for analyzed Solcor 3 and Tchecar Túmulo Sur individuals (only includes well preserved individuals). Mean modeled contribution and standard deviation presented by food category. Mean modeled ratios of C_4/C_3 plant and Terrestrial Meat/Legumes

Site	Lab no.	Burial no., museum no.	Sex	Modeled dietary contribution (%), mean ± sd				Modeled ratios	
				TM	Legumes	C_3	C_4	Meat/legume	C_4/C_3
Solcor 3	G-81	T8, 1161 A	F	23.1 ± 11.9	22.5 ± 16.2	35.0 ± 16.6	19.4 ± 5.8	0.51	0.36
Solcor 3	G-82	T70, 2513	F	27.6 ± 13.9	19.0 ± 13.8	29.9 ± 15.1	23.5 ± 6.1	0.59	0.44
Solcor 3	G-83	T117, 13.156	M	22.4 ± 13.8	19.2 ± 13.1	22.6 ± 12.6	35.8 ± 5.9	0.54	0.61
Solcor 3	G-84	T60, 2342	M	19.8 ± 9.1	33.9 ± 19.6	40.5 ± 19.0	5.8 ± 3.9	0.37	0.13
Solcor 3	G-85	T54, 2071	F	19.8 ± 11.3	31.2 ± 19.7	41.1 ± 19.4	8.0 ± 5.2	0.39	0.16
Solcor 3	G-86	T60, 2341	–	31.2 ± 13.4	18.0 ± 12.7	32.4 ± 14.3	18.4 ± 6.1	0.63	0.36
Solcor 3	G-88	T112, 13.111	M	22.2 ± 13.0	17.2 ± 14.5	36.3 ± 15.1	24.3 ± 6.0	0.56	0.40
Solcor 3	G-89	T16, 3061	F	30.1 ± 8.1	19.7 ± 15.4	39.6 ± 16.2	10.6 ± 5.6	0.61	0.21
Solcor 3	G-90	T44, 1871	–	25.7 ± 15.8	9.2 ± 7.1	32.3 ± 12.8	32.8 ± 7.3	0.74	0.50
Solcor 3	G-91	T101, 3597	–	21.1 ± 13.3	18.0 ± 11.8	17.2 ± 11.3	43.7 ± 6.6	0.54	0.72
Solcor 3	H-10	T70, 2514	M	30.8 ± 13.7	16.2 ± 14.3	40.9 ± 16.4	12.2 ± 6.5	0.66	0.23
Solcor 3	H-12	T107, 13.118	M	25.3 ± 13.5	17.2 ± 12.2	31.2 ± 13.2	26.3 ± 6.1	0.60	0.46
Solcor 3	H-13	T132, s/n	M	18.5 ± 12.8	12.3 ± 9.4	18.8 ± 9.8	50.4 ± 6.2	0.60	0.73
Solcor 3	H-7	T27, 1629	M	26.1 ± 12.3	15.0 ± 12.6	50.5 ± 14.9	8.4 ± 5.5	0.63	0.14
Solcor 3	H-8	T93, 3.083	M	21.4 ± 13.4	13.5 ± 8.8	16.1 ± 10.1	49.0 ± 6.5	0.61	0.75
Solcor 3	H-9	T30, 1683	F	19.6 ± 13.3	21.0 ± 16.8	39.2 ± 16.9	20.3 ± 6.4	0.48	0.34
Tchecar	I78	863, 11,177	F	21.3 ± 13.5	15.3 ± 10.7	32.0 ± 13.6	31.3 ± 6.1	0.58	0.49
Tchecar	I79	1173, 11,283	M	30.2 ± 15.0	14.7 ± 11.0	34.4 ± 12.8	20.8 ± 7.0	0.67	0.38
Tchecar	I80	687, 11.281	–	22.8 ± 14.0	16.8 ± 13.4	30.2 ± 15.4	30.2 ± 6.5	0.58	0.50
Tchecar	I81	1151, 11.130	M	26.9 ± 13.7	22.8 ± 15.0	30.4 ± 15.7	19.8 ± 6.5	0.54	0.39
Tchecar	I82	692, 11.123	–	23.4 ± 15.4	16.4 ± 12.7	28.3 ± 15.5	31.9 ± 7.2	0.59	0.53
Tchecar	I83	814, 11.106	M	22.2 ± 12.7	23.9 ± 16.2	33.7 ± 16.6	20.3 ± 5.8	0.48	0.38
Tchecar	I84	1161, 11.247	F	22.9 ± 13.8	14.7 ± 10.2	18.4 ± 11.0	44.1 ± 6.2	0.61	0.71
Tchecar	I85	801, 11,324	–	27.4 ± 14.3	16.0 ± 12.3	28.4 ± 12.9	28.2 ± 6.8	0.63	0.50
Tchecar	I86	680, 11,244	–	21.4 ± 14.2	20.0 ± 14.9	34.7 ± 16.1	23.9 ± 6.6	0.52	0.41
Tchecar	I87	1222, 11,143	F	27.3 ± 14.4	18.8 ± 12.8	31.1 ± 15.6	22.8 ± 6.9	0.59	0.42
Tchecar	I88	1105, 11,257	F	26.4 ± 14.8	14.0 ± 9.3	26.4 ± 12.1	33.2 ± 6.5	0.65	0.56
Tchecar	I89	1158, s/n	–	24.7 ± 13.3	15.1 ± 11.8	27.1 ± 14.5	33.1 ± 6.0	0.62	0.55
Tchecar	I90	1155, 11,304	F	22.2 ± 12.9	19.7 ± 14.3	31.3 ± 15.6	26.9 ± 6.2	0.53	0.46
Tchecar	I91	844, 11,116	–	17.6 ± 12.1	12.8 ± 8.6	16.1 ± 9.3	53.6 ± 5.7	0.58	0.77
Tchecar	I92	678, 11,160	M	20.9 ± 11.8	18.7 ± 13.8	30.6 ± 14.4	29.8 ± 5.5	0.53	0.49
Tchecar	I93	691, 11,499	M	20.5 ± 13.8	18.2 ± 13.7	28.1 ± 14.8	33.2 ± 6.5	0.53	0.54
Tchecar	I94	666, 11,308	F	24.7 ± 16.6	16.4 ± 12.0	31.3 ± 14.5	27.6 ± 7.6	0.60	0.47
Tchecar	I95	686, 11,189	–	19.8 ± 11.7	33.0 ± 18.2	32.6 ± 18.2	14.7 ± 5.3	0.37	0.31
Tchecar	I96	815, 11,307	F	28.7 ± 14.6	18.9 ± 13.4	30.1 ± 14.9	22.4 ± 6.6	0.60	0.43
Tchecar	I97	824, 11.263	–	26.3 ± 15.8	17.8 ± 11.8	25.5 ± 13.5	30.4 ± 6.9	0.60	0.54
Tchecar	I98	694, 11.141	F	23.2 ± 14.7	18.8 ± 14.1	31.5 ± 15.9	26.5 ± 6.6	0.55	0.46
Tchecar	J70	1158	–	25.8 ± 12.4	14.7 ± 10.2	21.6 ± 11.6	38.0 ± 5.8	0.64	0.64
Tchecar	J79	815, s/n	F	24.1 ± 12.9	18.7 ± 14.2	36.7 ± 16.2	20.6 ± 6.2	0.56	0.36
Tchecar	J80	686, s/n	–	25.2 ± 12.6	25.0 ± 16.3	31.6 ± 17.0	18.1 ± 5.7	0.50	0.36
Tchecar	J81	680, s/n	F	22.9 ± 13.5	23.7 ± 16.2	26.4 ± 14.5	27.1 ± 6.3	0.49	0.51
Tchecar	J82	807, s/n	–	27.2 ± 14.8	11.8 ± 9.7	37.0 ± 12.3	23.9 ± 9.7	0.70	0.39

$p = 0.27$–0.92), but the variances of all these measures, save one, were not significantly different (Table 4). Besides terrestrial mammal meat, for which the Levene's test p value was $p = 0.05$, all the other variance comparisons had p values ranging from 0.08 to 0.78, suggesting that male and female diets were equally, if minimally, different from one another at Tchecar. Indeed,

Table 4 Average isotopic data and average mean modeled foodstuff contributions for sample subgroups (site and sex)
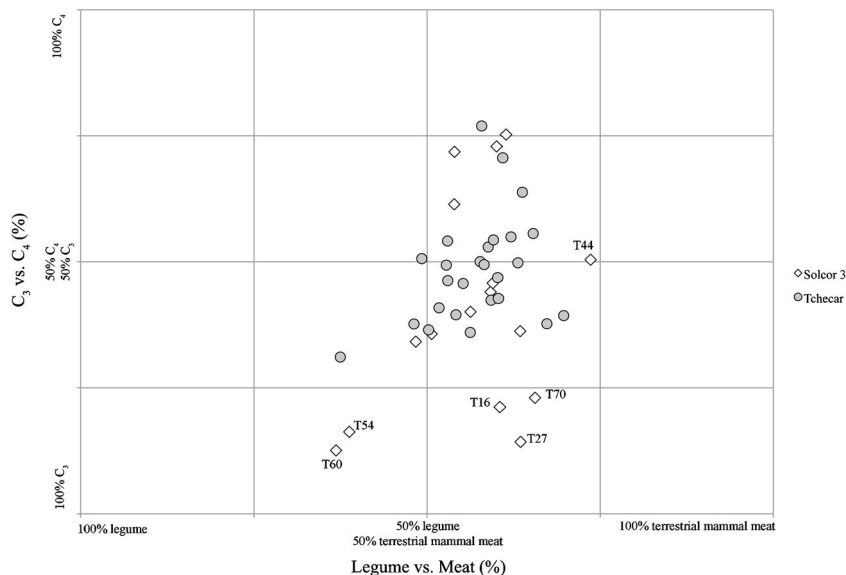
	n	Isotope values (‰)				Average mean modeled dietary contribution (%), mean ± sd			
		$\delta^{13}C_{co}$	$\delta^{15}N_{co}$	$\delta^{13}C_{ap}$	$\Delta^{13}C_{ap-co}$	TM	Legumes	C_3	C_4
Solcor 3	16	−13.9 ± 1.7	11.4 ± 1.3	−9.1 ± 1.9	4.8 ± 0.7	24.0 ± 4.2	18.9 ± 6.3	32.7 ± 9.8	24.3 ± 14.5
Females	5	−14.8 ± 0.4	11.1 ± 0.6	−9.8 ± 0.6	5.0 ± 0.2	26.3 ± 4.9	20.0 ± 1.7	35.2 ± 4.2	18.4 ± 4.8
Males	9	−14.0 ± 1.8	11.2 ± 1.1	−9.2 ± 2.4	4.8 ± 0.8	22.9 ± 3.9	19.5 ± 7.7	33.1 ± 11.7	24.5 ± 17.5
Tchecar Túmulo Sur	26	−14.1 ± 1.2	11.5 ± 0.9	−8.5 ± 1.1	5.6 ± 0.8	24.1 ± 3.0	18.3 ± 4.5	29.4 ± 5.0	28.2 ± 8.3
Females	10	−14.1 ± 0.5	11.5 ± 0.4	−8.5 ± 0.9	5.6 ± 0.6	24.4 ± 2.4	17.9 ± 2.9	29.5 ± 4.9	28.2 ± 6.8
Males	5	−14.4 ± 0.8	11.2 ± 0.6	−9.0 ± 0.7	5.3 ± 0.6	24.1 ± 4.2	19.7 ± 3.7	31.4 ± 2.6	24.8 ± 6.3

for the four isotopic and four food categories under consideration, males exhibited greater variance half the time ($\delta^{13}C_{co}$, $\delta^{15}N_{co}$, legume, and terrestrial mammal meat) and females the other half ($\delta^{13}C_{ap}$, $\Delta^{13}C_{ap-co}$, C_3 plants, and C_4 plants).

At Solcor 3, in contrast, the vast majority of variance was driven by diverse male diets (Table 4). While, the average isotopic signatures and diets of males and females at Solcor 3 are statistically indistinct, with Student's or Welch's t test p values ranging from 0.16 to 0.89, male diets exhibited greater variance than their female counterparts for all four of the isotopic measures and three of the four modeled food categories (excepting terrestrial mammal meat). For $\delta^{13}C_{co}$, $\delta^{13}C_{ap}$, and $\Delta^{13}C_{ap-co}$, as well as both the C_3 and C_4 plant categories, the differences in observed variance were statistically significant, with Levene's test p values between 0.02 and 0.05.

By most measures, then, the diets of Solcor 3 individuals were more varied than their counterparts at Tchecar Túmulo Sur, and the diets of Solcor 3 males were more varied than the females who were buried alongside them. Interestingly, the main dimensions of dietary variance were in plant intake, with meat consumption varying far less among and between the analyzed groups and individuals.

Discussion and conclusion

Based on the evidence of differential susceptibility to stress and divergent health outcomes within (Hubbe et al. 2012) and between (Torres-Rouff 2011) cemeteries, in concert with settlement pattern analyses (Llagostera and Costa 1999), researchers have argued that the Middle Period in the Atacama oases witnessed the strengthening of a local elite who controlled systems of access to distant resources (Llagostera 1996, 2004; Núñez 1991, 2007). Our recent research has indicated that differences within cemeteries in the region strongly reflect social dynamics in the oases (Hubbe et al. 2012; Torres-Rouff et al. 2015); thereby motivating an analytical shift from an exclusive focus on comparing sites to a perspective that also incorporates detailed examination of patterns of individual variation within sites and cemeteries. The individual nature of stable isotope data is ideal for engaging in this discussion.

As food in human societies extends beyond the merely nutritional to incorporate and respond to varied external stimuli, food systems can communicate key aspects of social identity, including class or social status (Allison et al. 1997; Guyatt et al. 1993; Pottier 1999). A time of burgeoning social
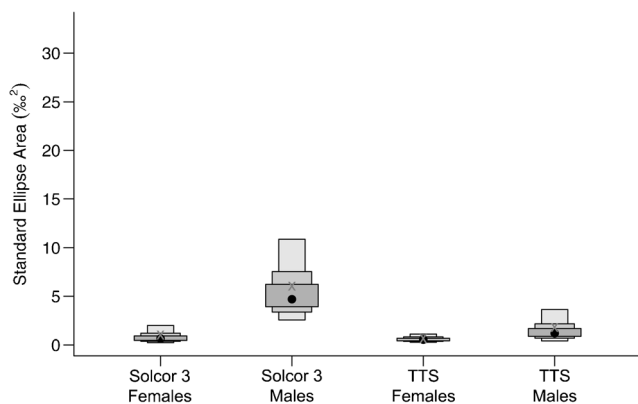
Fig. 3 Scatterplot of mean modeled ratios of C_4/C_3 plant and terrestrial meat/legumes for analyzed Solcor 3 and Tchecar Túmulo Sur individuals. Specific Solcor 3 individuals discussed in text labeled by tomb number

Fig. 4 Standard ellipse areas (SEA) of human isotopic data by site and sex grouping

inequality and human mobility should be associated with differential access to certain food items and/or the ability of particular individuals to choose from a broader/distinct array of potential foodstuffs (Curet and Pestle 2010; Garnsey 1999; Gumerman 1997; Hubbe et al. 2012; Smith 1987). The isotopic and diet modeling data presented here paint a rather clear picture of the ways in which diets varied between and, more dramatically, within Middle Period cemeteries, in ways that we suggest may reflect differential individual involvement in long-distance exchange and the broad, and seemingly uneven, distribution of resource access at this time.

While there seems to have been marked variability in dietary composition in Middle Period San Pedro de Atacama, it does not appear to have been apportioned solely between or among cemeteries or *ayllus*, such that the diet of individuals of one *ayllu* (as represented by a local burial population) would differ from its neighbors in a uniform fashion. Instead, our data indicate that certain cemeteries, and certain individuals within those cemeteries, while sharing similar average dietary makeup with one another, possessed far greater variability in their gustatory habits than others. Such was the case in our previously published analysis of individuals interred in the small Larache cemetery (Torres-Rouff et al. 2015, p. 592), and the case can be made even more strongly here. While individuals at Tchecar Túmulo Sur had generally uniform diets, the individuals of Solcor 3, and in particular the males buried therein, would appear to have diets that varied dramatically from one individual to the next.

The research presented here is of a broader comparative scale and allows us to argue that the driving factors of this diversity in the present case were likely the differential involvement of various Solcor 3 individuals in the Middle Period's systems of long-distance movement. In addition to suggesting differential access, particularly at Solcor, the more homogenous patterns seen at Tchecar strengthen what is known about the *local* food web. While the limited number of paleobotanical studies in this region do not allow for detailed exploration, the

abundance of the C_3 plant algarrobo (*Prosopis* spp.) in graves in both seed and ground form, argue for its preponderance in the local diet, something reflected in the high rates of C_3 consumption in our analyses. Material culture evidence from Tchecar presents an image of a population that was engaged in the local area but not entwined with the larger interregional networks that developed in the Middle Period (Torres-Rouff 2008). In contrast, as noted above, the paleodietary data from Solcor 3 reveal a population with significant differences in their resource access and consumption. While some of the Solcor 3 individuals fall into the same isotopic and dietary "space" as individuals from Tchecar, some present evidence of markedly different dietary patterns. This is not unexpected given: (a) the distinctiveness in mortuary treatment of subgroups of the Solcor 3 burials, (b) the evidence indicating incipient hierarchization found at Solcor, (c) that a number of likely non-local individuals were interred there, and (d) the presence of varied foreign material culture (Knudson and Torres-Rouff 2014; Llagostera et al. 1988; Torres-Rouff 2008). It is possible, then, that the variance we documented in diet reflects an interesting intersection of engagement with the large-scale trade networks of the period and the probable wealth and resource access that it brought some members of Atacameño society.

Moving away from this more sweeping narrative of difference between the cemeteries, these analyses allow us to consider the individuals whose lifeways resulted in the patterns we see here. Based on isotopic and foodstuff modeling, three distinct burials/groups of burials from Solcor 3 would appear to stand apart from local dietary customs and thus contribute to the dietary diversity seen at Solcor 3 (Figs. 2 and 3). The first of these consists of just one individual, a child (4–6 years old) from Tomb 44. While the plant diet of this individual was near the average value of all individuals presented here (32.3 ± 12.8 % C_3, 32.8 ± 7.3 % C_4), the model indicates that they were consuming more terrestrial mammal meat (as compared to legumes) than any of the other analyzed individuals. In part, at least, the high modeled value for terrestrial mammal meat could be a consequence of an elevated $\delta^{15}N_{co}$ signature (15.0 ‰) resulting from the residual effects of breastfeeding (see, for example, Fuller et al. 2006). It is worth noting, however, that this individual was also buried with an entire juvenile camelid and a hallucinogenic snuff tray with Tiwanaku iconography depicting a camelid carrying a bundle, possibly including plants (Fig. 5). The array of goods that accompanied this child in their grave suggests elevated social status, and the possibility that this particular burial treatment might speak to the participation of this child or their family in camelid caravanning or

Fig. 5 Excavation photograph of Solcor 3 Tomb 44. Note complete camelid skeleton and Tiwanaku snuff tray adjacent to child's skeleton

connections to the foreign Tiwanaku polity. Although their $Sr^{86/87}$ isotope signature testifies to local birth (Knudson and Torres-Rouff 2014), one possible interpretation of the dietary signature seen in our analyses is that this child may have engaged in travel (consuming camelid meat along the way) or that he/she was the beneficiary of access to such meat.

The second grouping of note comprises three individuals from tombs 16 (female), 27 (male), and 70 (male). Like the child from tomb 44, these three individuals had proteinaceous diets that skewed towards more terrestrial mammal meat (averaging 29 %) rather than legumes (which average 17 %), but, unlike the previous example, their plant diets were characterized by consumption of a large amount of C_3 species in place of C_4 (maize) consumption. While each of their graves contained a large number of artifacts, including snuff trays, musical instruments, baskets, ceramics, and bows/arrows, none of the included artifacts were demonstrably foreign, and the $Sr^{86/87}$ isotope signature of the one analyzed individual (the female from tomb 16) was also within the local range (Knudson and Torres-Rouff 2014). On the basis of their differences from the dominant local plant consumption patterns, one possibility is that these individuals may have been travelers, traders, or recipients/consumers of products of highland trade, resulting in access to more meat (as with the child from tomb 44, above) but also to plant products/plant combinations not typical of the local Atacameño diet, given that the *puna* plant biota is comprised of C_3 species alone.

We separate a final grouping, comprised of males from tombs 54 and 60, who had similar plant consumption habits to the prior group (skewed towards a heavy reliance on C_3 plants), but who showed a much heavier reliance (averaging 32.5 %) on legumes/less terrestrial meat than the previous group. Moreover, these two individuals are unique among the Solcor 3 burials in that they are the only two individuals who had labrets, one of whom showed the dental signs associated with long-term wear (Torres-Rouff 2003). Interestingly, labret use is typically associated with males from the initial Middle Period and earlier and is a long-standing tradition from the Atacameño area southward into Chile's Semi-arid North and portions of central Chile at this time (Niemeyer et al. 1998). It should be acknowledged that these two burials could date to the earlier portion of the Middle Period, when labret use was more frequent and maize formed a lesser part of local plant diet. However, it is also possible that, in contrast to the more highland derived dietary pattern associated with the former group, these individuals' diets may reflect a different type of circulation—one that was more focused towards other Chilean groups of the semi-arid North and even farther south, where both labret use and diets dominated by C_3 plants and low trophic level protein (legumes?) were commonplace in the period of interest here (Becker et al. 2015; Sanhueza and Falabella 2010). Moreover, recent research has indicated a significant heterogeneity for that region as well as an integration into larger spheres of influence. Isotopic work suggests that while diets in the Semi-arid North were varied, maize was a late addition to the dietary repertoire (Becker et al. 2015; Troncoso and Pavlovic 2013).

In summary, the isotopic analysis and Bayesian dietary modeling of Middle Period individuals from Tchecar Túmulo Sur and Solcor 3 provide unique, and otherwise unobtainable, insights into the lifeways (diets) of individuals living in the San Pedro oases at a time of burgeoning regional integration. From patterns of inter- and intra-*ayllu* dietary variation, we argue that the benefits of participation in the period's systems of regional trade and exchange were discontinuously distributed, such that certain *ayllus* were more strongly involved, and that certain individuals within *ayllus* reaped more of the benefits of that trade and of the prosperity of the time than others. While, on the one hand, the individuals buried at Tchecar Túmulo Sur would appear to have had relatively little involvement in the acquisition and consumption of non-local foods, thus contributing to their overall isotopic and dietary homogeneity, select individuals from Solcor 3 would appear to have been differentially involved in these systems of regional exchange, and to have consumed different foods as a consequence of such involvement. Without the benefit of individual-level isotopic analysis and the dietary insights afforded by Bayesian modeling of isotopic mixing, such reconstruction would be impossible, thus testifying to the centrality of such analytical methods in the modern archeological reconstruction of ancient social processes.

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