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Selection for nutrients by pregnant goats on a microphyll desert scrub

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*The behavioral consequences of pregnancy in goats were studied to test the hypothesis that pregnant females on rangeland select a diet richer in nutrients once the demands of gestation increase, and that nutrient content in goat diets changes with the grazing season. A total of 12 mature mixed breed goats either pregnant (*n *= 6) or non-pregnant (*n *= 6) were used during the dry period (February to May). Dietary samples obtained from the oral cavity of grazing goats (restrained with a short light rope permanently tightened around their neck) were used for chemical analyses. Across months, pregnant goats selected diets higher (*$P < 0.01$*) in crude protein (CP) than non-pregnant goats; this nutrient did not meet the requirements of late gestating goats. Pregnant goats made use of less (*$P < 0.01$*) fibrous feeds than non-pregnant goats. In order to cope with changing nutrient demands for pregnancy, goats adjusted their diet by increasing the selection of plants with 32% higher calcium content compared to forages selected by non-pregnant goats. The physiological state of goats did not alter the levels of phosphorus (P), magnesium (Mg) and sodium (Na) in their diets; these minerals were adequate to meet the demands of pregnancy. There were no effects of physiological state on concentrations of copper (Cu), zinc (Zn), manganese (Mn) and iron (Fe) in the goat diets during the dry season, with levels adequate for sustainability of pregnancy. Pregnant goats did not seek forages lower in tannins, alkaloids, saponins and terpenes. It was concluded that to cope with increasing pregnancy costs, goats adjusted their diets increasing selection of forages or plant parts with high nutritional value to maximize their net nutrient budget.*

Keywords: reproductive status, nutrient selection, tannins, alkaloids, minerals

Implications

Goat adaptation to heterogeneous, patchy and degraded rangelands is a vital feature for the reproductive effort. Goats in this landscape experience a level of nutrition that barely supports gestation across months of severe forage scarcity, although it is not clear what rules and at what timescale the average composition of their diet is mixed to receive the nutritional benefits detected in pregnant animals. However, non-pregnant goats select diets lower in nutrients than pregnant goats, which indicates that selection is shaped by physiological effort; thus, nutrient consumption is clearly driven by physiological needs. This knowledge presents goat producers in extensive rangeland systems with opportunities for identifying individuals with superior foraging behavior capable of proficiently sustaining their pregnancy utilizing locally available forage resources.

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Introduction

Much of the research into the foraging ecology of goats on rangelands has focused on the botanical composition of their diets (Papachristou and Nastis, 1993; Lopez-Trujillo and Garcia-Elizondo, 1995; Bartolome *et al.*, 1998). These studies indicate that goats exhibit an opportunistic foraging behavior, implying that they ingest a large range of different plants of varying nutrients and secondary compounds. This foraging behavior resembles that of cervids (intermediate feeder with a broad food spectrum; Alm *et al.*, 2002; Verheyden-Tixier *et al.*, 2008; Krojerová-Prokešová *et al.*, 2010), but contrasts with the food habits of sheep, which basically use the herbaceous layer of rangelands (grazer selectors; Kronberg and Malechek, 1997; Mellado *et al.*, 2005a).

Several studies in ruminants support the notion that ungulate herbivores select nutrients in amounts to meet their needs (Bugalho and Milne, 2003; Verheyden-Tixier *et al.*, 2008; Villalba *et al.*, 2008), and that this selection varies with the internal state (Kyriazakis *et al.*, 1999). The significance of

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the internal state, for example, pregnancy on nutrients intake, presents unique questions that have received less attention.

Nutrition during gestation plays a key role in the well-being of goats and their newborn kids, and further affects the pregnancy outcome (Vonnahme *et al*., 2003; Gilbert *et al*., 2005; Fowden *et al*., 2006). This is particularly important in grazing animals on rangelands, where unsupplemented pregnant animals often experience prolonged bouts of nutrient deficiencies, which results in fetal intrauterine growth restriction (Thomas and Kott, 1995; Redmer *et al*., 2004) or abortion (Mellado *et al*., 2004c).

Next to lactation, late pregnancy is the period with the greatest nutrient demands for fetal growth and the development of the potential for high milk production. Many of these requirements are met by adaptive physiological changes that occur during gestation (Rumball *et al*., 2008; Jaquiery *et al*., 2009), but food selection of pregnant herbivores in heterogeneous landscapes may also be altered in order to seek diets with higher protein (Cooper *et al*., 1994) or energy (Berteaux *et al*., 1998) content and lower toxic constituents (Villalba *et al*., 2009).

Little information is available on diet selection at the plant species or plant part levels for free-ranging pregnant goats (Mellado *et al*., 2005b) and, as far as we know, no attempt has yet been made to assess the nutrient content of diets selected by goats in relation to increased nutrient requirement during pregnancy. Although there is widespread recognition of the importance of adequate maternal nutrition during pregnancy in goats (Tovar-Luna *et al*., 2007), there is considerable uncertainty about its role in grazing goats in landscapes with scarce and patchy vegetation, where severe malnutrition is common (Mellado *et al*., 1991). Therefore, this study was conducted in an attempt to elucidate the role of pregnancy on maternal nutrition of goats in a microphyll desert scrub.

Material and methods

Study site

The experiment was conducted from February to May in the desert area of Northern Mexico (25°07′N, 101°40′W; altitude 2150 m) dominated by a microphyll desert scrub. The mean annual temperature is 16°C and average annual precipitation is 299 mm, with 75% occurring from June to October. Historically, this communal pasture has been heavily stocked and continuously grazed by large herds of goats, bovines and equines; therefore, goats grazed on a deteriorated rangeland showing a low forage (2164 kg/ha; Mellado *et al*., 2006) production potential.

The main woody species in this landscape are *Larrea tridentata* (DC.) Cov., *Agave lechuguilla* Torr. and *Acacia farnesiana* (L.) Willd. Primary grasses include *Bouteloua curtipendula* (Michx.) Torr. *Buchloe dactyloides* (Nutt.) Engelm. and *Aristida arizonica* Vasey. The dominant herbaceous plants are *Sphaeralcea angustifolia* (Cav.) D. Don., *Solanum elaeagnifolium* Cav. and *Croton dioicus* Cav., which comprise 70% of the total ground cover during the rainy season. However, grasses comprised <10% of the total vegetation cover.

Animals

A commercial flock of 160 adult goats typical of the farming systems of the arid zones of Northern Mexico was used. The breed of goats was undefined (a mixture of the breed of goats that originated in the Alps, as well as Nubians and native goats); the mean condition score (1 = extremely thin; 5 = extremely fat; palpation over lumbar vertebrae, ribs and sternum) was 2.0 and goats ranged in weight from 32 to 43 kg.

Goats had been exposed to adult sexually active bucks ($n = 5$) of proven fertility during 4 weeks in January (buck-to-doe ratio = 1:32). Transrectal real-time B-mode ultrasound scanning was used for the diagnosis of early pregnancy (around 30 days post-mating). On the basis of this diagnosis, 18 adult goats were selected: 12 pregnant and six non-pregnant. This uneven distribution of goats was attributed to the abortion rate of pregnant unsupplemented goats during the dry season in this landscape, which is around 50% (Mellado *et al*., 2005). Ultrasound examinations on days 60 and 90 post-mating were performed in order to confirm pregnancy. Half of the pregnant goats aborted in the last trimester of gestation ($n = 6$); thus, these goats were excluded from the study. Goat diets were obtained from the 12 goats remaining (six goats per group) fitted with a short plastic rope (1.5 m in length × 0.5 cm in diameter) tightened around their neck. This light rope allowed the goats to walk in all kinds of terrain without hindering their motion or feeding activity, and was used to momentarily restrain them to get the forage selected by them from their oral cavity.

Goats were grazed and driven by a herdsman, 8 h/day (1000 to 1800 h), and were penned from 1800 to 1000 h, with no extra food or salt supplementation. They spent the night in an open unroofed corral and had access to water only once a day. Goats were not subjected to an anthelmintic drenching program and were not immunized against endemic diseases.

Four sampling periods, each 4 days long, were conducted from February (second month of pregnancy) to May (last month of pregnancy), during the dry season. The diet selected by goats was estimated by direct collection of plants from the goat's mouth, by separating the mandibles of goats by hand, immediately after feeding bouts. This operation was repeated approximately every 5 min during a 3-h period, using one person per two goats, by restraining the animals by holding the permanent rope tightened to their necks. Collections were made during the morning grazing when goats were grazing most intensely after overnight fasting. Following forage collection, a portion of the sample was thoroughly rinsed, first with tap water and then with distilled water to remove saliva, and was used for mineral analyses.

Analytical procedures

Forages collected during the 4-day period were pooled and these samples were oven-dried and then ground to pass through a 1-mm sieve. Dry matter (DM) was determined by drying at constant weight at 60°C for 48 h in a forced-air

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oven, ash by incineration at 600°C for 2 h and crude protein (CP) by the micro-Kjeldahl procedure (N × 6.25; Association of Official Analytical Chemists (AOAC), 1996). All analyses were performed in triplicate. Fiber fractions – neutral detergent fiber (NDF), acid detergent fiber (ADF), acid detergent lignin (ADL) and cellulose – were determined by the procedures described by Van Soest *et al.* (1991) and Van Soest and Wine (1968). Cellulose was calculated as ADF–ADL.

Concentrations of calcium (Ca), magnesium (Mg), potassium (K), sodium (Na), copper (Cu), zinc (Zn), manganese (Mn) and iron (Fe) were determined by atomic absorption spectrophotometry. Phosphorus (P) was measured by colorimetry (AOAC, 1996).Total phenols were determined by the procedure of Swain and Hillis (1959) and condensed tannins (CT) (extractable, bound to protein and fiber; CT) in feed collected by goats were determined according to Makkar *et al.* (2003). The presence of saponins in the forages selected by goats was determined with the technique described by Galindo *et al.* (1989). The occurrence of terpenes in forage samples was determined according to the Food Chemical Codex (1981).

Statistical methods

The effects of physiological state, month of sampling and the physiological state × month interaction on nutrient content of diets were analyzed by ANOVA using the MIXED procedure of SAS (SAS Institute, Inc., Cary, NC, USA) accounting for repeated measures. The model was $Y_{ijk} = \mu + G_i + c_{j:i} + M_k + (GM)_{ik} + ßx_{ijk} + e_{ijk}$, where Y_{ijk} is the observation (dependent variable) of the *j*th goat in the *i*th group at the *k*th month, μ is the overall mean, G_i is the *i*th group, $c_{j:i}$ is the random effect of the *j*th goat within the *i*th group ($c_{j:i} \sim N[0, \sigma^2 c]$), M_k is the *k*th month, $(GM)_{ik}$ is the group by month interaction term, $ßx_{ijk}$ = initial body weight of goats as a covariate and e_{ijk} = the residual error term ($e_{ijk} \sim$ iidN [0, Σ]); where Σ is the variance–covariance of the residual errors with a first-order utoregressive structure for repeated measures within goats. Differences in proportions of dietary samples with saponins and terpenes were tested with a χ^2 analysis (PROC FREQ of SAS).

Results

Pregnant goats selected diets higher ($P < 0.01$) in CP than those chosen by non-pregnant goats during the gestation period (Figure 1). Dietary CP levels decreased steadily from February to May ($P < 0.01$) for all categories of goats, but levels of this nutrient were relatively high throughout the dry period.

Ether extract levels in diets of pregnant goats were greater ($P < 0.01$) than in those of non-pregnant animals. For both groups of goats, ether extract content did not change appreciably ($P > 0.01$) throughout the study period. NDF and ADF were lower in the diets of pregnant goats compared with non-pregnant animals. For both groups of goats, NDF and ADF were highest at the beginning of the dry period (February) and declined through April and May (Figure 1).

Differences in lignin levels were observed between pregnant and non-pregnant goats ($P < 0.01$). Lignin levels were highest for both groups during March–April (middle of the dry season period; Figure 1). Diets of pregnant goats had lower ($P < 0.01$) mean cellulose than did those of non-pregnant goats, with levels of dietary cellulose increasing as the dry period progressed. There was no significant interaction between the classes of goats and months for protein, ether extract NDF, NDF and cellulose content of diets selected by goats, showing that patterns of forage selection were similar as the season progressed.

The ash content of diets was not different between classes of goats (range: 8.3% to 12.9% of dietary DM). Irrespective of the category of goats, ash concentration in diets decreased at the end of the dry period (May; $P < 0.01$). The Ca content

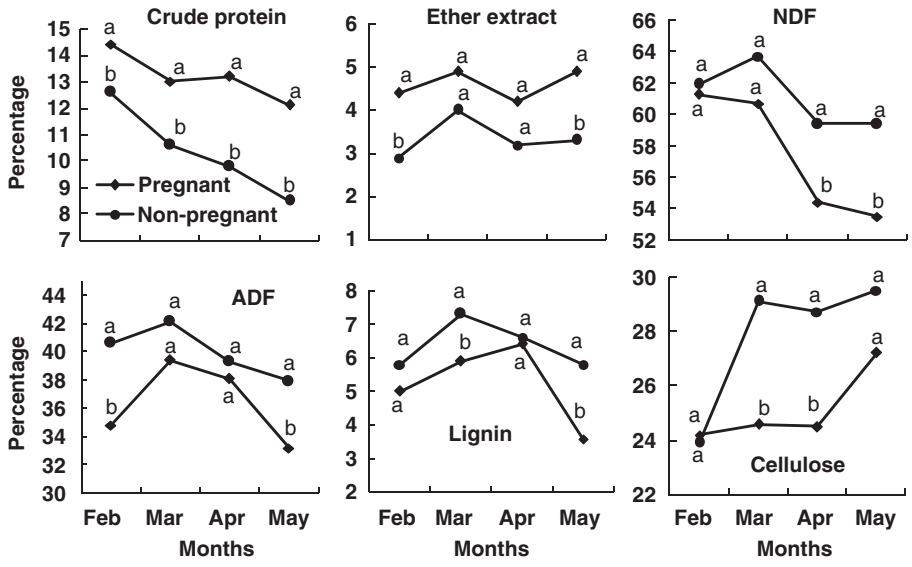


Figure 1 Chemical composition of dietary samples of pregnant and non-pregnant goats grazing a microphyll desert scrub during the dry period. Within months, means with different letters differ ($P < 0.01$). Except for ether extract, significant differences ($P < 0.01$) exist between months for forage constituents.

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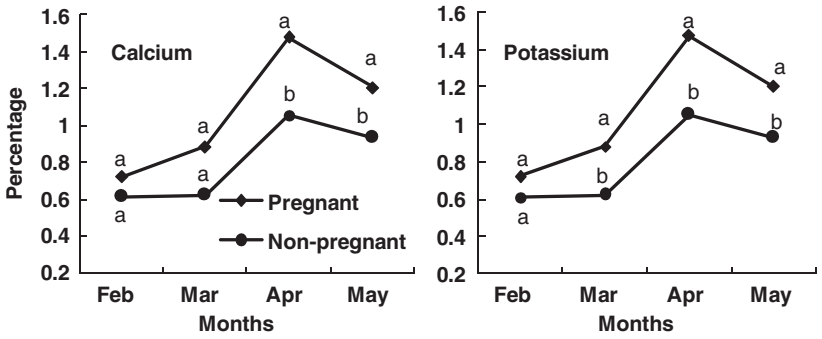


Figure 2 Ca and K levels of dietary samples of pregnant and non-pregnant goats grazing a microphyll desert scrub during the dry period. Within months, means with different letters differ ($P < 0.01$). Significant differences ($P < 0.01$) exist for levels of these minerals in forages selected by goats in different months.

of forages selected by non-pregnant goats was lower ($P < 0.01$) compared with that selected by goats that became pregnant (Figure 2). The Ca content in goat diets increased ($P < 0.01$) as the dry period progressed. This increase was particularly notorious in the pregnant goats in whom Ca levels in the forage selected increased twofold from February to April (Figure 2). No differences among goat groups were noted for P content in goat diets (0.42 ± 0.11 *v.* 0.37 ± 0.10% of dietary DM across months, values are mean $\pm$ s.d. for pregnant and non-pregnant goats; $P > 0.05$), but there was considerable fluctuation in P content of forages among months (range: 0.34% to 0.46% of DM), reflecting the diversity of species present in the diet and their differing maturation dates.

Both the Mg and Na contents were not different among diets selected by pregnant (0.16 ± 0.06% and 0.12 ± 0.06% of dietary DM across months) and non-pregnant (0.13 ± 0.03% and 0.12 ± 0.07% of DM across months) goats, although the levels of these elements varied considerably ($P < 0.01$) throughout the study period. K concentrations in diets selected by non-pregnant goats were lower ($P < 0.01$) than the levels of this mineral found in diets of pregnant goats (Figure 2). Levels of Cu (range: 9.1 to 13.8 mg/kg DM), Zn (range: 15.6 to 23.6 mg/kg DM), Mn (range: 82.9 to 113.0 mg/kg DM) and Fe (range: 291 to 474 mg/kg DM) in the diet of pregnant and non-pregnant goats did not differ. Likewise, the average tannin (range: 1.3% to 1.8% of dietary DM) and alkaloid (range: 0.08% to 0.14% of dietary DM) content of selected goat forages did not differ among groups of goats. The physiological state of the goats did not affect the percentages of dietary samples containing saponins and terpenes.

Discussion

Regardless of the physiological state, the level of CP in forages selected by goats was higher than expected, considering that they faced a severe shortage of predominantly dormant forage throughout the study period. Comparing the values obtained in this study with those published for goats in the same type of landscape (Juárez-Reyes *et al.*, 2004 and 2008), it seems clear that goats managed to select the most nutritious plant parts and plant speciesduring the dry period in order to maximize the ingestion of protein.

Pregnant and non-pregnant goats consumed diets dissimilar in protein content throughout the study period, with the highest level for the pregnant animals. Considering that the average DM intake of adult pregnant mixed breed grazing goats in this landscape in winter is 1.2 kg per goat per day (Juárez-Reyes *et al.*, 2004; Cerrillo *et al.*, 2006), the levels of this nutrient in the pregnant goats did not meet late pregnancy requirements (National Research Council (NRC), 2007, based on high physical activity). Thus, it seems that, in this particular environment, pregnant goats that carried their fetuses to term handled ingestion of enough high-quality forage to barely maintain a nutritional status to sustain their fetuses. It is interesting to note that even though protein availability to goats was at its lowest point during the annual cycle, pregnant goats maintained a fairly high level of protein in their diet, which indicates that pregnancy forced goats to increase their selectivity on the more profitable species and possibly they diversified their diet according to their nutritional needs (Villalba *et al.*, 2002). In this landscape, pregnant goats select twice as much forbs as non-pregnant animals (Mellado *et al.*, 2005b), which increases nitrogen retention (Arthun *et al.*, 1992). These results are in agreement with the result from sheep (Cooper *et al.*, 1994) regarding the fact that goats are able to discriminate between plants or plant parts with different levels of nitrogen, according to their physiological needs.

A daily intake of energy is highly correlated with that of protein (Wilmshurst and Fryxell, 1995; Olson *et al.*, 2008) and organic matter digestibility in ruminants (Olson *et al.*, 2008). Thus, pregnant goats showed a selective tendency toward a more nutrient-rich and digestible diet than non-pregnant goats. However, the lower protein content in the diet of non-pregnant goats indicates that there was likely no physiological need for non-pregnant goats to seek forages of exceptionally high CP. The steady decline in CP content in the diet of all groups of goats probably reflected changes in the botanical composition of the diet as well as a decline in the protein content of forages with advancing dry conditions.

Diets of pregnant goats were higher in ether extract than diets of non-pregnant goats. Ether extract in forages in arid

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environments consists largely of various oils and resins as well as pigments present in green forages. Gestating goats may have sought forages that remain green over winter with high content of carotenoids (part of the ether extract), as these compounds are involved in different reproductive processes (Ikeda *et al*., 2005; Sales *et al*., 2007; Kawashima *et al*., 2009). Since leaves are higher in ether extract than stems, apparently pregnant goats selected leaves in preference to stems, which would result in greater forage digestibility, and perhaps more importantly, increased forage intakes. Lipids in forages are generally positively related to CP (Idikut *et al*., 2009) and negatively related to cell walls (Ambreen *et al*., 2006); therefore, these data further show the higher diet quality of the pregnant goats compared with non-pregnant animals.

Pregnant goats selected diets lower in both NDF and ADF compared with non-pregnant animals. The energetic requirements of pregnant females peak during late gestation, and as a consequence, probably pregnant goats increased the search for forages with lower structural carbohydrates. This is important for the reproductive effort because the low forage abundance (Illius and Gordon, 1987) and high fiber content of forages (Abijaoude *et al*., 2000; Alonso-Díaz *et al*., 2008) decrease the short-term feeding rate of ruminants. Consequently, low food quality leads to higher retention periods and rumination, which lowers feed intake (Bhatti *et al*., 2008).

Thus, to meet the medium-term sustained nutritional demands for gestation, pregnant goats on rangeland seemed to select diets lower in structural carbohydrates, which would result in greater energy intake and nutrient digestibility (Moore and Coleman, 2001; Cline *et al*., 2009). Therefore, one behavioral adaptation needed by pregnant goats to cope with increasing nutrient demands in a resource-poor environment seems to be the avoidance of species of plants with high fiber content. In addition, pregnant goat diets contained less lignin and cellulose during the dry season than did those of non-pregnant goats, apparently because of a higher browse content of the diets selected by non-pregnant goats in this landscape (Mellado *et al*., 2005); browse is generally higher in lignin than in herbaceous material (Codron *et al*., 2007). The negative relationship between forage digestibility and lignin concentration has been amply documented (Jung and Vogel, 1986; Jung *et al*., 1997). Thus, it seems that pregnant goats avoided forages with high lignification of the plant cell wall in order to ingest forages of higher digestibility.

No differences in ash content of pregnant and non-pregnant goats were found, but ash values declined for all groups of goats as the season progressed, which was expected because the mineral content of arid rangeland forages declines as the growing season progresses (Frost *et al*., 2008). Pregnant goats exhibited substantially higher dietary levels of Ca, and higher Ca-to-P ratios than non-pregnant goats. This means that pregnant goats foraged more selectively than non-pregnant goats in search of plants with high Ca content, whose requirement increase rapidly in late gestation, because of the rapid fetal growth (Abdelrahman, 2008). This feeding strategy probably had the purpose of replenishing the Ca bone reserves since early gestation, in order to have at kidding enough Ca reserves to support Ca resorption from bone, as a result of immediate Ca demands for milk synthesis at kidding and through the first weeks of lactation (Liesegang and Risteli, 2005; Liesegang *et al*., 2006). The strong response for Ca by pregnant goats suggests that these animals had depleted their Ca body reserves in their previous lactation. The fact that goats can select mineral content in their diet and that selection is shaped by physiological effort has been also demonstrated by Ceacero *et al*. (2010) in red deer.

Dietary P in goat diets did not differ with physiological state. Considering the 1.2 kg DM intake of goats in this landscape (Juárez-Reyes *et al*., 2004), the levels of this mineral in forages selected by goats were sufficient to provide maximum weight gain, bone growth and pregnancy of goats (NRC, 2007). P has been identified as the most deficient macromineral in grasses used by cattle in rangelands of Mexico (Kawas *et al*., 1997) and western parts of the United States (Scrivner *et al*., 1988; Pinchak *et al*., 1989; Ganskopp and Bohnert, 2003), but goats in this study used forages with sufficient P to keep the normal development of their fetuses. Ruminants sense deficits of P in forages (Villalba *et al*., 2008); therefore, apparently goats selected a variety of foods from an array of plant species and made use of live tissue to obtain maximum P concentrations (Pinchak *et al*., 1989) in order to meet their P requirements. In fact, the P levels in forages selected by goats were twice as much as those found in plants used by goats in this landscape (Barnes *et al*., 1990).

The concentration of K in the pregnant goats' diets was substantially higher than the levels in diets of non-pregnant goats. For goats in different physiological states, the level of this element in forages chosen was well above the requirements for optimal growth and gestation (NRC, 2007). The important increase of this element in the diet of pregnant goats could be due to a higher ingestion of halophyte plants, which possess high concentrations of Na and K (Masters *et al*., 2005).

Pregnancy did not affect the levels of Mg, Na and microelements in forages selected by goats. Foraging theory predicts that herbivores are capable of assessing the nutrient content of forages, including minerals (Ceacero *et al*., 2010), and adjusting their diet according to needs. Goats in this type of vegetation were able to select forages with levels of microminerals considerably above the requirements for maximum growth and the reproductive process. The varied diet of goats in this landscape apparently allowed them to obtain sufficient microminerals in this area where forages used by goats in this ecoregion are deficient in several of these minerals (Ramírez *et al*., 1990; Ramírez-Orduña *et al*., 2008).

Pregnant goats did not select forage with a lower CT content than non-pregnant goats. The levels of tannins found in goat diets were far below the 50 g/kg DM considered negative for decreasing food intake (Barry *et al*., 1986); thus, all classes of goats had no need to seek forages with low tannin content. We acknowledge that the low levels of CT found in the diets of goats was likely due, in part, to saliva mixing with the plant material during sampling.

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Since tannin concentration is correlated with a sensation of astringency (Mali and Borges, 2003), goats avoid diets containing large amounts of tannins (Holechek *et al*., 1990; Lisonbee *et al*., 2009). In this study, the reduced tannin levels in forages selected by goats probably were beneficial instead of detrimental, because proteins of forages with low levels of these secondary compounds are protected from microbial degradation by forage tannins (Waghorn, 2008). Goats did not require higher levels of tannins to mitigate the impact of gastrointestinal parasites, as internal nematode parasitism is not a problem for these animals in this zone (Mellado *et al*., 2004a).

However, on average, the total alkaloids content of forage selected by goats was not high (0.10 mg/g), which is far below the average alkaloids content of major classes of plant rich in compounds of this landscape (Pfister *et al*., 2001). Contrary to expectation, pregnant goats selected forages with the same levels of alkaloids as did non-pregnant goats. In fact, pregnant goats selected forages with the highest levels of this secondary compound during the fourth month of pregnancy. These results are similar to those of Knubel *et al*. (2004), who observed that goats do not experience pregnancy-related changes in food selection when offered plants with teratogenic properties. Certain alkaloids are teratogenic and cause pregnancy losses in goats (Panter *et al*., 2000). Even so, in this landscape, alkaloid-containing plants are avidly eaten by goats and constitute, in certain periods of the year, the major portion of the goat diets (e.g. *Solanum elaeagniifolium*; Mellado *et al*., 2003 and 2004b). Although toxic plants can cause negative effects, goats may still consume them because of the plant's nutritional quality, availability or addictive chemical properties. Goats are somewhat physiologically adapted to cope with alkaloid concentrations in their diet (Kronberg and Walker, 2007), which makes them resistant to alkaloid toxicity (Cheeke, 1988), via a low rate of hepatic production of reactive metabolites (pyrroles) and (or) a high rate of activity of detoxifying enzymes. Moreover, goats ameliorate the toxic effects of alkaloids by diversifying forages with different classes of phytotoxins, which promotes chemical interactions that inhibit the toxic effects of these plant secondary metabolites in the intestinal tract (Rogosic *et al*., 2006; Lisonbee *et al*., 2009). Some foraging models show that animals minimize intake of toxins (Rapport, 1980), and this seems to be the case in this study where goats apparently traded off allocating resources for maintenance of pregnancy and ingestion of manageable levels of alkaloids. Hence, the alkaloid levels in forages selected by goats in this landscape are not critical factors that influence the foraging efficiency and, ultimately, fitness of pregnant goats.

Conclusions

Pregnancy played a dominant role in determining forages selected by goats, as pregnant goats selected diets richer in CP and Ca and lower in structural carbohydrates during the dry season, in order to sustain nutrient demands for development of their fetuses and synthesis of the colostrum. This suggests that pregnant goats foraged more selectively on the more profitable species than non-pregnant goats. Given that this higher selectivity for nutrients by pregnant goats occurred throughout gestation, it seems that goats are capable of identifying potential food items according to their nutrient content. Furthermore, goats seem to be able to keep track of the constantly changing nutrient content of forages and adjust their rank value in different phenological states.

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References

Abdelrahman MM 2008. The effect of high calcium intake by pregnant Awassi ewes at late gestation on minerals status and performance of ewes and newborn lambs. Livestock Science 117, 15–23.

Abijaoude JA, Morand-Fehr P, Tesie J, Schimidely PH and Sauvant D 2000. Diet effect on the daily feeding behaviour, frequency and characteristics of meals in dairy goats. Livestock Production Science 64, 29–37.

Alm U, Birgersson B and Leimar O 2002. The effect of food quality and relative abundance on food choice in fallow deer. Animal Behaviour 64, 439–445.

Alonso-Díaz MA, Torres-Acosta JFJ, Sandoval-Castro CA, Hoste H, Aguilar-Caballero AJ and Capetillo-Leal CM 2008. Is goats' preference of forage trees affected by their tannin or fiber content when offered in cafeteria experiments? Animal Feed Science and Technology 141, 36–48.

Ambreen N, Hanif NQ and Khatoon S 2006. Chemical composition of rice polishing from different sources. Pakistan Veterinary Journal 26, 190–192.

Association of Official Analytical Chemists (AOAC) 1996. Official methods of analysis, 16th edition. AOAC, Arlington, VA, USA.

Arthun D, Holecheck JL, Wallace JD, Galyean ML, Cardenas M and Rafique S 1992. Forbs and shrubs influences on steer nitrogen retention. Journal of Range Management 45, 133–136.

Barnes TG, Varner LW, Blankenship LH, Fillinger TJ and Heiman SC 1990. Macro and trace mineral content of selected South Texas deer forages. Journal of Range Management 43, 220–224.

Barry TN, Manley TR and Duncan SJ 1986. The role of condensed tannins in the nutritional value of *Lotus peduculatus* for sheep 4. Sites of carbohydrate and protein digestion as influenced by dietary reactive tannin concentration. British Journal of Nutrition 55, 123–137.

Bartolome J, Franch J, Plaixats J and Seligman NG 1998. Diet selection by sheep and goats on Mediterranean heath-woodland range. Journal of Range Management 51, 383–391.

Berteaux D, Crête M, Huot J, Maltais J and Ouellet JP 1998. Food choice by white-tailed deer in relation to protein and energy content of the diet, a field experiment. Oecologia 115, 84–92.

Bhatti SA, Bowman JGP, Firkins JL, Grove AV and Hunt CW 2008. Effect of intake level and alfalfa substitution for grass hay on ruminal kinetics of fiber digestion and particle passage in beef cattle. Journal of Animal Science 86, 134–145.

Bugalho MN and Milne JA 2003. The composition of the diet of red deer (*Cervus elaphus*) in a Mediterranean environment: a case of summer nutritional constraint? Forest Ecolofy and Management 181, 23–29.

Ceacero F, Landete-Castillejos T, García AJ, Estévez JA and Gallego L 2010. Physiological variables explain mineral intake in Iberian red deer. Physiology and Behavior 100, 122–127.

Cerrillo MA, López OO, Nevárez CG, Ramírez RG and Juárez RAS 2006. Nutrient content, intake and in vitro gas production of diets by Spanish goats browsing a thorn shrubland in North Mexico. Small Ruminant Research 66, 76–84.

Cheeke PR 1988. Toxicity and metabolism of pyrrolizidine alkaloids. Journal of Animal Science 66, 2343–2350.

https://doi.org/10.1017/S1751731110002715 Published online by Cambridge University Press

Cline HJ, Neville BW, Lardy GP and Caton JS 2009. Influence of advancing season on dietary composition, intake, site of digestion, and microbial efficiency in beef steers grazing a native range in western North Dakota. Journal of Animal Science 87, 375–383.

Codron D, Lee-Thorp JA, Sponheimer M and Codron J 2007. Nutritional content of savanna plant foods, implications for browser/grazer models of ungulate diversification. European Journal of Wildlife Research 53, 100–111.

Cooper SDB, Kyriazakis I and Oldham JD 1994. The effect of late pregnancy on the diets selection made by ewes. Livestock Production Science 40, 263–275.

Food Chemical Codex 1981. Food chemical codex, 3rd edition. National Academic Press, Washington, DC, USA.

Fowden AL, Giussani DA and Forhead AJ 2006. Intrauterine programming of physiological systems, causes and consequences. Physiology 21, 29–37.

Frost RA, Wilson LM, Launchbaugh KL and Hovde EM 2008. Seasonal change in forage value of rangeland weeds in northern Idaho. Invasive Plant Science and Management 1, 343–351.

Galindo FW, Rosales M, Murgueitio E and Larrahondo J 1989. Sustancias antinutricionales en las hojas de guamo, nacedero y mataratón. Livestock Research for Rural Development 1, 1–15.

Ganskopp D and Bohnert D 2003. Mineral concentration dynamics of 7 northern Great Basin grasses. Journal of Range Management 54, 640–647.

Gilbert JS, Lang AL, Grant AR and Nijland MJ 2005. Maternal nutrient restriction in sheep, hypertension and decreased nephron number in offspring at 9 months of age. Journal of Physiology 565, 137–147.

Holechek JL, Munshikpu AV, Saiwana L, Nunez-Hernandez G, Valdez R, Wallace JD and Cardenas M 1990. Influences of six shrub diets varying in phenol content on intake and nitrogen retention by goats. Tropical Grasslands 24, 93–98.

Idikut L, Boga M, Atalay AI, Kara SN and Kamalak A 2009. Effect of previous plant on chemical composition of sweet corn grain. Journal of Animal and Veterinary Advances 8, 1979–1981.

Ikeda S, Kitagawa M, Imai H and Yamada M 2005. The roles of vitamin A for cytoplasmic maturation of bovine oocytes. Journal of Reproduction and Development 51, 23–35.

Illius AW and Gordon IJ 1987. The allometry of food intake in grazing ruminants. Journal of Animal Ecology 56, 989–999.

Jaquiery AL, Oliver MH, Rumball CWH, Bloomfield FH and Harding JE 2009. Undernutrition before mating in ewes impairs the development of insulin resistance during pregnancy. Obstetric and Gynecology 114, 869–876.

Juárez-Reyes AS, Cerrillo-Soto MA, Meza-Herrera CA and Nevárez-Carrasco G 2004. Diet composition, intake, plasma metabolites, reproductive and metabolic hormones during pregnancy in goats under semi-arid grazing conditions. Journal of Agricultural Science 142, 697–704.

Juárez-Reyes AS, Nevarez-Carrasco G, Cerrillo-Soto MA, Murillo-Ortiz M, Luginbuhl JM, Bernal Barragan H and Ramírez RG 2008. Dietary chemical composition, plasma metabolites and hormones in range goats. Journal of Applied Animal Research 34, 81–86.

Jung HG and Vogel KP 1986. Influence of lignin on digestibility of forage cell wall material. Journal of Animal Science 62, 1703–1712.

Jung HG, Mertens DR and Payne AJ 1997. Correlation of acid detergent lignin and Klason lignin with digestibility of forage dry matter and neutral detergent fiber. Journal of Dairy Science 80, 1622–1628.

Kawas J, Armienta G, Kawas J, Olivares E and Torres O 1997. Seasonal changes of mineral concentrations of tropical grasses in Mexico. In XVIII International Grassland Congress Winnipeg, Manitoba and Saskatoon. Saskatchewan, Canada, 123pp.

Kawashima C, Kida K, Schweigert FJ and Miyamoto A 2009. Relationship between plasma β-carotene concentrations during the peripartum period and ovulation in the first follicular wave postpartum in dairy cows. Animal Reproduction Science 111, 105–111.

Knubel BFR, Panter KE and Provenza FD 2004. Pregnancy in goats does not influence intake of novel or familiar foods with or without toxins. Applied Animal Behaviour Science 85, 293–305.

Krojerová-Prokešová J, Barančeková M, Šustr P and Heurich M 2010. Feeding patterns of red deer *Cervus elaphus* along an altitudinal gradient in the Bohemian Forest: effect of habitat and season. Wildlife Biology 16, 173–184.

Kronberg SL and Malechek JC 1997. Relationship between nutrition and foraging behavior of free-ranging sheep and goats. Journal of Animal Science 75, 1756–1763.

Kronberg SL and Walker JW 2007. Learning through foraging consequences: a mechanism of feeding niche separation in sympatric ruminants. Rangeland Ecology and Management 60, 195–198.

Kyriazakis I, Tolkamp BJ and Emmans G 1999. Diet selection and animal state: an integrative framework. Proceedings of the Nutrition Society 58, 765–772.

Liesegang A and Risteli J 2005. Influence of different calcium concentrations in the diet on bone metabolism in growing dairy goats and sheep. Journal of Animal Physiology and Animal Nutrition (Berl) 89, 113–119.

Liesegang A, Risteli J and Wanner M 2006. The effects of first gestation and lactation on bone metabolism in dairy goats and milk sheep. Bone 38, 792–802.

Lisonbee LD, Villalba JJ and Provenza FD 2009. Effects of tannin on selection by sheep of forages containing alkaloids, tannins and saponins. Journal of the Science of Food and Agriculture 89, 2668–2677.

Lopez-Trujillo R and Garcia-Elizondo R 1995. Botanical composition and diet quality of goats grazing natural and gross reseeded shrublands. Small Ruminant Research 16, 37–47.

Makkar HPS, Singh B, Vats SK and Sood RP 2003. Total phenols, tannins and condensed tannins in different parts of *Rumex hast*. Bioresearch Technology 45, 69–71.

Mali S and Borges RM 2003. Phenolics, fibre, alkaloids, saponins, and cyanogenic glycosides in a seasonal cloud forest in India. Biochemical Systematics and Ecology 31, 1221–1246.

Masters DG, Rintoul AJ, Dynes RA, Pearce KL and Norman HC 2005. Feed intake and production in sheep fed diets high in sodium and potassium. Australian Journal of Agricultural Research 56, 427–434.

Mellado M, Foote RH, Rodríguez A and Zárate P 1991. Botanical composition and nutrient content of diets selected by goats grazing on desert grassland in northern Mexico. Small Ruminant Research 6, 141–150.

Mellado M, Valdez R, Lara LM and López R 2003. Stocking rate effects on goats. A research observation. Journal of Range Management 56, 167–173.

Mellado M, Gonzalez H, Garcia JE and Garcia R 2004a. Anthelmintic treatment of goats on an arid range and its effects on milk production in late lactation. Journal of Applied Animal Research 25, 91–95.

Mellado M, Olvera A, Dueñez J and Rodríguez A 2004b. Effects of continuous or rotational grazing on goat diets in a desert rangeland. Journal of Applied Animal Research 26, 93–100.

Mellado M, Valdez R, Lara LM and García JE 2004c. Risk factors involved in conception, abortion, and kidding rates of goats under extensive conditions. Small Ruminant Research 55, 191–198.

Mellado M, Olivares L, Lopez R and Mellado J 2005. Influence of lactation, liveweight and lipid reserves at mating on reproductive performance of grazing goats. Journal of Animal and Veterinary Advances 4, 420–423.

Mellado M, Olvera A, Quero A and Mendoza G 2005a. Diet of prairie dogs, goats and sheep on a desert rangeland. Rangeland Ecology and Management 58, 373–379.

Mellado M, Rodriguez A, Villarreal JA and Olvera A 2005b. The effect of pregnancy and lactation on diet composition and dietary preference of goats in a desert rangeland. Small Ruminant Research 58, 79–85.

Mellado M, Estrada R, Olivares L, Pastor F and Mellado J 2006. Diet selection among goats of different milk production potential on a Chihuahuan desert grassland. Journal of Arid Environments 66, 127–134.

Moore JE and Coleman SW 2001. Forage intake, digestibility, NDF and ADF, How well are they related? In Proceedings of American Forage and Grassland Council (ed. T Terrill), pp. 238–242. Springdale, AR AFGC, Georgetown, TX, USA.

National Research Council (NRC) 2007. Nutrient requirements of small ruminants, sheep, goats, cervids, and new world camelids. National Academy Press, Washington, DC, USA.

Olson KC, Cochran RC, Titgemeyer EC, Mathis CP, Jones TJ and Heldt JS 2008. Prediction of the energy content of tallgrass prairie hay. Journal of Animal Science 86, 1372–1381.

Panter KE, Weinzweig J, Gardner DR, Stegelmeier BL and James LF 2000. Comparison of cleft palate induction by *Nicotiana glauca* in goats and sheep. Theratology 61, 203–210.

Papachristou TG and Nastis AS 1993. Diets of goats grazing oak shrublands of varying cover in northern Greece. Journal of Range Management 46, 220–226.

https://doi.org/10.1017/S1751731110002715 Published online by Cambridge University Press

Pfister JA, Panter KE, Gardner DR, Stegelmeier BL, Ralphs MH, Molyneux RJ and Lee ST 2001. Alkaloids as anti-quality factors in plants on western US rangelands. Journal of Range Management 54, 447–461.

Pinchak WE, Greene LW and Heitschmidt RK 1989. Mineral dynamics in beef cattle diets from a southern mixed-grass prairie. Journal of Range Management 43, 431–435.

Ramírez RG, Rodriguez A, Tagle LA, Del Valle AC and Gonzalez J 1990. Nutrient content and intake of forage grazed by range goats in northeastern Mexico. Small Ruminant Research 3, 435–448.

Ramírez-Orduña R, Ramírez RG, Romero-Vadillo E, González-Rodríguez H, Armenta-Quintana JA and Avalos-Castro R 2008. Diet and nutrition of range goats on a sarcocaulescent shrubland from Baja California Sur, Mexico. Small Ruminant Research 76, 3166–3176.

Rapport DJ 1980. Optimal foraging for complementary resources. American Naturalist 116, 324–346.

Redmer DA, Wallace JM and Reynolds LP 2004. Effect of nutrient intake during pregnancy on fetal and placental growth and vascular development. Domestic Animal Endocrinology 27, 199–217.

Rogosic J, Estell RE, Skobic D, Martinovic A and Maric S 2006. Role of species diversity and secondary compound complementarity on diet selection of Mediterranean shrubs by goats. Journal of Chemical Ecology 32, 1279–1287.

Rumball CWH, Bloomfield FH and Harding JE 2008. Cardiovascular adaptations to pregnancy in sheep and effects of periconceptional undernutrition. Placenta 29, 89–94.

Sales JNS, Dias LMK, Viveiros ATM, Pereira MN and Souza JC 2007. Embryo production and quality of Holstein heifers and cows supplemented with ß-carotene and tocopherol. Animal Reproduction Science 106, 77–89.

Scrivner JH, Vaughn CE and Jones MB 1988. Mineral concentrations of black-tailed deer diets in California chaparral. Journal of Wildlife Management 52, 37–41.

Swain T and Hillis WE 1959. The phenolic constituents of *Pronus domestica* I: the quantitative analysis of phenolic compounds. Journal of the Science of Food and Agriculture 10, 63–67.

Thomas VM and Kott RW 1995. A review of Montana winter range ewe nutrition research. Sheep and Goat Research Journal 11, 17–24.

Tovar-Luna I, Goetsch AL, Puchala R, Sahlu T, Carstens GE, Freetly HC and Johnson ZB 2007. Efficiency of energy use for pregnancy by meat goat does with different litter size. Small Ruminant Research 71, 83–91.

Van Soest PJ and Wine RH 1968. Determination of lignin and cellulose in acid-detergent fiber with permanganate. Journal of the Association of Official Analytical Chemists 51, 780–785.

Van Soest PJ, Robertson JB and Lewis BA 1991. Methods for dietary fiber, neutral detergent fiber, and nonstarch polysaccharides in relation to animal nutrition. Journal of Dairy Science 74, 3583–3597.

Verheyden-Tixier H, Renaud PC, Morellet N, Jamot J, Besle JM and Dumont B 2008. Selection for nutrients by red deer hinds feeding on a mixed forest edge. Oecologia 156, 715–726.

Villalba JJ, Provenza FD and Bryant JP 2002. Consequences of the interaction between nutrients and plant secondary metabolites on herbivore selectivity, benefits or detriment for plants? Oikos 97, 282–292.

Villalba JJ, Provenza FD and Hall JO 2008. Learned appetites for calcium, phosphorus, and sodium in sheep. Journal of Animal Science 86, 738–747.

Villalba JJ, Soder KJ and Laca EA 2009. Understanding diet selection in temperate biodiverse pasture systems. Rangeland Ecology and Management 62, 387–388.

Vonnahme KA, Hess BW, Hansen TR, McCormick RJ, Rule DC, Moss GE, Murdoch WJ, Nijland MJ, Skinner DC, Nathanielsz PW and Ford SP 2003. Maternal undernutrition from early to mid gestation leads to growth retardation, cardiac ventricular hypertrophy and increased liver weight in the fetal sheep. Biology of Reproduction 69, 133–140.

Waghorn G 2008. Beneficial and detrimental effects of dietary condensed tannins for sustainable sheep and goat production – progress and challenges. Animal Feed Science and Technology 147, 116–139.

Wilmshurst JF and Fryxell JM 1995. Patch selection by red deer in relation to energy and protein intake, a re-evaluation of Langvatn and Hanley's (1993) results. Oecologia 104, 297–300.

https://doi.org/10.1017/S1751731110002715 Published online by Cambridge University Press