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Foraging Behavior of Criollo vs. Brahman × Criollo Crossbreds in the Bolivian Chaco: Case Study

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ABSTRACT

Diet selection and performance of Criollo Chaqueño and Brahman × Criollo Chaqueño were studied in three seasons in the dry forests of the Bolivian Chaco using direct observations. During the dry season (DS) and the rainy season (RS), the Criollo cattle diet consisted of a higher proportion ($P < 0.05$) of woody plants compared with the crossbreds, while the crossbreds included a higher proportion of grasses. Leaf litter was selected in the DS by Criollos but almost not by crossbreds ($P < 0.05$; 23% and <1% of diet selection, respectively). Season ($P < 0.001$) had an overall effect on body weight change with a loss of weight in the DS. However, between the DS and the RS the body weight of the Criollos increased ($P < 0.05$), whereas it did not differ ($P > 0.05$) for the crossbreds. Other than for the Criollos, the body weight of the crossbreds decreased ($P < 0.05$) from the DS to the transition period. Especially during the DS, Criollos made more use of forage resources from shrubs and trees and thus, seem to be better adapted to year-round forest grazing compared with the crossbreds.

Introduction

The Gran Chaco is a dry forest ecosystem covering parts of Argentina, Paraguay, and Bolivia. In the rural region of the Bolivian Chaco, extensive cattle husbandry in forest-grazing systems using Criollo cattle with different levels of crossbreeding with zebu cattle is an important agricultural activity. Criollo cattle are cattle of Spanish origin introduced to Latin America by the Spanish conquistadors at the end of the 15th century (Martínez et al., 2012). Criollo Chaqueño are well adapted to this harsh environment with seasonal rainfall and drought periods. In many parts of Latin America, the numbers of pure Criollo cattle are shrinking because of replacement or crossbreeding with improved breeds exotic to the area (Martínez et al., 2012). In the Bolivian part of the Chaco, crossbreeding with *B. indicus* breeds started mainly in the second half of the 20th century (Giovambattista et al., 2000). In the Bolivian Sub-Andean mountain forests Criollo cattle are able to make broad use of different forest resources and are able to adapt foraging behavior to seasonal circumstances (Marquardt et al., 2010). However, whether the foraging behavior of Criollo cattle differs from that of exotic breeds or crossbreds kept under the same conditions is unknown. The objective of the present case study was to compare the diet selection and performance of Criollo Chaqueño (or simply "Criollo") with crossbreds of Brahman × Criollo Chaqueño ("crossbred") kept in the Chaco dry forests over three seasons.

Methods

Study Area and Study Site

The study was conducted at the Estación Experimental El Salvador, Machareti, Department of Chuquisaca, Bolivia, from August 2011 to February 2012. The climate in the area is subtropical and semiarid with annual average temperatures of about 23°C and maximum temperatures can reach >40°C. In 2011 to 2012, the mean annual precipitation varied from about 600 to 800 mm, with most rainfall occurring between December and February (from recordings at the climate station in Camiri, SENAMHI, 2003). The study site comprised 350 ha of natural forest. The vegetation consisted of dry forest vegetation with a few small open grassland patches. Plant cover data is shown in Supplementary Table S1 available online at https://doi.org/10.1016/j.rama.2018.06.002.

Experimental Animals

Twelve local Criollo Chaqueño cows and 12 crossbred cows (♂ Brahman × ♀ Criollo Chaqueño) were randomly selected from a predefined group based on age range, health, and tameness. Before the experiment started, the Criollos and crossbreds, on average, were 28.7 ± 4.3 and 28.4 ± 7.8 mo old, and the body weight was 328 ± 22 and 399 ± 52

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kg, respectively. Initially, none of the animals were accompanied by a calf, but six Criollo and two crossbred cows gave birth between November and January. The Criollos originated from a herd of 1 350 cattle of the Experimental Station El Salvador. The crossbreds were selected from a herd of 53 cattle owned by a smallholder farmer in La Salvación approximately 100 km from the study site within a region with similar vegetation. Both genotypes had been reared and kept year round in forest environments similar to the study site. After selection, but before the actual experiment started, the two genotypes were kept for 3 wk separately in two paddocks of improved pasture consisting of primarily *Panicum trichoides* Sw.

Experimental Design

The experiment was subdivided into three observation periods covering the dry season (DS; 21 August–19 September 2011), the transition period (TP; 28 October–26 November 2011), and the rainy season (RS; 10 January–5 February 2012). The study site was subdivided into two fenced paddocks of similar size (175 ha each), vegetation, and topography, new to both genotypes. During the observation periods, animals of the same genotype were kept together in one of the paddocks to avoid any influence on feeding behavior among the genotypes. During the time in between the experimental periods and after half of the observation periods had been completed, the genotypes were switched between the paddocks so that both genotypes spent the same amount of time in each paddock. The forage on offer was adequate to meet animal demands throughout each season. Each observation period consisted of 24 measurement d (12 d in each paddock) and 3 to 6 d in between with no measurements after the herds were switched.

Measurement of Diet Selection

For measuring diet selection, a direct observation technique using "bite categories" adapted from Agreil and Meuret (2004) was employed after a 10-d familiarization process between observer and animals on one randomly selected focal animal per d. Diet selection was recorded every 3 to 4 min during a consecutive period of 30 s from morning (around 0600 hours) to evening (1700 hours) by an observer team located at a distance of 2 to 3 m from the respective animal. The number of bites per plant species was recorded together with the respective botanical functional group (FG; grasses, herbs, trees, shrubs, ferns, epiphytes, leaf litter, and climbers) and plant category to estimate the proportionate biomass intake simulated per plant category and bite size (small, half, and full; see Footnote 1 in Tables 1 and S2 (available online at https://doi.org/10.1016/j.rama.2018.06.002).

Samples of unknown plant species were identified at the Herbarium of the Museo de Historia Natural Noel Kempff Mercado in Santa Cruz de la Sierra. The chemical composition of the major selected species is given in Table S3 (available online at https://doi.org/10.1016/j.rama.2018.06.002).

Measurement of Body Weight

All animals were weighed before the experiment started (18 July) and then twice per season, 5 to 6 d before (initial body weight) and the day of or 1 d after the observation periods were completed (final body weight). Cattle were kept in a small paddock without feed or water overnight and then weighed.

Statistical Analysis

Statistical analyses were performed using the MIXED procedure of SAS 9.3 (2002–2010, SAS Institute Inc. Cary, NC). Each individual animal was considered as an experimental unit. The model for comparison of diet selection of FG was set up as *genotype* (*G*), *season* (*S*), and the interaction ($G \times S$) as fixed effects, *Paddock* (*Pa*) as random factor, *S* as repeated, and *animal* (*A*) within *G* as subject. Some data had to be log transformed before analysis. In this case the estimates and SEM from the nontransformed data and superscripts and *P* values of the transformed data are displayed. For the parameter "fruits" (only relevant in TP), the model was reduced with *G* as single fixed effect and *Pa* as random factor. LSmeans are displayed in the table. Diet selection of different plant families and plant species was analyzed separately per season using *G* as single fixed effect and transformations if needed. In cases where data were not normally distributed after transformations, the SAS procedure NPAR1WAY was used to run a Kruskal–Wallis test to compare genotypes.

The body weight change per d during the observation periods was analyzed using *G*, *S*, and the interaction as fixed effects. *Season* was included as repeated factor, and *A* was nested within *G* as subject. The body weight (mean of the initial and final body weight per season) was analyzed with the same but slightly modified model separately

Table 1
Diet selection (proportional amount of biomass, in air dry matter) of Criollo Chaqueño (Criollo) and Brahman × Criollo Chaqueño (Cross) in three seasons per botanical functional group. LSmeans and standard error of the mean (SEM) are displayed.[1]

Functional group[2]	Dry season		Transition period		Rainy season		SEM	*P* value		
	Criollo	Cross	Criollo	Cross	Criollo	Cross		Genotype (G)	Season (S)	G×S
n[3]	12	10	11	11	9	11				
Herbaceous	15.9^{d}	24.0^{cd}	24.4^{cd}	37.3^{bc}	46.3^{b}	71.7^{a}	6.39	0.002	<0.001	0.11
Grasses	2.3^{c}	17.2^{ab}	10.0^{bc}	16.5^{b}	12.5^{bc}	29.1^{a}	4.51	<0.001	0.002	0.075
Herbs	13.6^{c}	7.4^{c}	14.0^{c}	20.4^{bc}	34.7^{ab}	42.3^{a}	4.55	0.37	<0.001	0.069
Woody	35.4^{a}	8.6^{b}	52.6^{a}	39.6^{a}	38.0^{a}	15.3^{b}	7.48	<0.001	<0.001	0.44
Tree	5.9^{b}	7.6^{b}	39.1^{a}	37.6^{a}	5.3^{b}	5.4^{b}	7.57	0.51	<0.001	0.71
Shrub	6.6^{b}	0.7^{d}	7.6^{bc}	1.6^{cd}	33.7^{a}	9.9^{b}	4.34	<0.001	<0.001	0.36
Leaf litter[4]	22.9^{a}	0.3^{b}	6.0^{b}	0.8^{b}	0[5]	0[5]	2.87	<0.001	0.004	<0.001
Fruits[6]	0[5]	0[5]	32.2	27.2	0[5]	0[5]	7.43	0.64	—	—
Epiphytic	47.4^{a}	66.2^{a}	18.0^{b}	18.7^{b}	10.5^{b}	9.0^{b}	7.65	0.76	<0.001	0.50

a–d LSmeans carrying different superscripts within a row are different at $P < 0.05$.
1 Proportional amount of biomass was calculated as % of total amount of biomass selected per animal per season. The total amount of biomass per animal was estimated from direct observations conducted for 30 s every 3 to 4 min from around 0600 hours to 1700 hours. Each animal was observed on 1 d each season. Biomass intake was estimated from bite numbers, bite sizes, and the weight of the respective bites (in grams of air DM) as calculated from simulations (i.e., mimicking the animal bites) per bite category and bite size; see Table S2.
2 Climbers, ferns, and dried branches made up only a small contribution to diet selection and are not displayed.
3 Data from one Criollo from the RS and one crossbred from the TP were not included because the observation time was too short and two Criollos and one crossbred could not be observed in the RS. Data of three individual animals (two crossbreds from the DS and one Criollo from the TP) were excluded as outliers detected by graphically checking the residuals in order to fulfill the requirement of normal distribution of the residuals.
4 Displayed separately but mainly belonging to the functional group of the shrubs and trees.
5 Not selected in the respective season, and thus, this season was not included in the statistical analysis.
6 Also included in the functional group of the trees.

per genotype, where *S* was the only fixed effect. Multiple comparisons among LSmeans were performed using Tukey's method. *P* values of less than 0.05 were considered significant. Boxplots were created using SigmaPlot 13.

Results

Season had an effect on the diet selection of all botanical functional groups displayed in Table 1. Across genotypes, diet selection of herbaceous plants, as well as of grasses and herbs separately, was higher ($P < 0.05$) during the RS as compared with the TP and DS (no difference between TP and DS was detected). Overall, epiphytes contributed more than half of the diet selected during the DS. Fruits, which were not selected in the DS or RS, made up about 30% of the diet selection for both genotypes in the TP, with no difference ($P > 0.05$) detected between the Criollos and crossbreds (Table 1). Genotype had an effect on diet selection of herbaceous plants and within this group, of the grasses, with a higher contribution to the diet of the crossbreds, while woody plants in general and especially shrubs were ingested in a higher proportion by Criollos. There was an effect of the interaction of genotype and season on leaf litter selection (Table 1). Although the contribution of leaf litter to diet selection by crossbreds was less than 1% in the DS and TP, leaf litter made up 23% of the diet selection of Criollos in the DS, which then decreased ($P < 0.05$) to 6% in the TP. Although there were several differences in the contribution of the different functional groups to diet selection between the two genotypes in the DS and RS, no such differences were found in the TP (Table 1).

The contribution of the different plant families to diet selection was different in the three seasons (Table 2). However, the three most selected plant families in each season in terms of proportionate biomass intake were also found within the 10 most selected plant families of the respective other seasons. The contribution of Bromeliaceae (with *Tillandsia vernicosa* as the only species) to the diet selection was slightly higher for the crossbreds compared with the Criollos in the DS ($P < 0.05$), and no such differences were detected between the genotypes in the TP and RS (Table 2). Cannabaceae with *Celtis* spp. as the only genus made a higher contribution to diet selection of the Criollos compared with the crossbreds in the DS and RS. The Poaceae represented the most important plant family in the RS and made a higher contribution ($P < 0.05$) to diet selection in the crossbreds than in the Criollos both in the DS and RS (but not detected for the TP, Table 2). Acanthaceae (mostly *Justicia goudotii* V.A.W. Graham) made up a higher contribution to the diet selection of the Criollos compared with the crossbreds ($P < 0.05$) in the DS, but not in the other seasons, while Fabaceae made up a higher share of the diet selection of the crossbreds compared with the Criollos in the DS ($P < 0.05$).

Overall, the crossbreds had higher body weight ($P < 0.05$, not shown in figure). Season had an effect on body weight in both genotypes (Figs. 1A and B). The body weight of the Criollos increased from the DS to the RS (317 and 347 kg, respectively), while for the same period no difference ($P > 0.05$) in body weight was detected in the crossbreds, which, however, lost weight from the DS to the TP (382 and 360 kg, respectively). Season had an effect on body weight change per d ($P < 0.001$; Fig. 1C). Across genotypes, the body weight change (kg per d) was positive in the RS and TP ($0.44 \text{ kg} \cdot \text{d}^{-1}$ and $0.32 \text{ kg} \cdot \text{d}^{-1}$, respectively; $P > 0.05$) and negative in the DS ($-0.20 \text{ kg} \cdot \text{d}^{-1}$; $P < 0.05$ compared with the RS and TP).

Discussion

Diet Selection and Animal Performance

Diet selection from herbaceous plants was highest for both genotypes during the RS compared with the other seasons. However, the crossbreds selected significantly more herbaceous plants in this period than the Criollo Chaqueño. Across genotypes, woody plants had the highest share in diet selection in the TP. Although cattle are classified as grazers (Hofmann, 1989), it is known from several studies that cattle

Table 2
Diet selection (proportional amount of biomass, in air dry matter) of the 10 most consumed plant families and 10 plant species per season (means of both genotypes) as selected by Criollo Chaqueño (Criollo) and Brahman × Criollo Chaqueño (Cross) given as % of the total amount of biomass selected per animal. LSmeans and standard error of the mean (SEM) are displayed.

Family/species	Dry season			
	Criollo	Cross	SEM	*P*
n	12	10		
Bromeliaceae[1]	41.0	57.1	5.28	0.036
Leaf litter	22.9	0.3	3.52	<0.001
Poaceae	2.3	16.9	1.76	<0.001
Panicum trichoides	0.7	5.2	0.98	0.005
Setaria sp.	0.4	3.5	0.56	<0.001
Cynodon dactylon	0	2.9	1.24	0.047
Lasiacis sorghoidea	1.2	1.5	0.48	0.421
Acanthaceae	10.4	5.2	1.51	0.019
Justicia goudotii	8.4	4.6	1.16	0.025
Parmeliaceae[2]	6.3	9.1	1.65	0.222
Capparaceae	3.2	4.4	1.19	0.356
Capparis tweedieana	0.9	2.9	1.00	0.073
Cannabaceae[3]	5.0	0.2	0.63	<0.001
Fabaceae	0.7	2.9	0.57	0.004
Sapindaceae	1.7	0.5	0.43	0.105
Malvaceae	1.2	0.7	1.02	0.313

Family/species	Transition period			
	Criollo	Cross	SEM	*P*
	11	11		
Fabaceae	33.0	17.4	6.45	0.104
Prosopis alba	30.7	12.4	6.35	0.156
undefined Fabaceae	2.2	4.6	1.72	0.351
Bromeliaceae[1]	16.1	16.9	7.13	0.518
Poaceae	9.4	15.8	2.88	0.131
Cynodon dactylon	1.3	7.0	2.48	0.404
Panicum trichoides	2.3	2.8	1.02	0.686
Amaranthaceae	7.3	15.2	4.86	0.542
Guilleminea densa	6.8	15.2	4.78	0.397
Simaroubaceae[4]	1.7	10.4	3.28	0.098
Capparaceae	4.8	2.3	1.64	0.973
Capparis speciosa	4.5	0.6	1.57	0.496
Leaf litter	6.0	0.8	1.97	0.197
Verbenaceae[5]	5.6	0.05	2.55	0.060
Acanthaceae	2.5	2.5	1.02	0.605
Anemiaceae	3.4	0.6	0.99	0.097

Family/species	Rainy season			
	Criollo	Cross	SEM	*P*
	9	11		
Poaceae	12.2	28.2	4.27	0.012
Cynodon dactylon	5.1	9.5	3.46	0.368
Acanthaceae[6]	10.8	15.5	2.50	0.182
Cannabaceae[3]	20.7	2.7	2.29	<0.001
Malpighiaceae[7]	9.7	10.4	1.68	0.740
Verbenaceae[8]	9.8	10.1	3.62	0.754
Bromeliaceae[1]	10.0	9.0	4.86	0.688
Euphorbiaceae[9]	6.5	4.3	2.01	0.480
Amaranthaceae	4.4	5.9	2.74	0.688
Guilleminea densa	4.2	5.9	2.69	0.688
Rubiaceae[10]	6.9	3.0	2.14	0.262
Anemiaceae[11, 12]	3.8	5.3	1.75	0.661

[1] *Tillandsia vernicosa*,
[2] *Usnea* spp,
[3] *Celtis* spp,
[4] *Castela coccinea*,
[5] mainly *Lantana fucata*,
[6] mainly *Justicia goudotii*,
[7] *Aspicarpa sericea*,
[8] *Priva boliviana*,
[9] *Acalypha lycioides*,
[10] *Coutarea hexandra*,
[11] *Anemia tomentosa* var. *anthriscifolia* as the only species from this family, respectively.
[12] Ranked 11 but displayed here as species rank 10 was represented by nondefined Poaceae.

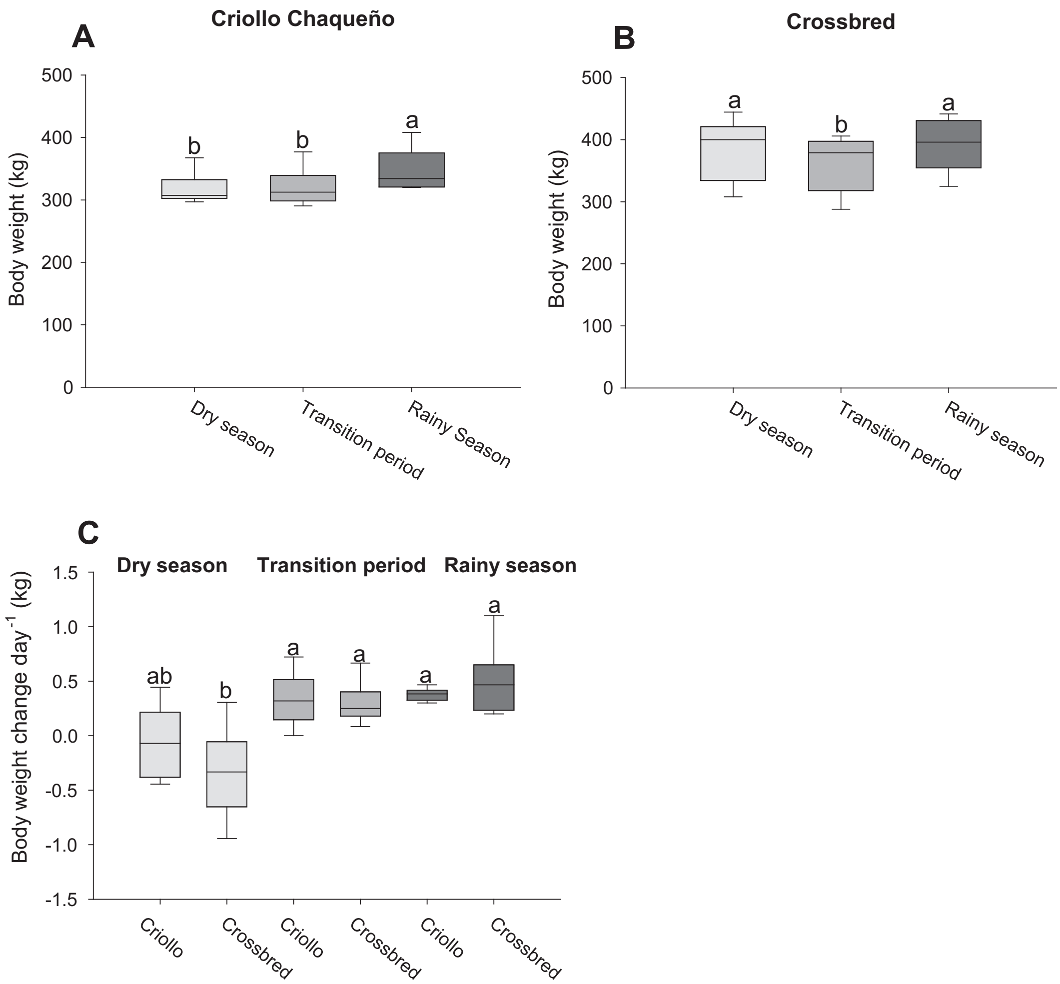

Figure 1. Body weight (mean of the initial and final body weight per season) of (**A**), Criollo Chaqueño and (**B**), crossbreds. Only animals that were not calving during the experiment were used, resulting in $n = 6$ and $n = 9$ for the Criollos and crossbreds, respectively. Season (S): $P < 0.001$ for both genotypes. **C**), Body weight change per d (kg) of Criollo Chaqueño (Criollo) and crossbreds during the observation period in three seasons (Genotype [G]: $P = 0.34$; S: $P < 0.001$; G × S: $P = 0.24$). Criollo: $n = 6$, crossbreds: $n = 9$. a–b indicate LSmeans carrying different superscripts within the graph are different at $P < 0.05$.

kept in natural forested rangelands include considerable proportions of browse in their diet, especially during unfavorable seasons (Marquardt et al., 2010). In the present study, Criollos overall selected more woody plants compared with the crossbreds. Criollos also made more use of widely available forage resources, such as leaf litter in the DS (23% leaf litter in the diet), than the crossbreds that almost entirely neglected this resource. Leaf litter selection during the DS also has been observed elsewhere (Pfister and Malechek, 1986; Marquardt et al., 2010). Although plant cover of grasses was low, grasses made up about 17% (DS and TP) and almost 30% (RS) of the diet selection of the crossbreds. In contrast, the proportional grass selection of the Criollos was not significantly different between seasons and did not exceed one-eighth of the total diet selection per season. These examples seem to demonstrate a more selective foraging behavior of crossbreds, while the Criollos showed a more pragmatic and less selective foraging behavior by using the resources available. However, a common pattern in both genotypes was that only a relatively small number of key species made up the largest part of diet selection. *Justicia goudotii* (Acanthaceae) and *Tillandsia vernicosa* (Bromeliaceae) appeared within the group of the 10 most selected plant species in all three seasons and both genotypes. The contributions of the 15 most important plant species made up 85% to 99% of the diet selection in each season and genotype. This is consistent with other studies of forest ecosystems in Bolivia; although cattle were found to feed on a broad variety of different plant species, only a small number of plant species made up the largest part of the diet composition (Marquardt et al., 2010).

Differences in experience with the vegetation on offer might lead to differences in diet selection (Ganskopp and Cruz, 1999). However, as the two genotypes were reared in a similar type of vegetation, and differences in diet selection between the genotypes were also present in RS (about 6 mo after the experiment started), experience is not assumed to have played a large role in the differences found in the diet selection.

The performance measurements support our hypothesis that the local Criollo Chaqueño are better adapted to the Chaco dry forests than crossbreds, especially during the DS. Between 19 September (the final body weight measurement during the DS) and 22 October (the initial body weight measurement in the TP), the average weight loss of the Criollos was small (2 ± 7.4 kg; half of the animals lost weight, and the other half gained weight), while the crossbreds lost, on average, 20 ± 12.5 kg (all animals lost weight), data not shown in Figure 1.

Implications

The present results give an initial indication of better adaptation by the purebred Criollo Chaqueño to the conditions of the dry forest ecosystem at this study site compared with crossbreds, especially during the DS. Local Criollo Chaqueño seemed able to cope better with the limited forage on offer during the DS and were less prone to deterioration of performance compared with crossbreds with exotic breeds. This would make the Criollo cattle especially valuable for smallholder livestock keepers with limited economic resources for feeding supplements during critical periods, and a viable option for sustainable production of meat without the need to convert forests into pastureland. However, more research is needed to confirm this assumption by including additional performance parameters such as reproductive rates. As this is a case study, which used a relatively small number of animals as experimental units, the results apply only to this study site and cannot be generalized to other regions. Supplementary data for this article are available online at https://doi.org/10.1016/j.rama.2018.06.002.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.rama.2018.06.002.

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