Nutrition of Domesticated SACs

Basic Digestive Anatomy/Physiology

Buccal Cavity. SAC lips are thin. The upper lip is divided by a middle groove (liporine lip) and the lower lip is relatively large. Lips are mobile allowing enhanced selective capability.

Dental formulae are diverse and related to feeds and defense; the permanent dental formulae is:

$$2 \quad I \ \frac{1}{3} \quad C \ \frac{1}{1} \quad PM \ \frac{1\text{-}2}{1\text{-}2} \quad M \ \frac{3}{3}$$

In the lamoids, the upper incisor has a flexible caudal section in the jaw allowing horizontal and vertical movement to become caniniform. All four canines develop in the male. So, with the extra upper caniniform tooth it appears as if there are two canines in each upper jaw. SACs complete their tooth development and replacement between 4.5 to 5 years of age.

Salivary Glands. Salivary glands in SACs are similar to advanced ruminants. Secretory rates and composition of saliva in lamoids also appear to resemble advanced ruminants. However, other researchers showed that pH and concentrations in *alpaca* saliva were similar to sheep but *alpaca* salivary flow was greater, suggesting greater buffering power in the *alpaca*.

Stomach. The stomachs of SACs differ from advanced ruminants. They have three distinct compartments. A transverse pillar divides the large, first compartment (C1) into cranial and caudal sacs. The C1 is connected to a smaller second compartment (C2). SACs have a ventricular groove which apparently has the same function as the reticular groove in advanced ruminants. The ventricular groove terminates at the tubular passage to the third compartment (C3), an elongated compartment slightly dilated at its proximal end.

Two types of mucosa are found on the internal surface of C1 and C2. The recessed saccules are lined by a glandular mucosa in the ventral part while the exposed surfaces are covered by stratified squamous epithelium in the dorsal part. In *llama*, about half of the total surface area (6,700sq. cm.) is occupied by a glandular area. The surface of C3 is covered with glandular epithelium. The terminal one-fifth of the C3 is thick and corresponds to the site of gastric glands, similar to the abomasum in cattle. Of this one-fifth, half of the surface is covered with fundic epithelium and the rest, toward the pylorus, with pyloric epithelium. Most consider this small distal region separately from C3 and refer to it as the "hind stomach".

The stomach volume of C1, C2, and C3 accounts for 83, 6, and 11 per cent of total stomach volume respectively. In adult *llama*, contents in C1 and C2 account for 15 per cent of the body weight and C3 for one to two per cent . It was found that *llama* have a smaller C1-C2 volume than the sheep reticulo-rumen volume when compared on a metabolic body weight basis. At eight weeks of age, *alpaca* stomach tissue proportions are similar to adult animals. Microbial activity reaches adult levels at the age of twelve weeks, coincident with high volatile fatty acid production and a drop in pH in C1 and C2.

Secretion of Stomach Glands. The mucinogen glandular mucosa present in all compartments of the stomach (with the exception of the mucosa of the C3 distal fifth, hind stomach) has a similar structure to advanced ruminants, despite differences in physical arrangements. Some studies indicated that the glandular saccules secreted significant amounts of bicarbonate in association with a reciprocal uptake in C1 from the lumen which may provide a substantial contribution to buffering digesta in C1 and C2. Other researchers reported that the main function of this glandular region in the stomach of SACs is rapid absorption of solutes and water. Absorption rates reached about two to three times more than in the rumen of sheep and goat. With respect to C3, the rate of absorption was significantly higher than values measured in the omasum of sheep and goats, even considering differences in body weight.

Motility. Forestomach motility in SACs has been described by several researchers. Each contraction cycle begins with the ventricular groove, followed by a single rapid contraction of C2. Then the ventricular groove contracts again accompanied by the caudal portion of C1. This sequence is referred to as "A-contractions". Following these are "B-contractions" consisting of the cranial portion of C1 and C2 and the caudal portion of C1. This sequence of movements is repeated two to seven times per contraction cycle. In short, the SAC's forestomach undergoes a more continuous activity than in the advanced ruminants.

Fermentation. Production of volatile fatty acids (VFA) from bacterial fermentation in C1 has been studied in the *llama* and the *guanaco*. VFA concentration reached highest levels between 1.5 to 2.0h after feeding. In a comparative study, VFA production and pH in *alpaca* and sheep at two different altitudes (at sea level and at 3,320m), with the same feeding regime, found the same response reported for *llama* and *guanaco* at sea level. However, at 3,320m, the peak VFA concentration in *alpaca* was reached much later, at 6h after feeding. At high altitudes, sheep showed a significantly faster initial fermentation rate than *alpaca*; however, no differences were found at sea level. In both species, the magnitude of feed fermentation was always greater at high altitude than at sea level.

It is suggested that *alpacas* have a more efficient buffering mechanism than sheep because VFA concentrations are similar, but pH values are different. The pH value for sheep was more acidic than for the *alpaca*. This would allow SACs to approach higher bacterial yields because acidic conditions increase the maintenance energy requirements of forestomach bacteria. Further, cellulolytic bacteria apparently obtain lower yields at lower pH values.

In a study determining total VFA in gastrointestinal digesta of the *alpaca* and *llama*, great fermentative activity was found in the first two compartments. Important VFA concentrations also occurred in the proximal two-thirds of C3 and in the caecum and proximal colon. The greater concentrations in *alpaca* and *llama*, compared with available data for sheep, cattle, and deer, suggest a more efficient (almost complete) absorption of VFA from the stomach of SACs. With respect to concentrations of different VFAs, the amount of gas eructated in the *alpaca* was similar to cattle on a per unit of body weight basis.

Retention Time of Food in the Digestive Tract. Retention of digesta in the *alpaca* (50.3 h) was found to be longer than for sheep (43.2 h). Reported retention in *llama* 63.2 h and sheep was 40.9 h. In a study of gastrointestinal transit time in ten mammal species, it was found that the *llama* retained larger particles for a longer period of time than cattle or horses.

With respect to the liquid passage rate in the C1 and C2 of SACs in comparison to sheep, a faster rate in the *llama* (10.4%/h) was found than in sheep (7.7%/h). The more rapid liquid passage rate in *llama* might be due to the higher ratio of salivary flow to forestomach size. Other researchers reported an improvement in microbial protein synthesis of up to 25 per cent as a result of the increased liquid dilution rate from application of artificial saliva. On the other hand, the relatively shorter retention of ruminal fluid in the *llama,* compared to sheep, indicates that the *llama* may have improved microbial growth in C1 and C2, assuring a minimum amount of energy to maintain microbial population.

Nutritional Requirements

Nitrogen. Only one report exists on nitrogen requirements of SACs. In a nitrogen balance trial in *alpaca*, it was estimated that the maintenance requirements at 0.38 g digestible nitrogen or 2.38 g digestible protein per unit of metabolic weight (kg W 0.75), which was lower than for sheep and beef cattle (2.79g/kg W 075). In *llama* on a low protein ration, efficiently recycled body urea into the gastrointestinal tract and 85 per cent of recycled urea was utilised. *Llamas* excreted lower renal urea values than sheep and goats under similar feeding regimes. In addition, *llamas* seemed to hydrolise more urea in the forestomach than other ruminants; therefore, more nitrogen for protein synthesis by microbes would be available in *llamas*.

Energy. Using carbon balance techniques with the *llama*, it was estimated that the maintenance requirement of metabolisable energy was 61.2 kcal/kg W 0.75, a value lower than 98 kcal/kg W 0.75 for sheep. Likewise, the *llama*, especially during reduced food intake, has a lower basal metabolism than sheep and goats under similar conditions. *Llamas* were able to reduce energy expenditure from 61 kcal/kg W 0.75 during the control period to 52 kcal/kg W 0.75 during food restriction, which is lower than the fasting metabolism of advanced ruminants.

Minerals and Vitamins. No specific deficiencies in minerals have been reported in SACs. Studies on mineral contents of pastures grazed on by *llama* and *alpaca* indicate a low phosphorous (P) and copper (Cu) content during the dry season. *Alpaca* grazing on cultivated and natural pastures during the dry and rainy seasons were found to have the lowest values of serum P, and serum calcium did not change due to type of pastures or season.

Cu concentrations of 48mg per cent in *alpaca* livers of apparently normal animals were found. Although Cu concentration is influenced by dietary proportions of molybdenum and Sulphur, Cu levels from 25 to 75mg per cent in the liver of other ruminants constitute a valid diagnosis for deficiency. On the other hand, when trying to supplement with Cu sulphate, *alpacas* demonstrate high susceptibility to Cu toxicity.

It is interesting that SACs apparently are unable to lick. Numerous efforts to supplement mineral salts in adult *alpaca* or *llama* have met with little success. Under penned conditions, minerals supplied are chewed at the block rather than licked. However, they recovered, with the lips, grounded mineral salts when given in pots. Under most management conditions, salt should be made available as loose salt in a container out of the weather.

There is no information on vitamin deficiencies in SACs. However, we assumed that B-vitamin biosynthesis occurs in the forestomach, as in other ruminants, and is sufficient to supply their requirements. Despite injecting vitamins A, D, and ADE in pregnant *alpacas* two months before parturition, no birth weight differences were found in first service *alpaca* between treatments. Pre-mating injections of vitamins A, D, and E into adult *alpacas* have no effect on fertility.

Ability to Digest Forage

Several comparative studies in *in vivo* digestibility between *alpacas* and sheep, *llamas* and sheep, have been undertaken. One study found noticeable differences between *alpacas* and sheep, with *alpacas* exhibiting higher digestion coefficients. Other researchers reported higher digestion coefficients for *llamas* than sheep, while one study reported no differences. Discrepancies in digestibility between species might be attributed to the fact that animal selectivity was not taken into account in some experiments.

It has been shown that there is greater selectivity in sheep than in *alpacas*. Other researchers noted that feed portions refused by selector animals were more lignified usually. If selection is not quantified, it may lead to apparently higher digestion coefficients in selector animals. Another reason for discrepancies may be the quality of feed used. In diets with less than 75 per cent crude protein, differences between *alpacas* and sheep were greater than when dietary crude protein was above 10.5 per cent .

Greater digestion coefficients were reported for *llamas* than for sheep on low and medium quality diets, but digestion coefficients were similar for *llamas* and sheep on high quality diets. Greater SAC efficiency may be related to the longer retention time of digesta than in sheep. Digestibility of high quality diets is relatively unaffected by retention time in the reticulo-rumen. Greater efficiency of digestion in SACs also may be due to more frequent contractions of the forestomach, the rumination cycle, and the proportion of salivary flow to forestomach size. These attributes provide for more efficient maceration, mixing, and absorption of digesta. Greater digestibility values in SACs on low nitrogen feed could be explained by the ability to maintain higher $NH4+$ concentrations in C1 and C2 compared to sheep, which provides *llamas* with more nitrogen for microbial synthesis, thus improving digestibility.

Ability to Graze Selectively

<u>Botanical Composition of Diets</u>. Studies in Peru in the early 1970s, showed that *alpacas* consumed tall grasses in the wet season and short grasses in the dry season. Preferred species were *Festuca dolichophylla*, *Distichia muscoides*, *Trifolium amabile*, and *Bromus uniloides*.

Analysing faecal material for microhistological components of plants, it was found that grass consumption was higher during the driest months and consumption of grass-like species was inversely related to grass in the diet. Forbs in the diet increased in the early wet season. *Alpacas* ate more leaf material as the rainy season progressed. Young *alpacas* consumed more grass-like plants, forbs, and seeds than adults.

Other authors noted that *alpacas* are highly adaptable grazers; where grass was available, it made up the bulk of the *alpaca* diet, but on a site with low grass availability and abundant sedges, the diet was dominated by sedges. Although forbs did not contribute a large proportion of the animal diet, they were consistently eaten. As the dry season progressed, the diet of "*bofedal*" *alpacas* (those occupying perennially green areas) became largely sedges and reeds (78%), while Altiplano *alpaca* diets were dominated by grass (60%). In general, *llamas* preferred to graze on drier areas dominated by tall and coarse bunchgrasses, while *alpacas* used more moist bottomlands than sheep and *llamas*.

In the Peruvian highlands, 90 per cent of the total livestock are kept by smallholders and small communities, and *llamas* and *alpacas* are mixed with sheep and managed together. Few studies have compared dietary composition among these herbivores in order to understand how they share the forage resources. One study compared dietary botanical composition between *alpacas* and sheep in the southern highlands of Peru. *Alpacas* selected more tall grasses and less short grasses than sheep. Grass-like plants were important to *alpacas* in the early rainy season. The highest index (70%) of diet similarity was during the intermediate months between the dry and rainy season.

Likewise, the dietary composition of *llamas*, *alpacas*, and sheep under grazing conditions on three different pastures were studied; an improved pasture (*Festuca rubra*, *Lolium perenne*, and *Trifolium repens*); a *Festuca dolichophylla* range site (*Fedo*); and a *Festuca rigida* range site (*Feri*). On the improved pasture, sheep ate at least 2.6 times more legumes than SACs. This lower rate of legume selection by SACs might explain why bloat has not been reported in SACs. On the rangeland, *llamas* selected tall, coarse bunchgrasses and *llamas* ate more stems and less leaves than *alpacas* and sheep. This selection by *llamas* suggests that they can be classified as bulk and roughage eaters during the dry season - as other authors have classified Old World camelids.

Sheep showed a tendency to select less tall grasses and more leaves than *alpacas* and *llamas*. This tendency for intermediate selection, between the level of *llamas* and sheep, by *alpacas* suggests that *alpacas* are more grazer-selectors than *llamas*. *Alpacas* are more adaptable and appear to be able to use a wide variety of forage types. In the dry season, diet similarity was high between the *llamas* and *alpacas* on the *Feri* range sites and between *alpacas* and sheep on the *Fedo* range sites. In a complementary grazing system, the *llamas* and sheep offer the most efficient way of harvesting available forage, while *alpacas* seem to be adequate for single-species' use of rangeland.

<u>Nutritive Composition of Diets</u>. In the highland region of the Andes, few studies on diet quality under range conditions have been conducted. Studies working with *alpacas* and *llamas* indicated that, during the dry and late season, crude protein and digestibility reached the lowest levels. In the rainy season, diet quality was highest. The authors suggested that improved protein nutrition during the dry season may help solve the problems of low fertility common in *alpacas*. Sheep diet quality studies for the highland regions are also scarce.

In another comparative grazing study, the *llama* had the lowest dietary quality, sheep the highest, and the *alpaca* was intermediate. The higher dietary quality for sheep was attributed to greater selection than that observed for *alpacas* and *llamas*. Sheep preferred leaves, forbs, and short grasses, which are known to be higher in nutrient content. The *llamas* had less preference for these plants than sheep and *alpacas*. The intermediate dietary quality for *alpacas* confirmed their intermediate position in forage selection between those of *llamas* and sheep. Small ruminants like the *alpaca* are predicted to be more selective than large herbivores like the *llama*.

<u>Voluntary Intake</u>. Forage intake is an important aspect in formulating range and animal management strategies. Most intake information available for SACs comes from comparative studies of sheep under penned conditions. Feed consumption studies comparing SACs and sheep have shown an overall average intake by the *alpaca* and *llama* of 1.8 and 2.0 per cent of body weight respectively. Daily consumption of the *llama* on a metabolic weight (g/kg W 0.75) basis was lower than that of sheep.

Voluntary intake studies under grazing conditions are scarce. Consumption in the dry season, with some exceptions, is similar to or greater than in the rainy season. A lower intake in the rainy season when dietary quality is higher could be because animals increase gut capacity in response to lower diet quality during the dry season. Another factor may be the high water content of plants during the rainy season. However, addition of water, *per se*, to the rumen has little effect upon intake because it is largely absorbed and removed. Water retention caused by the "sponge effect" of coarse structural components of ingested forage can have an inhibitory effect on intake and could explain why intake is not higher in the rainy season than in the dry season.

Dry matter intake in terms of kg per metabolic body weight under grazing conditions for the *llama* and *alpaca* ranges from 38 to 67g, depending on the type of pasture and season of use. Similar to studies under penned conditions, consumption under grazing conditions is lower in SACs than sheep; on a metabolic weight basis, the *llama* and *alpaca* had the same level of intake grazing on improved and native range pastures, but intake values were 36 per cent lower for SACs than for sheep on improved pasture and 26 per cent lower on native range pastures. Table 18 presents a typical daily forage intake for the *llama* and *alpaca* during the dry and wet seasons.

Table 18: Daily Intake for *Llamas* and *Alpacas* by kg of Metabolic Weight (Pv. 75)

	Season	*Llama*	*Alpaca*	Reference
Festuca dolichophylla	Dry	50.5g OM*		Reiner et al.
Muhlenbergia fastigiata	Rain	44.3g OM		(1987)
F. rigida	Dry	42.0g OM		Farfan et al.
	Rain	40.0g OM		(1986)
F. dolichophylla	Dry	59.4g DM**		Huisa (1986)
Plantago tubulosa	Rain	51.7g DM		
F. rigida	Dry	44.3g DM	42.4g DM	San Martin
	Rain	39.7g DM	41.2g DM	(1987)

* Organic matter
** Dry matter
Source: FIDA 1990.

Lower intake values in SACs are probably a result of large body size and relatively lower energy requirements. This allows SACs to be less selective of plant parts (leaves) than smaller animals with smaller mouth parts. Stems, which are consumed more by SACs than sheep, would be retained for a longer time in the forestomach than leaf fractions. Also, SACs have smaller rumen volumes and lower particulate passage rates than sheep, and these are highly and negatively correlated with intake.

Domesticated SACs seem to be adapted to areas where more coarse forage is available and nutrients are diluted by structural carbohydrates that are difficult to digest. These characteristics are present in the Andean Highlands where long dry periods (6 to 7 months of every normal year) and cyclic years of drought are not uncommon. These climatic variations contribute to the scarce supply of quality forage. SACs have adapted by reducing intake and decreasing the transit time of digesta through the tract to enhance microbial attack of forage high in structural carbohydrates.

Stocking Ratios

Normal adult body weights for sheep, *alpacas*, and *llamas* in the Peruvian highlands are 40, 65, and 108 kg respectively. For comparative purposes, these values correspond to 15.9, 22.9, and 33.5 kg of metabolic weight (kg W 0.75), respectively. Thus, the respective *alpaca* and *llama* metabolic weights are 1.4 and 2.1 times those of sheep. Further, the metabolic weight of the *llama* is 1.5 times that of the *alpaca*. Considering a 30 per cent lower intake in SACs than in sheep, the stocking ratio would be 1.0:1.0 for *alpaca*:sheep (1.4x0.7) and 1.5:1.0 for *llama*:sheep (2.1x0,7). These *alpaca*:sheep and *llama*: sheep ratios are quite different from published stocking ratios which, without differentiation between the *alpaca* and *llama*, indicate ratios from 1.5 to 1.8 per sheep unit. It is important to note that these ratios do not incorporate herbage and environmental characteristics.