2008-11-21

Hair, Feces and Breath Isotope Fractionation in Alpacas (Llama pacos), Llamas (Llama glama) and Guanacos (Llama guanacoe) from Bolivia and Chile

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HAIR, FECES AND BREATH ISOTOPE FRACTIONATION IN ALPACAS (*Lama pacos*), LLAMAS (*Lama glama*) AND GUANACOS (*Lama guanacoe*) FROM BOLIVIA AND CHILE

by

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A thesis submitted to the faculty of
Brigham Young University
In partial fulfillment of the requirement for the degree of

Master of Science

Department of Plant and Wildlife Sciences
Brigham Young University

December 2008

BRIGHAM YOUNG UNIVERSITY

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ABSTRACT

HAIR, FECES AND BREATH ISOTOPE FRACTIONATION IN ALPACAS (*Lama pacos*), LLAMAS (*Lama glama*) AND GUANACOS (*Lama guanacoe*) FROM BOLIVIA AND CHILE

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This study was conducted to determinate carbon and nitrogen isotope fractionation in Bolivian and Chilean alpaca, llama and guanaco, hair, breath, plasma and feces. We also wanted to determine forage selection for these camelids using stable isotope technology. From the data, niche feeding and diet selection habits will determinate based on fecal composition. Bolivian sites were located near the high snow Altiplano Mountains at Tomarapi, Sajama, and at the Technical University Oruro's research center at Condoriri, Bolivia. Chilean samples were collected at INIA's (Instituto Nacional de Investigacion Agropecuaria) Kampenaike Research Station, Punta Arenas, Chile. Bolivian alpacas and llamas were 3 to 5 years of age from producer herds and the Oruro University's camelid herd. Chilean animals were selected from INIA-Kampenaike's camelid herd. The alpacas, llamas and guanacos were selected based on heath status: no conformation defects, illness, genetic abnormalities or apparent nutrition problems. Samples were taken of fiber, feces, and blood from alpacas, llamas, and guanacos. Forage samples from pastures and grazing areas were taken. Forage species that were collected came from the asteraceae, berberidaceae, gramineae, caryophyllaceae,

leguminoseae, plantaginaceae, gentianiaceae and the chenopodaceae families and ranged from -15.5‰ to -33.9‰ $\delta^{13}C$ and -3.0‰ to 6.4‰ $\delta^{15}N$. Isotope values for feces and fiber were similar for the two Bolivian sites, but the Chilean values were significantly more depleted. This was attributed to the forage isotopic values being significantly more depleted than those found in Bolivia. Forage selection, based on fecal and forage isotopic signatures supported the observation that alpacas, llamas and guanacos eat different forages. This is dependent on forage source and time of year (dry versus wet season). Stable isotope technology will be a useful tool in determining forage selection and species competition or interactions in South American Camelids.

ACKNOWLEDGEMENTS

I owe my appreciation to the following people for making this thesis possible:

First of all, I would like to thank my major professor and advisor, Dr. Todd F. Robinson, who helped and directed me in the writing and data analysis process; who also made it possible with his vast knowledge and expertise, which made the completion of this project possible.

I would like to thank Dr. Paul N. Johnston for his suggestions and knowledge.

I would like to thank Dr. Beverly L. Roeder, for her professional advice with this camelid project.

I also extend my gratitude to the entire Department of Plant and Wildlife Sciences, Brigham Young University for giving me the opportunity to complete my master's degree.

I am also indebted to the Ezra Taft Benson Agriculture and Food Institute (BAFI) for funding this project. I especially thank Instituto Benson Bolivia Lic. Elizabeth Garcia for her unconditional support and encouragement.

I would like to thank Universidad Catholica Boliviana Ing. Alberto Abastoflor and his committee for giving support and encouragement.

My appreciation to Ben Stearns and Megan Wilson for helping take samples in Bolivia and Chile for this project. I owe my appreciation to Dr. Todd F. Robinson for the friendship we have developed along the way and his family for being the most gracious and giving people I have ever met.

Finally, I would like to thank my family Petrona Lopez Tapia, Victoria Lopez Lopez, Felipe Quispe Choque and my nephews Ever and Brittany and friends who have supported and encouraged me along the way.

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INTRODUCTION

Andean countries of South America are the principle location for South American Camelids including: alpacas (*Lama pacos*), llamas (*Lama glama*), vicuñas (*Lama vicugna*), and guanacos (*Lama guanacoe*). These animals have existed since the discovery of the America's as wildlife and domesticated animals. Bolivia has mostly llamas and alpacas located in the mountains and bofedales. Peruvian camelids consist mainly of alpacas and to lesser extent llamas, but there are large herds of wild vicuña roaming the high plains of both Peru and Bolivia. Chile has the majority of the world's guanaco located in the Patagonian region, but do have llamas and alpacas located in the northern Andean region. Guanacos are considered cosmopolitan animals, living on highland and lowland lands. South American native people have domesticated llamas and alpacas but guanaco and vicuna are not domesticated.

The South American Camelids (SAC) belong to the family Camelidae of the order Artiodactyla ungulates and they are separate from other ruminants in the infra-order Tylopoda (pad footed) because they differ in stomach morphology (three compartments), absence of horns or antler, and the replacement of hooves with callous pads ending in claws (Novoa and Wheeler, 1984). Guanacos and vicunas exist only in the wild and can be sedentary or migratory. Guanacos are located primarily in the valleys of Patagonia (Chile and Argentina) with lesser numbers occurring in the mountains of Bolivia and Peru (San Martin et al., 1988).

Grazing systems in Bolivia and Chile are controlled by landowners and sheep producers. The llamas have been grazing in dry land hillsides with a majority of the

forage being shrubs of *Margiricarpus pinnata* and *Baccharis sp*. and alpacas have been grazing in high Andean bofedales (naturally irrigated meadows and marshes located at the base of snowcapped mountains). Vicunas graze together with alpacas during the rainy season. Chilean llamas and alpacas are grazed primarily under pastoral systems, where grazing is controlled by fencing, versus the system used by Bolivian producers who use shepherd grazing.

The South American Camelid population in Bolivia is about 2.8 million head (2.5 million llamas, 325,000 alpacas, 20,000 vicunas and 2,000 guanacos) in an area of 200,000 Km^2 at an altitude of 3800 m to 4800 m above sea level. Average temperature is 4 to 8 ºC and the annual precipitation is 200 mm to 800 mm/year (Unepca, 2003). Alzerreca (1978) reported that natural grazing areas encompassed 201,924 km^2 which is about 18.4% on Altiplano and high Andean plains. Bolivia has three regions where the majority of the camelids are located: Oruro, Potosi, and La Paz - Cochabamba. The camelid population is growing annually at a rate of about 2.1% for llamas and 2.7% for alpacas (Ministerio de Agricultura Ganaderia y Desarrollo Rural MACA 2003).

The guanaco population declined after the introduction of domestic sheep and the emerging conflicts with sheep producers. Apart from conflicts with sheep ranching, guanacos have declined due to poaching, legal over-hunting, and lack of sound management.

Guanaco populations have a different conservation status at country level and is usually based on population size. Argentina has the largest population (91% of total), and therefore the species is classified as either not endangered (Reca, Úbeda & Grigera, 1996) or potentially vulnerable (Díaz & Ojeda, 2000). Chile, on the other hand, classifies

the guanaco as vulnerable (9% of the total population; Glade, 1993). Finally, Bolivia (< 0.02%), Paraguay (< 0.01%) and Peru (< 0.5%) have classified their population as endangered, following International Union for Conservation of Nature criteria (IUCN, 1994; Tarifa, 1996).

There are different opinion about the guanaco distribution in southern Chile and Argentina. Krumbiegel (1944) indicated that the distribution of *Lama guanicoe* ranges from Patagonia and Tierra del Fuego up to a northern limit of the 35°S parallel and considered the populations from Buenos Aires as the northernmost populations of the Patagonian subspecies. Alternatively, Torres (1992) describes the population habitat as one, ranging from Chile and Argentinean Patagonia region up to a northern limit of the 38°S parallel.

GENERAL CAMELID CHARACTERISTICS

Physical Characteristics

The four species of South American camelids are llamas, alpacas, vicunas and guanacos. The llamas and alpacas are domesticated and vicuna and guanaco are wild. Among alpacas, there are two breeds, huacaya and suri. The huacaya is more resistant to cold weather because they have bulky fiber. The suris need more attention in cold weather because their fleece is in ringlets and lays flatter to the animal, not providing as much insulation. The difference between these two is in the fiber and live weight; the suris have longer fiber and heavier live weight than huacayas. Alpacas (*Lama pacos*) are found at elevations of 3700 m to 4800 m and are strictly a selective grazer, preferring the bottomlands vegetation of meadows and marshes called bofedales. Alpacas are

characterized by their high quality of fiber production. Alpacas are premier fiber-producing animals in the Altiplano region of Bolivia, Peru, Argentina, and Chile.

Llamas (*Lama glama*) are divided into two breeds: thamphulli and k'ara. The thamphulli breeds have more fiber, coverage of their face and down their legs, whereas the k'ara have clean faces and no fiber on their legs (Fowler et al., 1989). The thamphulli breed has been bred for fiber and meat production, while the k'ara has been bred for packing and meat. Llamas are found at moderate elevations of 2300 to 4000 m above sea level. Llamas are the largest South American Camelid. The llama is a mixed feeder; a grazer and a browser, preferring to graze on dry tablelands and slopes, feeding on the tall coarse bunchgrass community dominated by fescue (*Festuca dolichophylla*), but it also brows available shrubs and trees.

The guanaco (*Lama guanacoe*) is a South American Camelid that inhabits nearly all arid non-tropical habitats south of the Amazon basin. Its range formerly extended from southern Ecuador south along the Andean mountains into Tierra de Fuego, and east into all of Patagonia, from sea level to 4,000 m elevation (Dennler de la Tour., 1995). The guanaco is a mixed feeder; a grazer and a browser, inhabiting desert grassland, savanna, and shrub land; it may even be seen in forests (Fowler et al., 1989). It is found in one of the driest deserts of the world, the Atacama in Chile, and in the wet archipelago region of Tierra del Fuego, where rain falls year round.

The vicuna (*Vicugna vicugna*) is one of two species of wild lamoids. It inhabits the high Andes at elevations of 3700 to 4800 m (Murray 1998). This is a harsh environment, with cold temperatures, sparse vegetation, semiarid grassland, and barren pampas. The vicuna is a grazer of forbs and grasses and tends to be a nomadic grazer;

they do not graze in herds but rather as individuals or in family groups of ten to twenty. Vicunas are characterized by high quality fiber and unique color. In a study of vicunas' fiber, Cueto et al., (1985) found 13 to 14 $m\mu$ diameter with a coefficient of variation 19.3%. Vicuna are the smallest of the South American Camelids.

General Digestive Characteristics

Even though camelids are taxonomically classified as pseudo ruminants, they are functionally ruminants. They have three compartments; the first, compartment 1 or C1, is the largest where microbial fermentation occurs; it is also lined with saccular glands that secrete bicarbonate to buffer ingesta. The pH is maintained due to the buffer, so these animals are less prone to bloating as a result. These saccules are also present in the second compartment (C2) similar to the ruminant omasum. The last compartment is the true glandular stomach (C3; Solis, 1997) where acid digestion occurs. Camelid digestive physiology has evolved to be more efficient at utilizing the poor quality forage of the mountain rangelands and bofedales ecosystems by slowing digesta passage and recycling nitrogen (San Martin and Bryant, 1989).

The mean retention time (MRT) for digesta passage in camelids is longer than other ruminates (Florez, 1973; San Martin, 1987; Sponheimer et al., 2003). This may account for the camelid's higher digestion efficiency of fiber and more lignified grasses. Florez (1973) found a longer retention of digesta in alpacas (50.3 h) than sheep (43.2 h). San Martin (1987) reported retention times in llamas of 63.2 h and sheep of 40.9 h. Whereas, Sponheimer et al. (2003) comparing llamas, alpacas, goats and horses found

MRT of 72, 71, 54 and 27 hours, respectively. Heller et al. (1986) showed that retention time of passage of the fluid phase in guanacos was 36.2 hours, while the passage time of particles was 52.0 hours. In a comparative study of gastrointestinal transit time in ten mammalian species, Clemens and Stevens (1980) indicated llamas retained larger particles for a longer period of time than cattle or horses. Rubsamen and Engelhardt (1979) concluded that the camelid forestomach is faster and more efficient in absorbing solutes than the small intestine of sheep (Table 1).

Table 1. Solute intestinal absorption for camelids and sheep.

Solute	Forestomach-Llama (mmol/h)	Colon-Sheep (mmol/h)
Water	65.1	330
Na	18.6	50
Cl	16.2	16.8
SCFA	96.6	65
HCO_3	4.5	6

Adapted from Rubsamen and Engelhardt (1979)

GRAZING AND FEEDING HABITS

Location

South American Camelids are located in different altitudes and grazing habitats. Ulla Ulla-La Paz and Sajama-Oruro Bolivia are the most important locations in Bolivia for raising alpacas and vicunas because they have bofedales around the Sajama and Anmin Apolobamba snowcapped mountains. The llamas are grazed by shepherding on dry grasslands usually hillsides. The llamas and alpacas are not migratory, because they are domesticated, and graze on the same bofedales and dry grazing lands year round. The

vicunas live in high grazing lands, where there are bofedales with good grass production. The guanacos migrate from low to higher elevation. This dynamic grazing happens seasonally driven by food abundance of the grasslands.

Seasonal Affects

During the dry season (May – October) Bolivia's Altiplano has almost no precipitation and little change in forage growth on the dry grazing lands. At this elevation, less than 5% of the land is suitable for cultivation (Gilles, 1980). The change of the seasons can affect camelid production and reproduction, being better when forage is abundant. During the dry season, there is not enough natural forage for animals, so the alpaca and llama producers must provide additional feeds as barley, alfalfa and oat hay to maintain the camelid's body weight and to support the animal's production.

The Bolivian Altiplano is about 3800 meters above sea level and experiences varying seasons. The wet season is December thru May. In this season, forage is abundant with high nutritional value. Nutrient composition of native and introduced grasses varies greatly seasonally, altitudinally, and according to soil type. Vicuna and guanaco gain weight and body condition in this season and burn fat in winter or dry the season.

Southern Chile is known for cold winter weather with variant wind direction and short days. This harsh climate has negative effects on the guanaco's body condition. The Patagonia Summer offers warm, sunny days and cool nights. Patagonia summer days are long (18 hours). During the winter months the guanaco will lose body condition and during the summer months, where forage is plentiful, they will gain body condition.

BOTANICAL COMPOSITION OF GRAZING LANDS

Bolivian Grasslands

South America Camelids eat mostly native grasses. The sweet and younger plants are preferentially selected for during the rainy season. The Altiplano, being situated over 3800 m above sea level and seasonally low temperature and intense solar radiations (San Martin and Bryant, 1989), has many kinds of native plants that have adapted to these harsh conditions are selected by alpacas, vicunas, guanacos, and llamas. Ten percent of the Andean grassland is covered with bofedales, which constitutes the most important socio-environmental region. The remainder is dry land flat land and hills. In these grasslands, the most relevant population of botanical plant species are *Polylepis tarapacana* (Queñua), the bushes associated with *Stipa* spp. population of *Parastrephia lepidophylla* (Ovijthola), *P. lucida* (Khoa thola), *Baccharis incarum* (Nhaca hola), and yareta (*Azorella compacta*) (Alzérreca, 1992).

The botanical families of the Bolivian Tomarapi, and Sajama bofedales were identified as gramineas (29.4%), compuestas (29.4%), leguminosas (5.9%), solanaceas and cariophyllaceas (3.9%) and another 13 botanical families representing about 2% (Table 2; Vargas, 2000).

Chilean Grasslands

Patagonia's grassland consists of a canopy of bushes, forbs, trees and shrubs, grasses and other graminoids. The region is characterized by two distinctive climate

periods. Summer (December-February) is marked by strong westerly winds, warm temperature, high precipitation (average =102mm) and the landscape is open with rolling hills, vegetation rarely >1 m high, and easy observation of animals (Roland et al., 1999). Grasses (*Festuca gracillana, Anarthrophyllum patagonium*) and shrubs (*Mulinum spinosum, Senecion patagonicus,* and *Berberis buxifolia*).

Table 2. Botanical families registered in six locations of Central Altiplano Oruro-Bolivia

No.	Botanical Families	Number of species	%
1	Poaceae	15	29.4
2	Asteraceae	15	29.4
3	Fabaceae	3	5.9
4	Solanaceae	2	3.9
5	Cariophillaceae	2	2.0
6	Cyperaceae	1	2.0
7	Euphorbiaceae	1	2.0
8	Ephedraceae	1	2.0
9	Geraniaceae	1	2.0
10	Malvaceae	1	2.0
11	Chenopodiaceae	1	2.0
12	Rosaceae	1	2.0
13	Verbenaceae	1	2.0
14	Labiataceae	1	2.0
15	Cruciferaceae	1	2.0
16	Oxalidaceae	1	2.0
17	Boraginaceae	1	2.0
18	Caesalpinaceae	1	2.0
19	Brasicaceae	1	2.0
	TOTAL	51	100.0

(adapted from Vargas 2000)

The vegetation of arid and semi-arid Patagonia is structured in herbaceous and shrub steppes (Beeskow et al., 1995). In terms of vegetation composition, the area has been classified in 2 phytogeological provinces (Leon et al., 1998). Principal species

represented are the shrubs *Chuquiraga avellanedae, Lycium chinense, Mulinum spinosum* and *Nassauvia spp.*

Botanical composition of diets

Studies in Peru by Tapia and Lascano (1997) showed that alpacas from bofedales in Puno, consumed mainly tall grasses in the wet season and short grasses in the dry season. Preferred species included *Festuca dolichophilla, Distichia muscoides, Trifolium amabile* and *Bromus unioloides*. The frequency of botanical families consumed by alpacas during the dry and humid season were juncaceae 27.78%, cyperaceae 21.03%, gramineae 15.02%, rosaceae 12.39% and unbeliferaceae 6.61% (Lopez 2004). Currently about 80% of all llamas and alpacas are under the control of traditional shepherd grazing in designated territories.

Analysis of fecal material using micro histological components of plant materials, Bryan and Farfan (1984) found grass consumption was higher during the driest months with consumption of grass-like species inversely related to grass in the diet. Forbs in the diet increased in the early wet season. Alpacas ate leafier material as the rainy season progressed. Yearling camelids consumed more grass-like plants, forbs and seeds than adults did. The alpaca is the most adaptable camelid, selecting native plants according to forage abundance (Bryan and Farfan, 1984; Huisa et al., 1985).

Species composition of a guanaco's diet indicates a preference for gallery forest and shrub communities composed mainly of *Colletia spinosissima* and *Mulinum spinosum*, respectively, at an intermediate height on slopes in the area (Bahamonde et al., 1986). This can change from winter to summer diets, but they consume more shrubs and

trees in winter time because the lower grasses are covered with snow. The food habitats of the guanaco elsewhere have been described for mixed forest and grasslands of the southern Patagonia region in Chile (Raedeke, 1980). Guanacos of the northern Chilean coast have diets consisting mainly of lichens in both the winter and summer samples (68% and 67% of the diet respectively; Table 3; Raedeke and Simonetti, 1988).

Table 3. Composition of the seasonal diets of guanacos in coastal northern Chile based on fecal analysis.

Forage class	Winter		Summer	
	Percentage	SD of mean	Percentage	SD of mean
Lichens	68	3.03	67	2.92
Shrubs	17	-	16	-
Forbs	11	0.85	8	0.7
Grasses	4	0.76	<1	0.12
Thorns	-	-	5	0.94
Seeds	-	-	3	0.43
Fruits	-	-	1	0.15
Total	100		100	

(Adapted from Raedeke and Simonetti, 1988)

The composition of the guanaco diet those in the northern Patagonia region is reported to include a greater amount of land material from trees and shrubs (*Mulinum spinosum* 23.2% and *Colletia spinosissima* 18.9%), forbs (*Acaena spp*. 15.4%) and to a lesser extent grasses and graminoids (Bahamonde et al., 1986).

Guanacos are known as browsers while vicunas are selectors of high quality grasses. Guanacos of the Torres Pine Nation Park, Chile prefer gramineae species (Ortga et al., 1988); preferring to graze the marshy grassland pockets of the mountainous regions to the hillsides (Figure 1). Bushes were consumed when gramineae was covered by snow

Figure 1. Guanacos of the Torres del Pine Nation Park in Chile grazing gramaneae rich marshy pockets.

(Bahamonde et al., 1986). Work with guanacos in Estancia Fortin de Chacabuco, Argentina (Bahamonde et al., 1986), estimated the selectivity in spring and summer was towards forbs (44% for spring and 50% for summer), gramineas (32% for spring and 18% for summer), and trees and shrubs (14% for spring and 15% for summer).

GRAZING DYNAMICS

Domesticated Camelids

Llamas and alpacas are controlled by farmers to accomplish even distribution of grazing lands. Llamas most often graze on hills and dry places with low nutrient quality in plants. The camelid producer will often own large amounts of grazing lands and have a shepherd control the grazing of the animals. In Condoriri, Oruro, Bolivian farmers plant

barley and oat for sheep and cows, and graze alpacas and llamas after harvesting grain. This is a relatively new method of additional grazing for camelids to gain nutrients in the dry season. Llamas constantly move during grazing often moving up to 10 miles during the day.

Alpacas have a different grazing dynamic than llamas. As an example, the Tomarapi, Sajama, Bolivian community has year round bofedales because of the water run-off from the Sajama mountains snow that feeds into the low land bofedales (Figure 2). Alpacas select their food according to palatability on the bofedales. Alpaca producers do not need to supplement feed their animals because the bofedales are productive year-round. In the dry season, the alpacas may travel about 5 miles grazing the bofedales. On the bofedales, alpacas compete with vicunas for the forage during the wet season.

Figure 2. Bofedales at the base of Mount Sajama in Tomarapi, Sajama, Bolivia.

Wild Camelids

Currently it is suggested that the guanaco is the parent species of the llama; the llama is thought to have been domesticated between 6000 to 7000 years ago, while the vicuna is the parent species to the alpacas (Wheeler 1983).

The family groups of vicunas consist of an adult male and about 16 females with crias of that year (Figure 3; Franklin 1980). About 75% to 85% of these groups stay in a permanent territory, while others are in family category groups in marginal territories or are migratory family groups (Franklin et al., 1997). The family territory can occupy

Figure 3. Vicuna family group foraging. Family groups consist of a dominant male, several females and their cria.

about 8 to 40 hectares (Koford 1957). The size of a group depends on the quality of the grazing lands and other resources. The dominant male can establish and keep a territory

for about one year (Torres 1992). The groups of juvenile males consist of about 5 to 50 head and are expelled from their family groups by the dominant male or by an adult female (Hoffman et al., 1989). Groups of vicunas graze among alpaca herds on the bofedales in the summer and in the winter move to the hills where there is an abundance of food.

During the spring and summer breeding seasons, guanacos in Torres del Paine National Park are organized into four principal social groups: family groups, solo males, male groups, and female groups. Family groups contain one territorial male with several females and their young (4 to 5 months old), whereas solo males are territorial males that are seeking or defending a territory without females. Male groups consist of non-territorial males of all age classes. Furthermore, there are female groups that are less common and include females of all ages with or without young (Franklin, 1980, 1997; Ortega et al., 1988). During territorial periods, young male guanaco are often forced to leave the territories they have inhabited (Franklin, 1983; Walther et al., 1986).

ECONOMICAL, SOCIAL AND BIOLOGICAL IMPORTANCE

The production of SAC is under control of independent producers that are dependent on their herds for economic income. Most Bolivian camelid producers will produce fiber and meat from llamas and alpacas. Bolivias camelid industry is mainly found around the regions of La Paz, Oruro and Potosi because these departments are located on the high land. The colder weather makes it difficult for sheep and cattle to

survive. Fernandez et al. (1996) reported that approximately 200,000 families depend on alpacas and their products for their economic sustenance.

CARBON AND NITROGEN ISOTOPES

Isotope background

Stable isotopes are those isotopes of an element which are stable and that do not decay through radioactive processes over time. Most elements consist of more than one stable isotope. For instance, carbon has six radioactive isotopes (^{9}C, ^{10}C, ^{11}C, ^{14}C, ^{15}C and ^{16}C) of which ^{14}C is perhaps the best known because of its utility in dating biological materials and as a tracer in metabolic studies (Ehleringer, and Cerling 2002). The relative abundance of the stable isotopes is ^{12}C 98.89%, and ^{13}C 1.11%.

Elemental carbon has six protons, designated by its atomic number of six. In its most common form, it also has six neutrons (Krogh 2005), giving it the formula of ^{12}C for its atomic mass. The isotope form ^{13}C has six protons and seven neutrons. Atomic weight is expressed as standard atoms; the isotope of carbon has 6 protons and six neutrons in its nucleus. If an atom is designated as carbon-12 or ^{12}C, it is arbitrarily assigned an atomic weight of 12 Daltons (John Dalton ‰). The number of protons in the atoms nucleus, which is its atomic number, defines each element. However, the nuclei of a given element may have varying numbers of neutrons. Because neutrons have weight (about the same as that of protons), such atoms differ in atomic weight.

Isotope Units of Measurement and Their Relationship

The delta (δ) notation has been adopted for expressing relative differences in stable isotope ratios between samples and standards. The $\delta^{13}C$ value is calculated from the measured carbon isotope ratios of the sample and standard gases (McKinney et al., 1950). There are different methods to determine carbon isotopes. The abundance of stable isotopes is typically presented in delta notation (δ), in which the stable isotope abundance is expressed relative to a standard presented in two equations (Sponheimer et al., 2003), and reported in thousand or per unit (‰).

$$\delta = \left(\frac{R_{sample}}{R_{standard}} \right) * 1000\ ‰$$

Where *R* is the molar ratio of the heavy to light isotopes

$$R = \frac{^{13}C}{^{12}C} \quad \text{or} \quad \frac{D}{H} \quad \text{or} \quad \frac{^{18}C}{^{16}O}$$

By international convention, $\delta^{13}C$ values are always expressed relative to a calcium carbonate standard known as PDB. This standard was a limestone fossil of *Belemnitella americana* from the Cretaceous period. Pee Dee assigned a $\delta^{13}C$ value of 0‰, where it's absolute $^{13}C/^{12}C$ ratio (*R*) has been reported to be 0.0112372 (Craig, 1957).

Isotope Ratio Mass Spectrometry

In order to make use of these small but significant variations, stable carbon isotope ratios ($^{13}C/^{12}C$) are measured with extremely high precision. The only type of

instrument currently capable of such high precision measurements is a dual-inlet gas isotope ratio mass spectrometer (GIRMS) equipped with two or more ion beam collectors. This type of instrument was first described by Mckinney et al., (1950). Modern state-of-the-art instruments are of the same basic design. Since 1950, advances in electronics, ion optics, and vacuum technology have improved the attainable precision by approximately tenfold. The high precision afforded by these mass spectrometers is due to simultaneous collection of two or three ion beams (masses) of interest and to repeated measurements of sample and standard gases during a single isotope ratio determination.

Carbon Isotope Fractionation

Carbon isotope fractionation has been used to study various domestic and wildlife animals around the world (Sponheimer et al., 2003). Ecologists have used nitrogen isotopes (in tandem with carbon isotopes) to determine the trophic behavior of diverse fauna on gulls (Thompson et al., 1999), raptors (Harding & Stevens, 2001), bears (Hobson et al., 2000) and voles (Handing & Stevens, 2001). There are only a few studies that have used isotope fractionation techniques in South American camelids and these were in controlled environments (Sponheimer et al., 2003a and b; Ayliffe et al., 2005).

Isotopic signatures can be determined in animal tissues, hair, feces, carbon dioxide from breath and blood. When compared to feed consumed by the animal, isotope signatures provide an acute or chronic picture of what foods the animal has actually assimilated. Animal tissues are built from available nutrients consumed, such as carbohydrates, proteins, and lipids. The extent to which a tissue resembles the different

dietary components depends on the isotope percent composition of the food as well as the type of tissue examined (Hobson et al., 1996; MacAvoy et al., 2005; Tieszen et al., 1983; Tieszen and Farge 1993).

Isotope fractionation in hair protein of mammals reflects the level of animal nutrition over a given temporal period. Stable isotope ratios have been used as dietary indicators for prehistoric human populations (Deniro and Epstein, 1977; Schoeninger et al., 1983; Schoeninger et al., 1998; Farnsworth et al., 1985; Ambrose and De Niro, 1986a; Heaton et al., 1986; Walker and Deniro, 1986). Sponheimer et al. (2003a, 2003b) and Ayliffe et al., (2005) have shown carbon isotope diet to tissue spacings (fractionation) for various animals species on controlled diets. This research provided fractionation data that can be applied to field studies where varieties of forages are consumed in this species.

Diet-hair fractionation can range between +2.7‰ and +6.1‰ for mammals fed identical diets. Several researchers have hypothesized that diet-collagen fractionation can be increased by thermal or nutritional stress (Sponheimer et al., 2003a). West et al. (2004) demonstrated that hair from horses shows changes in isotopic signature within 6-hrs of a dietary change.

Nitrogen isotope fractionation

Nitrogen isotopes have been used to determine ecological changes in herbivores grazing habitats. The nitrogen isotope composition of herbivore feces is consistently enriched in ^{15}N compared to the diet by 0.5‰ to 3‰ (Steele and Daniel, 1978; Sutoh et al., 1987, 1993). Nitrogen isotope fractionation is closely related to trophic level of the

food chain of carnivores and herbivores, even though a portion of herbivore fecal nitrogen is not of dietary origin, but rather derived from sloughed endogenous tissues and gut microbial cell walls (Van Soest, 1994).

Breath Carbon Dioxide

Carbon dioxide is a gas produced by cellular respiration in animals. Carbon dioxide is one of the most abundant gases in the atmosphere and plays an important part in vital plant and animal processes such as photosynthesis and respiration. Carbon dioxide is an end product in organisms that obtains energy from breaking down sugars, fatty and amino acids with oxidation used in their metabolism. In the lung, internal respiration is a process by which oxygen is transported to body tissues and carbon dioxide is carried away from them by exhalation. Carbon dioxide is a guardian of the pH of the blood, which is essential for survival in high Andean altitudes. CO_2 in the atmosphere is increasing in various regions around the world, centered around large populations and pollutants produced. These changes will be evident in forage carbon values as the plants utilize the carbon for carbohydrate production.

CONCLUSION

The four species of South American camelids are each managed in different ways and each have a different feeding strategy. Determining how they interact with other species, within or beyond the camelid family species, is an important aspect that needs further research. Stable isotope technology is a non-invasive method that can be used to

compare dietary and substrate samples, such as hair, feces and breath. This technology can help elucidate these nutritional ecology questions without disrupting wild camelid populations or production status of domestic herds.

Hair, feces and breath isotope Fractionation in alpacas (Lama pacos), llamas (Lama glama) and guanacos (Lama guanacoe) from Bolivia and Chile

ABSTRACT

This study was conducted to determinate carbon and nitrogen isotope fractionation in Bolivian and Chilean alpaca, llama and guanaco, hair, breath, plasma and feces. We also wanted to determine forage selection for these camelids using stable isotope technology. From the data, niche feeding and diet selection habits will determinate based on fecal composition. Bolivian sites were located near the high snow Altiplano Mountains at Tomarapi, Sajama, and at the Technical University Oruro's research center at Condoriri, Bolivia. Chilean samples were collected at INIA's (Instituto Nacional de Investigacion Agropecuaria) Kampenaike Research Station, Punta Arenas, Chile. Bolivian alpacas and llamas were 3 to 5 years of age from producer herds and the Oruro University's camelid herd. Chilean animals were selected from INIA-Kampenaike's camelid herd. The alpacas, llamas and guanacos were selected based on heath status: no conformation defects, illness, genetic abnormalities or apparent nutrition problems. Samples were taken of fiber, feces, and blood from alpacas, llamas, and guanacos. Forage samples from pastures and grazing areas were taken. Forage species that were collected came from the asteraceae, berberidaceae, gramineae, caryophyllaceae, leguminoseae, plantaginaceae, gentianiaceae and the chenopodaceae families and ranged from -15.5‰ to -33.9‰ $\delta^{13}C$ and -3.0‰ to 6.4‰ $\delta^{15}N$. Isotope values for feces and fiber

were similar for the two Bolivian sites, but the Chilean values were significantly more depleted. This was attributed to the forage isotopic values being significantly more depleted than those found in Bolivia. Forage selection, based on fecal and forage isotopic signatures supported the observation that alpacas, llamas and guanacos eat different forages. This is dependent on forage source and time of year (dry versus wet season). Stable isotope technology will be a useful tool in determining forage selection and species competition or interactions in South American Camelids.

INTRODUCTION

Camelids Grazing in southern Chile and the Altiplano of Bolivia are exposed to constant dietary changes due to season, elevation, and quality of grazing lands. The literature indicates that camelid digestive efficiency increases at high altitudes (San Martin and Bryant, 1989; Lopez and Raggi, 1992). Camelids have high digestibility of lignified plants and bushes with harsh climate changes in the Andes Mountain of Bolivia and Chile. The alpaca, llama, guanaco and vicuna are able to digest poorer quality forage and produce high quality fiber and meat.

Very little is known about the nutrition and dietary ecology of South American camelids. What is known about alpaca, llama, and guanaco nutritional requirements is based mainly on research from animals consuming locally grown forages that may not represent natural forage selection (San Martin and Bryant, 1989). The study by Huasasquiche (1974) indicated a maintenance digestible N requirement of 0.38 $g/W^{0.75}$ or 2.38g crude protein per unit of metabolic weight (kg $W^{0.75)}$ for alpacas. This was attributed to the efficiency phenomenon associated with the difference in altitude. In a summary by San Martin and Bryan (1989), it was noted that similar species of camelids demonstrated higher feed efficiency and improved digestibility at the high altitudes of the Altiplano compared to sea level, the reason is yet to be elucidated.

The process of dietary change can be understood with carbon isotope fractionation. Stable isotope analysis is now frequently use to investigate wildlife ecology and, in recent years, there has been increasing emphasis on using stable isotopes

to explore dietary changes within individuals or populations over time. Some studies have even analyzed several tissue and turnover rates simultaneously to reconstruct dietary life histories (Sponheimer et al., 2006). Turnover of stable carbon isotopes in muscle, liver, and breath CO_2 of alpacas indicates the half-lives of carbon in alpaca's liver and muscle are about 6 times greater than those in gerbils (Sponheimer et al., 2006). Carbon isotope analysis on camelid and other mammal substrates been done under controlled conditions (Robinson et al., 2006; Sponheimer et al., 2003a, 2003b) while very little research has been conducted in the camelids environmental habitat (Cerling and Harris, 1999). Most mammalian stable isotope studies have used opportunistic sampling strategies, and thus little is known about the foraging behavior, population dynamics, and health status of individuals that might result in isotopic heterogeneity (James et al., 2007).

The objectives of this study were to determine carbon isotope fractionation in alpaca, llama and guanaco, hair, breath, plasma and feces under natural condition in Bolivia and Chile. We also wanted to determine what forages were selected by the camelids. From the data, niche feeding will be determined in conjunction with reconstructing diet selection habits based on fecal output.

MATERIALS AND METHODS

Location

This research was conducted in Bolivia and Chile. Bolivia sites were located at 4800 m Oruro, Condoriri and 5000 m Sajama above sea level in the high, snowy Altiplano Mountains of the Oruro Departments. Bolivian samples were collected in two different locations: in Tomarapi, Sajama, and at the Technical University Oruro's

research center at Condoriri, Bolivia. Tomarapi, Sajama, is located between 17° 39’ and 18° 39’ South and 67° 38' and 68° 45' West at 6,542 m above sea level. Condoriri, Oruro is located 17° 31’ 41’’ South, 67° 14’ 02’’ West at 4257 m above sea level with an average 360 mm annual precipitation and 10.3°C temperature (ABOPA, 2005). The Chileen samples were collected at INIA’s (Instituto Nacional de Investigacion Agropecuaria) Kampenaike Research Station, Patagonia-Tierra de Fuego, located 54°12′ South, 68°45′ West at 11 m above sea level.

Animals

The Bolivian alpacas and llamas were 3 to 5 years of age. These animals were chosen from producer herds and the Oruro University’s camelid herd. Chilean animals were selected from INIA’s Kampenaike camelid herd. The alpacas, llamas and guanacos were selected based on heath status: no conformation defects, illness, genetic abnormalities or apparent nutrition problems.

Bolivia Camelids

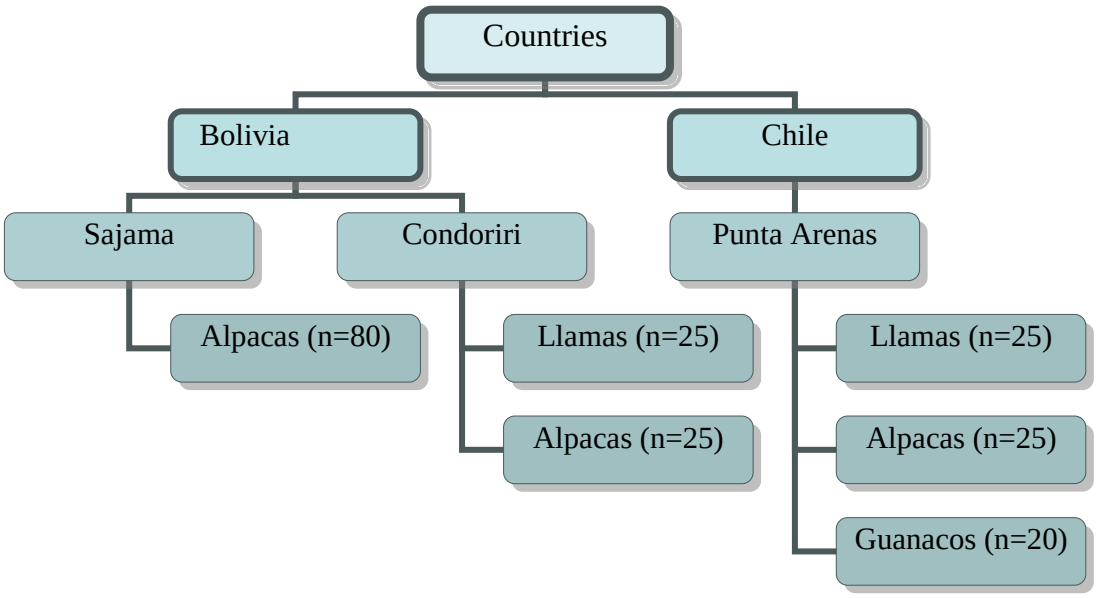
The alpaca producers were located at the Tomarapi, Sajama, Oruro, location. We selected 80 alpacas from three neighboring herds grazing the same bofedal region. Twenty-five alpacas and twenty-five llamas were selected from the Condoriri herd. The llamas and alpacas of the Condoriri herd were grazed on a barley field for four hrs/day, and then spent the rest of the day grazing on native grass rangeland.

Chile Camelids

Twenty-five llamas, twenty-five alpacas, and twenty guanaco were selected from the INIA-Kampenaike camelid herd. The llamas and alpacas were housed in the same pasture, which consisted of a lowland meadow primarily composed of *Festuca dolicophilla* and *Poa pretensis* and a shrubby hillside.

Methodology

Research structure



Plant Botanical Families Identification

Botanical species by families were identified for the forage samples using the following plant morphology identification: stem, type of leaf, flowering period and type,

related species, habitat, plant size, medicinal use, root development using Andean botanical classification reference books. The Bolivian Andean native species were identified using Flora Ilustrada Altoandina, Pestallozzi (1998), Plantas altoandinas Peruanas, Choque et al., (2000). These plant species were grouped in botanical families by type for each species and location.

Samples

For isotope fractionation, samples were taken of fiber, feces, and blood from alpacas, llamas, and guanacos. Forage samples were taken from pastures and grazing areas. The samples were frozen at -5^{o}C for transportation and stored for late analysis.

Breath collection and analysis

Breath samples were collected by placing a flexible plastic cup over the camelid's muzzle. Attached to the base of the cup was a 60 ml syringe into which a mixture of respired and atmospheric gas was collected during the exhalation phase of each breath. The breath sample from the syringe was evacuated into a 6- ml headspace vial that was then quickly capped with a rubber septa (Alltech, Deerfield, IL) held in place with crimped aluminum seals (Passey et al., 2005).

Forage, feces, hair and blood analysis

Forage and feces were ground through a Wiley Mill with a 40µm mesh. Carbon and nitrogen isotope ratios (δ^{13}C and δ^{15}N, respectively) were determined using a Carlo-

Erba Elemental Analyzer coupled to a Finnigan Delta-S mass spectrometer, or using a Costech Elemental Combustion System coupled to a Finninfan MAT 252 mass spectrometer (Passey et al., 2005). Blood samples were freeze-dried using a Thermo spin-vac freeze-drier (Thermo) then run through a Carlo-Erba Elemental Analyzer coupled to a Finnigan Delta-S mass spectrometer. Hair was cleaned using methanol/chloroform at a ratio of 1:2 then 2:1 followed by five rinses of distilled deionized water and then analyzed using the Carlo-Erba elemental analyzer couple to the Finnigan Delta-S mass spectrometer.

RESULTS

Botanical Families and Composition

Bofedales in the Tomarapi, Sajama, Bolivian region are diverse in botanical families (Figure 4). The most dominant botanical families are ciperaceae, gramineae and

Figure 4. Bofedal region of Tomarapi, Sajama, Bolivia. This is the bofedal that the alpacas were grazed on.

hidrophyllaceae (Table 4). The mean $\delta^{13}C$ was -25.8, -12.9, -25.5, -25.1, -22.9 and -24.8‰ for cyperaceae, cactaceae, rosaceae, asteraceae, hydrophyllaceae and gramineae, respectively. The $\delta^{15}N$ was -1.4, 5.3, 0.7, 4.3, 1.8 and -0.6‰, respectively. Of interest is the *Muhlembergia fastigiata* species that exhibits a C_4 carbon signature of -13.71. Figure 5 illustrates the isotopic signature each botanical family has in relationship to the others found in the grazing area. There is a clear separation for each botanical family. The cactaceae family is a CAM – photosynthetic species and shows the typical $\delta^{13}C$ enrichment (-12.89‰).

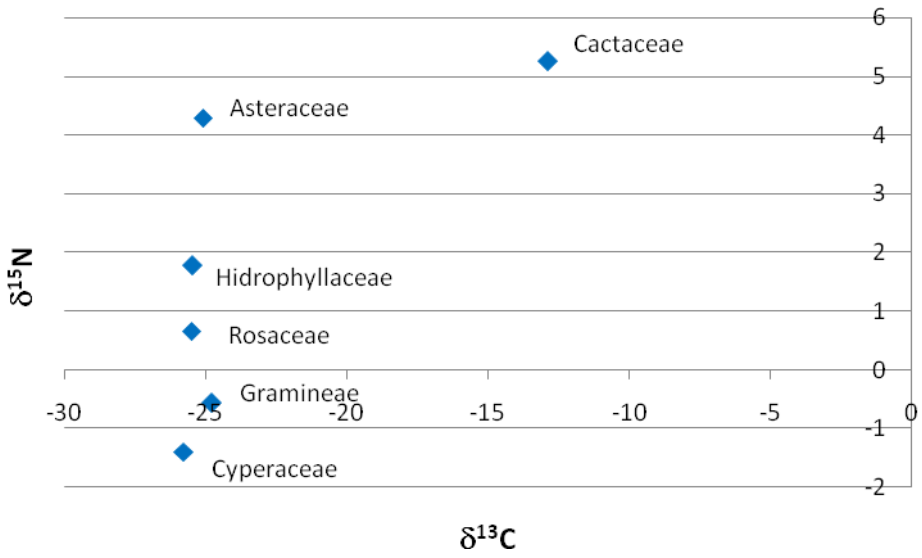


Figure 5. Botanical family $\delta^{13}C$: $\delta^{15}N$ interaction from the Tomarapi, Sajama, Bolivia bofedales.

Table 4. Botanical and isotopic composition by family from the Tomarapi, Sajama, Bolivia.

Botanical families	**# of species**	**δ^{15}N ‰**	**δ^{13}C ‰**
Cyperaceae	4	**-1.40**	**-25.78**
Hipochoires taracsacoides		*-1.49*	*-26.30*
Scirpus decerticola		*-1.92*	*-25.01*
Carex sp		*-1.61*	*-25.82*
Cirpus sp		*-1.05*	*-25.76*
Cactaceae	1	**5.26**	**-12.89**
Opuntia boliviana			
Rosaceae	2	**0.66**	**-25.48**
Alchemilla diphophylla		*2.72*	*-25.29*
Allchemilla pinnata		*-1.40*	*-25.67*
Asteraceae	1	**4.29**	**-25.08**
Parastrephya lepidophylla			
Hidrophyllaceae	4	**1.78**	**-25.45**
Ranunculus flagelliformes		*0.14*	*-22.86*
Elodea potamogetum		*2.97*	*-24.29*
Hidrocotile sp		*1.32*	*-27.41*
Hidrocotile ranunculoides		*3.61*	*-27.22*
Gramineae	7	**-0.56**	**-24.75**
Muhlembergia fastigiata		*2.60*	*-13.71*
Deyeuxia filifolia		*-0.55*	*-26.78*
Stipa ichu		*-0.36*	*-24.67*
Festuca orthophylla		*-3.74*	*-25.96*
Deyeuxia rigescens		*-0.05*	*-26.06*
Festuca dollichophylla		*1.04*	*-25.75*
Wermeria pygmeae		*1.79*	*-26.27*

Llamas and alpacas in Oruro, Bolivia, were grazed on a barley field mixed with some native grass species (Figure 6). Llama and alpaca grazing ranges outside of the barley fields (Figure 7) were composed of eleven species of graminea, one asteraceae, one leguminoceae and one species of gentianiaceae. Isotopic signatures by species and botanical family (Table 5) were: gramineae 2.08 δ^{15}N and -28.69 δ^{13}C, asteraceae 5.54 δ^{15}N and -25.39 δ^{13}C, leguminoceae -1.05 δ^{15}N and -24.77 δ^{13}C. *Muhlembergia*

fastigiata collected at the Condoriri, Oruro, Bolivia site was similarly enriched in carbon as those samples collected at the Tomarapi, Sajama, Bolivia site (-15.54‰). *Boutelova simplex* was also enriched ($\delta^{13}C$ = -16.66‰) when compared to the other gramineae species.

Table 5. Botanical composition by family for the Condoriri, Oruro, Bolivia site.

Botanical families	**# of species**	**$\delta^{15}N$ ‰**	**$\delta^{13}C$ ‰**
Gramineae	11	**2.08**	**-28.69**
Deyexia filifolia		*1.23*	*-25.71*
Muhlembergia fastigiata		*1.18*	*-15.54*
Stipa ichu		*0.99*	*-25.55*
Stipa obtusa		*0.45*	*-26.79*
Bromus lanatus		*6.09*	*-25.58*
Festuca orthophylla		*-5.85*	*-25.64*
Hordeum vulgare		*4.68*	*-25.81*
Hordeum sp		*6.25*	*-26.43*
Avena sativa		*1.56*	*-25.56*
Boutelova simplex		*-0.65*	*-16.66*
Deyeuxia rigenscens		*0.51*	*-26.13*
Asteraceae	1	**5.54**	**-25.39**
Parastrephya lepidophylla			
Leguminoceae	1	**-1.05**	**-24.77**
Medicago sativa			
Gentianiaceae	1	**3.40**	**-27.44**
Erodeum cicutarium			

Figure 6. The llamas and alpacas located at the Condoriri, Oruro, Bolivia site were grazed on barley fields and dry range land. Each day the animals were allowed to graze on this field of barley four hrs/day.

Figure 7. Dry rangeland grazed by alpacas and llamas at the Condoriri, Oruro, Bolivia site were grazing.

The $\delta^{13}C$: $\delta^{15}N$ interaction (Figure 8) for each botanical family demonstrates the niche signature for each. *Hordeum vulgare* is included because of its predominance in the llama and alpaca's daily diet. The signatures illustrated here for Oruro are similar to those illustrated for the Sajama forages.

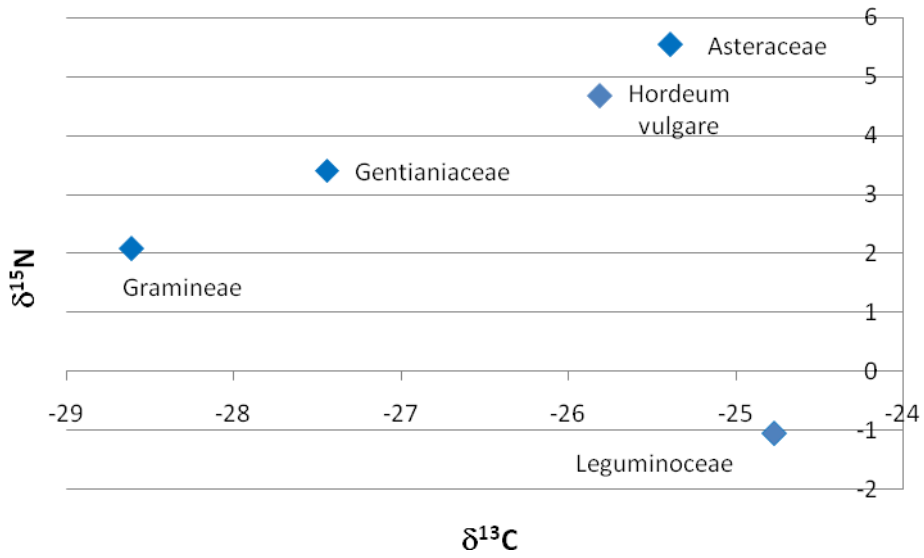


Figure 8. Botanical composition $\delta^{13}C$: $\delta^{15}N$ interaction by family from the Condoriri, Oruro, Bolivia site. These values include all of the botanical specie means grazed by the alpacas and llamas.

Guanacos grazing pastures at the INIA-Kampenaike Research station in Punta Arena, Chile were composed of the following botanical families: gramineae, leguminoseae, asteraceae and, to a much lesser extent, other forb plant species (Table 6). The gramineae species included *Deyeuxia emences, Poa gramineae, Poa annua, Poa asperiflora* and *Bromus catarticus.* Carbon isotope values indicated all gramineae species were C_3 plants, with ratios between -28.69‰ to -30.64‰ for $\delta^{13}C$ and 0.64‰ to 1.44‰ for $\delta^{15}N$. Leguminoceae included *Trifolium amabile* (-30.64‰ $\delta^{13}C$ and -2.63‰ $\delta^{15}N$).

Table 6. Botanical composition by family for plant species from the Instituto Nacional de Investigation Agropecuaria (INIA), Kampeniake Research Center, Punta Arenas, Chile.

Fields	**Botanical families**	**# species**	**δ^{15}N ‰**	**δ^{13}C ‰**
Guanaco pasture	**Gramineae**	3	**1.08**	**-29.66**
	Bromus sp		*0.64*	*-29.46*
	Poa sp		*1.15*	*-29.31*
	Deyeuxia sp		*1.44*	*-30.20*
	Leguminoceae	1	**-2.63**	**-30.64**
	Trifolium amabile			
	Asteraceae	1	**-1.29**	**-28.66**
	Chiliotrichium diffusum			
	Berberidaceae	1	**-2.99**	**-29.14**
	Berberis Buxifolia			
Llama and alpaca pasture	**Asteraceae**	3	**-0.48**	**-30.70**
	Azorella evifurcata		*-1.01*	*-29.22*
	Colobanthus quitens		*1.26*	*-33.94*
	Chiliotrichium diffiusum		*-1.29*	*-28.66*
	Plantaginaceae	1	**0.15**	**-28.65**
	Bougueria nubicola			
	Gramineae	6	**0.66**	**-30.55**
	Bromus sp		*0.64*	*-29.46*
	Deyeuxia sp		*1.44*	*-30.20*
	Festuca sp		*-1.35*	*-29.33*
	Poa sp		*1.15*	*-29.31*
	Polypogon interuptus		*-2.02*	*-31.26*
	Stipa ichu		*-2.02*	*-30.20*
	Leguminoceae	1	**-2.63**	**-30.64**
	Trifolium amabile			
	Caryophyllaceae	1	**3.51**	**-31.07**
	Cetastium arvensis			
	Berberidaceae	1	**-2.99**	**-29.07**
	Berberis buxifolia			

asteraceae included *Chiliotrichium diffusum* (-28.66‰ $\delta^{13}C$ and -1.29‰ $\delta^{15}N$). From visual observation, we could see that approximately 30% of the pasture was covered with *Chiliotrichium diffusum* with some (about 5%) *Berberis buxifolia* shrubs. The *Chiliotrichium diffusum* shrubs were heavily browsed (Figure 9), some almost completely defoliated. The *Berberis buxifolia* shrubs showed some defoliation, but to a much lesser extent.

Figure 9. Shrubs (*Chiliotrichium diffusum*) located in the pastures where the guanacos from the INIA-Kampenaike Research Station, Punta Arenas, Chile, were grazed. These shrubs were heavily browsed on.

Llama and alpaca pastures were predominantly composed of gramineae (*Deyeuxia vicugnarum, Deyeuxia eminens, Stipa ichu, Bromus lanatus, Polypogon interruptus and Festuca gracillima;* mean of 0.66‰ δ^{15}N and -30.55‰ δ^{13}C), plantaginaceae (*Bougueria nubicola*; 0.15‰ δ^{15}N and -28.65‰ δ^{13}C), asteraceae (*Colobanthus quitens, Azorella evifurcata* and *Chiliotrichium diffusum;* average of -0.48‰ δ^{15}N and -30.70‰ δ^{13}C), caryophyllaceae (*Cetastium arvensis;* 3.51‰ δ^{15}N and -31.07‰ δ^{13}C), Berberidaceae (*Berberis buxifolia*; -2.99‰ δ^{15}N and -29.07‰ δ^{13}C) and leguminoceae (*Trifolium amabile*; -2.63‰ δ^{15}N and -30.64‰ δ^{13}C).

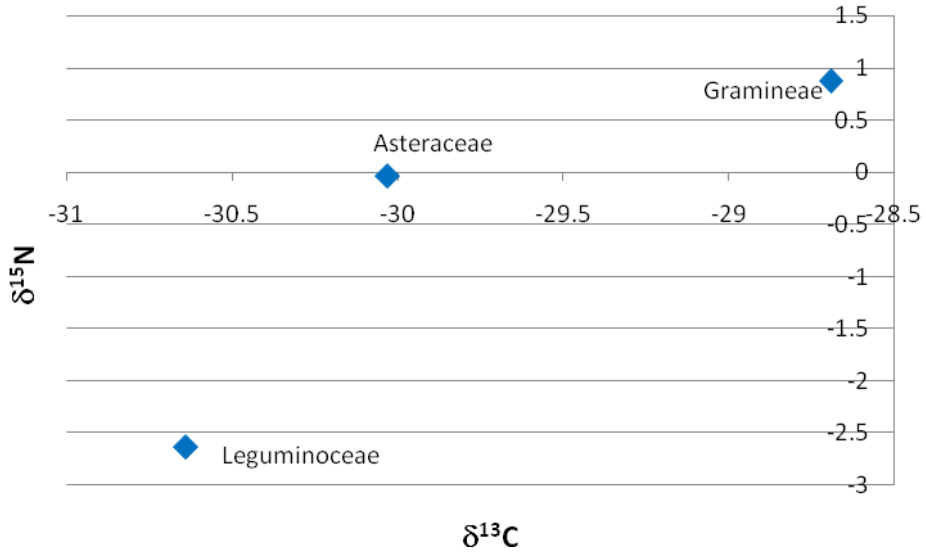


Figure 10. Botanical family δ^{13}C: δ^{15}N signatures from the Instituto Nacional de Investigation Agropecuaria (INIA), Kampenaike Research Center, Punta Arenas, Chile guanaco pastures.

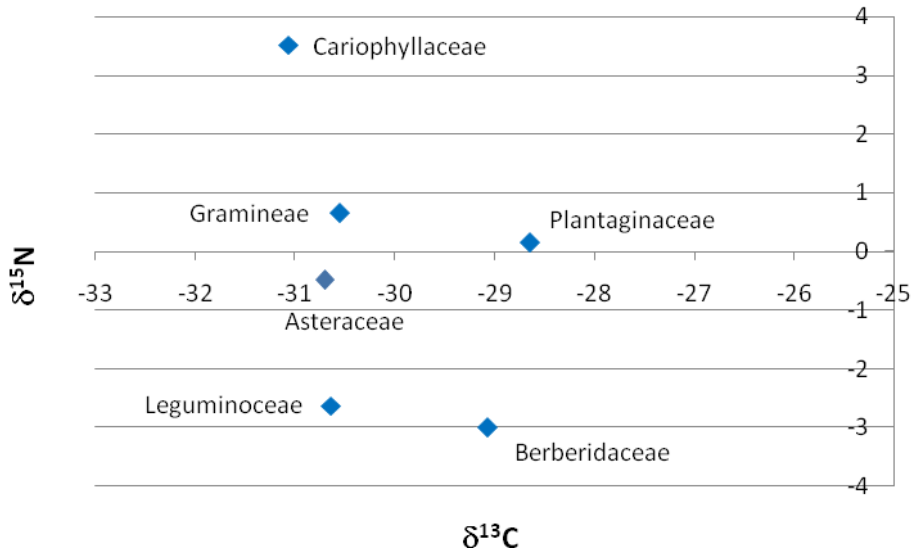


Figure 11. Botanical family $\delta^{13}C$: $\delta^{15}N$ signatures from the Instituto Nacional de Investigation Agropecuaria (INIA), Kampenaike Research Center, Punta Arenas, Chile, llama and alpaca pastures.

The signature for each botanical family $\delta^{13}C$: $\delta^{15}N$ is indicated for the guanaco pasture (Figure 11) for the llama and alpaca pasture (Figure 11). The signatures between the two pastures are nearly identical, and both are more depleted than those for the Tomarapi, Sajama, and Condoriri, Oruro, Bolivia samples. Thus showing an altitudinal difference for the plant species between the sites.

Blood Metabolites

Blood metabolites were determined in the Tomarapi, Sajama, Bolivia group to asses nutritional status (Table 7). Creatinine, albumin, and total plasma protein (TPP) were not different between the three farms. Urea N was different between Farm 2 and Farms 1 and 3. Glucose was different between Farm 1 compared to Farms 2 and 3, which were not different. Non-esterified fatty acid concentrations were not different between

Farms 1 and 2, but were different from Farm 3, while triglycerides were different between Farm 1 and Farms 2 and 3.

Table 7. Blood plasma metabolites of alpacas from three farms from the Tomarapi, Sajama, Bolivia valley grazed on bofedales.

	Farm				
	1	2	3	SEM	Reference Values[c]
Urea N, mmol/L	15.4[ab]	13.9[b]	17.4[a]	0.7	6.4-24.3
Glucose, mmol/L	6.2[a]	5.3[b]	5.5[b]	0.1	4.1-8.5
Creatinine, µmol/L	142.3	140.6	135.3	5.3	140-320
TPP[1], g/L	76	67	69	14	51-78
Albumin, mmol/L	3.3	3.2	3.1	0.7	2.1-3.6
Triglycerides, mmol/L	356.7[a]	413.2[b]	434.7[b]	25.0	
NEFA[2], mmol/L	205.5[a]	190.4[a]	328.4[b]	23.3	

[1]Total plasma protein
[2]Non-esterified fatty acids
[ab]Mean within row with different superscripts differ at $P<0.05$
[c]Values are from Fowler (1998)

Isotope Results

Whole blood and plasma samples were collected from the Sajama alpacas and the isotopic signatures are presented in Table 8. Whole blood and plasma across the three farms were different. Farm 2 had a more enriched $\delta^{13}C$ (-22.1‰) for whole blood versus the other farms, and Farm 3 a more depleted $\delta^{13}C$ (-22.9 ‰) for plasma. On the other hand, $\delta^{15}N$ was different for whole blood and plasma between the three farms, with Farm 1 being more depleted (2.8‰ and 3.6‰ for whole blood and plasma, respectively). Fecal $\delta^{13}C$ and $\delta^{15}N$ were different for Farm 3, where both $\delta^{13}C$ and $\delta^{15}N$ was more depleted. No significant differences were noted between the three farms for fiber $\delta^{13}C$, but the three farms showed a difference between each other for $\delta^{15}N$.

Table 8. Isotope ratios of whole blood, plasma, feces and hair from alpacas at three farms located at the base of Mount Sajama, Bolivia and grazed on bofedales.

	Farm			SEM
	1	2	3	
$\delta^{13}C$				
Whole blood	-22.6[a]	-22.1[b]	-22.8[a]	0.1
Plasma	-22.1[a]	-21.8[a]	-22.9[b]	0.2
Feces	-25.0[a]	-24.6[a]	-25.7[b]	0.1
Fiber	-22.3	-22.3	-22.6	0.1
$\delta^{15}N$				
Whole blood	2.8[a]	3.5[b]	3.3[b]	0.1
Plasma	3.6[a]	4.2[b]	4.8[b]	0.2
Feces	0.5[a]	0.8[a]	1.7[b]	0.2
Fiber	5.0[a]	6.5[b]	5.6[c]	0.2

± expressed as ‰
[abc]Mean within row with different superscripts differ at $P<0.05$

Sajama grazing land consists of bofedales and dry fields. Figure 12 illustrates a high preference for cyperaceae and gramineae botanical families by the alpacas. These values were determined using the IsoSource 1.3 model; using forage and fecal $\delta^{13}C$ and $\delta^{15}N$ to determine the proportion of forage consumed (Phillips and Gregg, 2003). Hidrophyllaceae, asteraceae and rosaceae botanical families were selected to a lesser extent. Cyperaceae, and gramineae are the dominant species, followed by hidrophyllaceae because these species are wetlands preferential. Asteraceae, *Margiricarpus pinnata, parastrefia lepidophylla,* are shrub species and are adapted to the dry grazing land. Cactaceae species are found in the region and appear to be consumed at a low percentage. The dry lands are located on the hilly areas above the bofedales and are grazed early morning and late afternoon as the alpacas are moved from their nightly enclosures, located on the hillsides, to the bofedale pasturelands during the day.

Carbon and nitrogen isotope results for breath, feces and fiber of alpacas and llamas are presented in Table 9. Fiber samples were sent to another lab, and

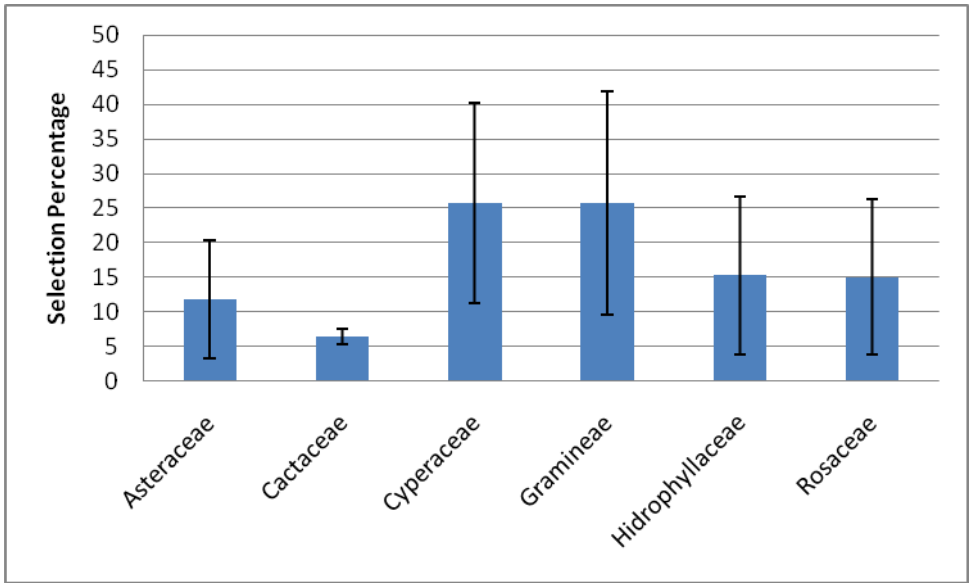


Figure 12. Forage selection of alpacas at the Tomarapi, Sajama, Bolivia site. Selection is based on $\delta^{13}C$ and $\delta^{15}N$ values from fecal samples. Error bars are standard deviations provided by the IsoSource 1.3 model (Phillips and Gregg, 2003).

only the alpaca samples were analyzed because the llama samples were misplaced. Breath $\delta^{13}C$ for alpacas was -23.0‰ and llama -18.7‰ with a significant difference of 4.3‰ between alpacas and llamas. Isotope fractionation of $\delta^{13}C$ and $\delta^{15}N$ for feces analysis showed no differences between alpacas - 25.6‰ and 5.6‰, and llamas - 25.4‰ and 5.0‰ for $\delta^{13}C$ and $\delta^{15}N$, respectively.

Condoriri Oruro-Bolivia grazing land is characterized by shrubs (asteraceae) and grasses (gramineae) botanical families. Because the camelids were grazed on barley (*Hordeum bulgare*) fields for four hrs/day, we separated those results from the

Table 9. Carbon and nitrogen isotope ratios of breath, feces and fiber of alpacas and llamas grazing on pastures and rangelands at the University of Oruro, Condoriri, Bolivia.[1]

	Camelid Species		SEM
	Alpaca	Llama	
Breath			
$\delta^{13}C$	-23.0[a]	-18.7[b]	1.4
Feces			
$\delta^{13}C$	-25.6	-25.4	0.2
$\delta^{15}N$	5.6	5.0	0.5
Fiber			
$\delta^{13}C$	-22.5	-	0.1
$\delta^{15}N$	6.4		0.5

[ab]Mean within row with different superscripts differ at P<0.05
[1] Expressed as ‰

other gamineae species. The dietary consumption by alpacas and llamas, based on fecal isotope results, shows similar diet selectetion between the two species (Table 9 and Figure 13). Asteraceae (*Parastrephia lepidophylla*) followed by *Hordeum vulgare* were the predominant forage species selected for by both species, followed by gentianiaceae, gramineae and leguminiseae.

Alpaca fecal samples from Chile were lost when the freezer they were stored in malfunctioned. Breath from the three Chilean species showed a significant difference between the alpacas (more depleted) llamas, and guanacos (Table 10). Guanaco feces was significantly more depleted than the llama, -32.2‰ and -30.8‰ $\delta^{13}C$, respectively. Fecal $\delta^{15}N$ was different between llamas and guanacos, 1.3‰ and 3.3‰ $\delta^{15}N$,

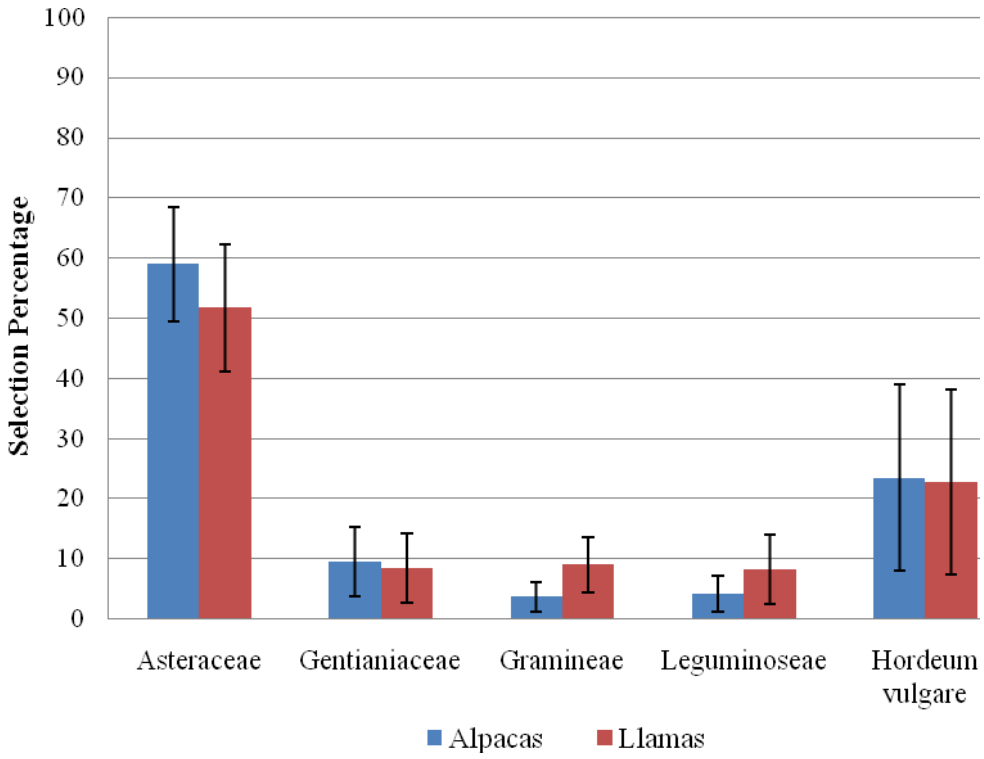


Figure 13. Forage selection of alpacas and llamas at the Condoriri, Oruro, Bolivia site. Selection is based on $\delta^{13}C$ and $\delta^{15}N$ values from fecal samples. Error bars are standard deviations provided by the IsoSource 1.3 model.

Table 10. Carbon and nitrogen isotope ratios of breath, feces and fiber of alpacas, llamas and guanacos grazing on pastures at INIA-Kampenaike, Punta Arenas, Chile.[1]

	Camelid Species			SEM
	Alpaca	Llama	Guanaco	
Breath				
$\delta^{13}C$	-23.4[a]	-21.4[b]	-21.9[b]	0.2
Feces				
$\delta^{13}C$	N/A	-30.8[a]	-32.2[b]	0.6
$\delta^{15}N$	N/A	1.3[a]	3.3[b]	0.2
Fiber				
$\delta^{13}C$	-25.5	N/A	N/A	
$\delta^{15}N$	6.9	N/A	N/A	

[1]Expressed as ‰

[ab]Mean within row with different superscripts differ at P<0.05

respectively. Fiber isotopic values were only determined from alpacas since the llama and guanaco samples were misplaced by another lab where samples were submitted for analysis.

Figure 14 illustrates the forage selection of at the INIA-Kampenaike station based on feces and forages collected. The forb family caryophyyaceae is slected for the most, with the asteraceae, gramineae and leguminoseae following. Forage selection for the guanacos was not completed because the guanaco feces was more depleted than any of the forages from the pasture, so the IsoSource model could not determine the selection profile.

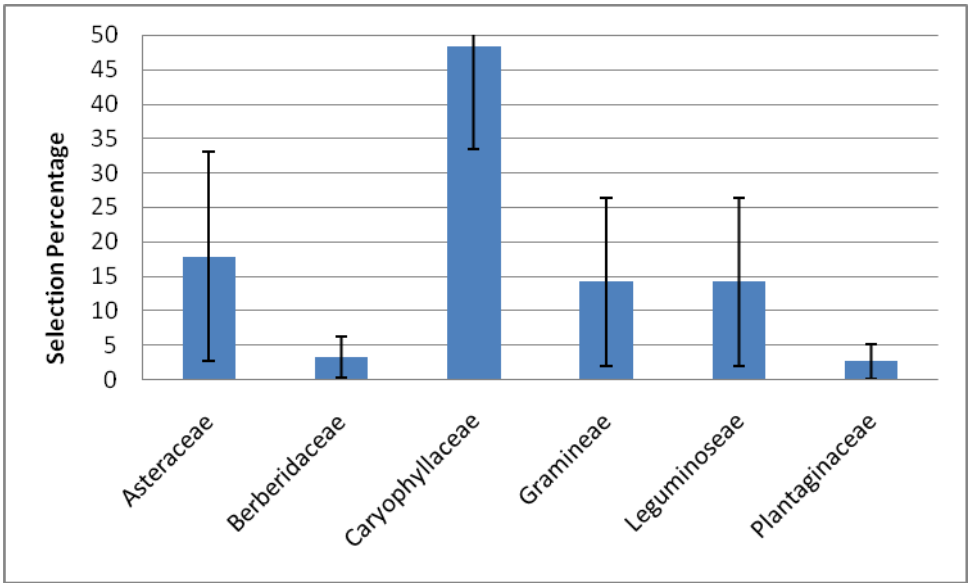


Figure 14. Forage selection of llamas at the INIA-Kampenaike, Chile site. Selection is based on $\delta^{13}C$ values from fecal samples. Error bars are standard deviations provided by the IsoSource 1.3 model.

Figure 15 illustrates the $\delta^{15}N$ fractionations for alpaca's fiber from Chile and Bolivia. The fiber fractionation determined from the three sites indicate that the Sajama

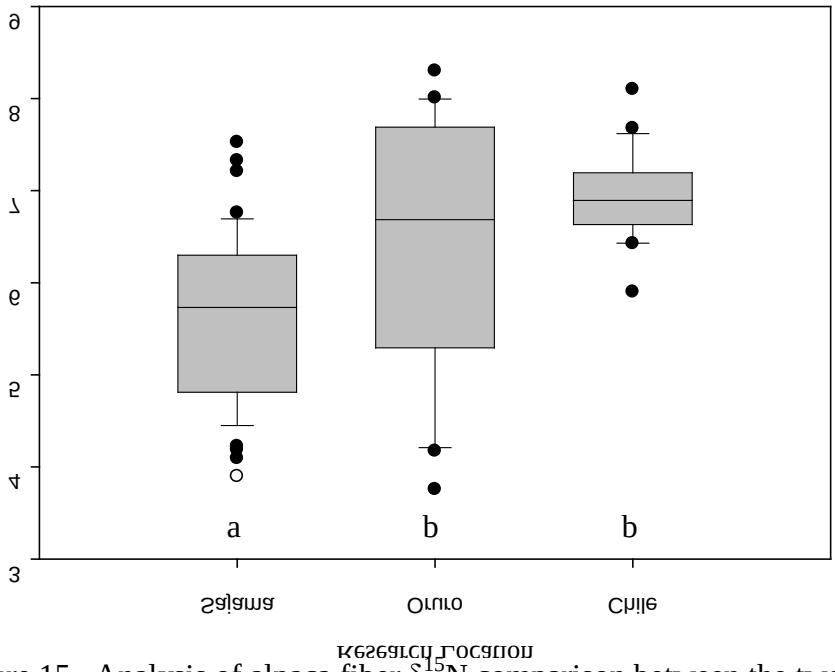


Figure 15. Analysis of alpaca fiber $\delta^{15}N$ comparison between the two research sites in Bolivia, Sajama and Oruro and the Chilean site. [ab] denote significant differences at $P<0.05$.

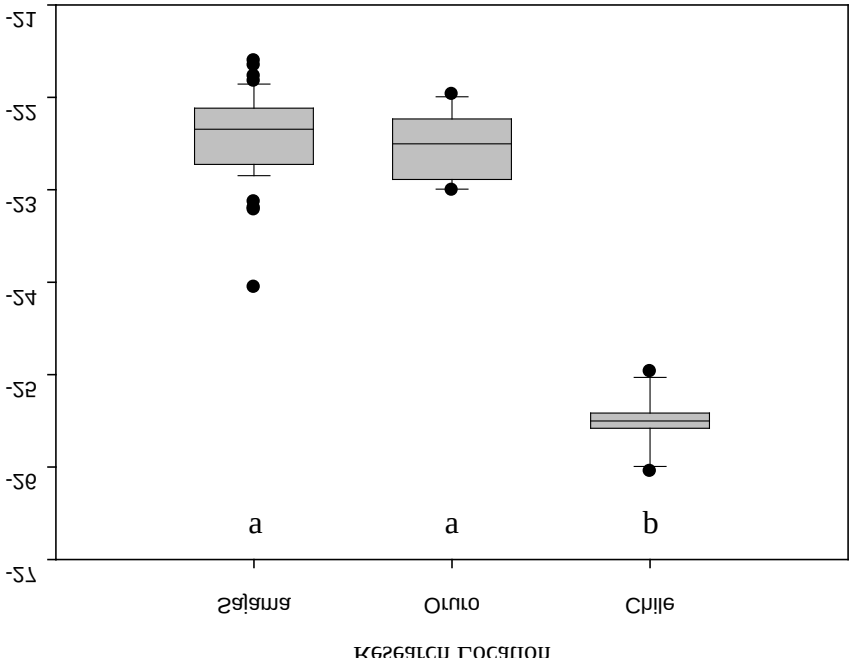


Figure 16. Analysis of alpaca fiber $\delta^{13}C$ comparison between the two research sites in Bolivia, Sajama and Oruro and the Chile site. [ab] denote significant differences between the three sites at $P<0.05$.

alpacas have a significantly more depleted $\delta^{15}N$ than the Oruro or the Chilean sites. The hair $\delta^{15}N$ values were enriched, ranging between 4.0‰ to 8.5‰.

Analysis of alpaca fiber $\delta^{13}C$ fractionation between Sajama, Oruro, and Chile are present in Figure 16. The Chilean alpaca fiber is significantly more depleted when compared to the Sajama and Oruro alpacas. Chilean $\delta^{13}C$ values are between -26‰ and -25‰, while the Bolivian sites were also similar at -23 to -22‰.

DISCUSSION

Bolivian and Chilean grazing lands have similarities in the botanical families but with differences in plant species. The three sites consisted of three variations of grazing land types: Tomarapi, Sajama was a bofedal grazing land, Condoriri, Oruro, was a dry land grazing type, and the INIA- Kampenaike grazing land was improved pastures. Though similar plant species were found at all three locations, the animals at each location on site selected for different niches. Bolivian Altiplano grazing canopies are predominantly gramineae, cyperaceae, asteraceae and small botanical species such rosaceae, hidrophyllaceae and leguminoceae, while the Chilean grazing land canopy sampled was mostly gramineae and asteraceae botanical families. The alpaca and llama pastures at the INIA-Kampenaike station were designed to have lowland grass and dry land hillsides. The lowland grass was mainly *Festuca* sp., *Bromus* sp. and *Deyeuxia* sp., while the dryland hillsides were composed of *Chiliotrichium diffiusum* with undercover of *Poa* sp., *Stipa* sp., and *Trifolium amabile*. The guanaco pasture was a grass pasture with large sections of *Chiliotrichium diffusum* and *Berberis buxifolia*. Chilean alpacas,

llamas and guanacos have reduced grass selectivity, based on the selectivity reconstructed from the fecal to forage comparison, and guanaco observations. This may be caused by internal and/or external affects. Internal affects could include less palatability of species found in the pasture due to over grazing. External factor could be low temperature, cold weather, altitude, and solar radiation. These factors can cause carbon isotope fractionation values to be depleted.

The $\delta^{13}C$ and $\delta^{15}N$ values from Bolivia are the first that we know of; no other forage isotopic samples have been determined. Isotope determination has been made in Tierra de Fuego Argentina. Twenty-four grass samples were collected between 1982 and 1998 and averaged -27.6‰ ± 1.9‰ $\delta^{13}C$ (Cerling et al., 1999). Our values are similar to those determined by Cerling and coworkers.

Blood metabolites were collected to determine the nutritional status of the Tomarapi, Sajama, Bolivia, animals. The results are well within reference ranges and indicate the animals are in good nutritional status. The values are similar to those reported by Burton et al. (2003) and Robinson et al. (2005). There are differences between the three farms and this is due, in part, to the differences in management between the three producers. The NEFA values are high, but due to the capture and restraint stress, the values are believed to be within reference range. Variations can also be attributed to time of day, when the samples were collected (first thing in the morning), and the fact that they were a single sample not an average over a 24 hours estimate.

There is evidence that hair $\delta^{13}C$ values reflect the carbon-isotope composition of dietary protein, rather than the composition of the whole diet (Tieszen and Fagre 1993). West et al. (2004) showed that horses fed a C_3 grass, then fed a pulsed amount of a C_4 grass for two, hours resulted in the C_4 signature showing up in the hair 6-hrs later. In our study, the alpaca fiber $\delta^{13}C$ was enriched by ~3‰ over the average feed values, indicating that the Bolivian fiber was more enriched by 3‰ over that of the Chilean alpacas. This difference between the two locations attributed to an altitudinal effect, with the lower altitude forage in Chile being about 3‰ more depleted than those of Bolivia. The hair to diet fractionation was similar to those reported by Sponheimer et al. (2003). The carbon isotope composition of carbonate in mammalian bioapatite is related to diet, is preserved on archaeological and geological time-scales, and is widely used for reconstructing dietary preferences and availability of different food resources to mammals (Koch, 1998). Studies such as these can be need to help to reconstruct herd-management strategies of ancient pastoralists and seasonal environments in which ancient human lives.

South American Camelid grazing habits are different between the four species. Alpacas tend to be mixed feeders, preferring the graze gramineae species. Alpacas chose the lowland grassy areas of the bofedales and also the lowland pasture areas at the INIA-Kampenaike site. Alpaca diet is based mainly on cyperaceae, asteraceae, gramineae, hidrophyllaceae in bofedales, and leguminoceae, with secondary selectivity for berberidaceae, caryophyllaceae, rosaceae, leguminoceae and cactaceae as alternative species (Lopez, 2004). Lopez (2004) reported alpacas grazing selectivity followed botanical families: juncaceae 38.67%, cyperaceae 35.67%, and gramineae 19.16%.

The llamas preferred and spent the majority of their time up on the dry land hillsides (personal observation and Burton, 2001). Llamas are also mixed feeders, but are predominantly browsers. Alzérreca, (1992) reported gramineae (*Stipa ichu, Festuca sp.,* and *Calamagrostis sp*) species have low nutritional values in llama pastures and are high in lignin and cellulose.

Guanacos are similar to llamas in their feeding behavior, except they will browse on the hillsides during the wet season and move down to the marshy grass lands areas during the dry season. In Sierra Las Tapias, Kenneth et al. (1988) reported that the guanaco's diet consisted mainly of lichens in both the winter and summer periods (68% and 67% of the diet, respectively). Raedeke (1980) and Bonino, and Pelliza-Sbriller (1997) reported guanaco diets consisted of a wide variety of forage types with grasses and forbs composing between 60% to 90% of dietary intake; this is particularly true in Tierra del Fuego. When there is an abundance of forage, guanacos select for gramineae and leguminoceae, and asteraceae is selected as browsing species die. Bahamonde et al. (1986) reported guanacos spring diet to be *Acaena spp.* (38.3%), *Festuca pallescens* (13.8%), forbs (44.3%), and shrubs (13.8%). We observed that during the late dry season, when our samples were taken, the guanacos browsed heavily on the *Chiliotrichium diffusum* and the tender *Poa* and *Trifolium spp.* found under the shrub canopy.

CONCLUSION

From our data it can be concluded that grazing land does play a role in the type of forages selected for by camelids. Alpacas grazed on bofedales consume predominantly

gramineae and cyperaceae species, while alpacas grazed on dry lands will select for asteraceae species. Lamas selected differently between Chile and Bolivia, where the Bolivian llamas selected for shrub species and the Chilean llamas selected for forbs species. We were unable to determine what the guanacos foraged on, but did observe that they graze on the *Chiliotrichium diffusum* quite heavily.

The data obtained will provide baseline data for future research to characterize at niche feeding between domestic livestock and wildlife in both Bolivia and Chile.

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