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Are winter rangelands enough to satisfy the nutritional requirements of late-gestation transhumant goats in Patagonia?

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Abstract

Transhumant herds graze across two different rangeland types according to the season. Winter rangelands differ from summer rangelands in the amount and quality of available fodder, with the former being the less productive. In cold areas, winter rangeland has low forage quality where goats may suffer severe nutritional restrictions during gestation which lead to significant reproductive losses in the form of abortions and perinatal losses. In Argentinian northern Patagonia, the transhumant Criollo goat is a dual-purpose breed, producing both meat and cashmere and grazing on winter rangelands where they complete their reproductive cycle. Our objective was to evaluate to what extent the winter rangelands of northern Argentine Patagonia satisfy the nutritional requirements needed by Criollo transhumant goats during late gestating. We evaluated a study between 2010 and 2012 where we analysed the body weight and body condition score of the goats reaching the winter rangelands and before kidding. We also analysed the botanical composition of their diet, the quality forage (metabolizable energy, crude protein and digestibility) contribution offered by the species and the proportions of the nutritional requirements of the goats during the last third of gestation. Significantly, we found a decrease in body weight and body condition score in late gestation. In 2010, the goats' diet showed a nutritional deficiency value of 0.6 Mcal/day metabolizable energy and 30.43 g/day crude protein; in 2011, a deficiency of 0.77 Mcal/day metabolizable energy and 65.48 g/day crude protein; and in 2012, a deficiency of 0.75 Mcal/day metabolizable energy and 55.41 g/day crude protein. Forage present 51, 52 and 48% digestibility in each year, respectively. We conclude that forage quality in winter rangelands in Argentinean Patagonia is not high enough to satisfy the nutritional requirements of Criollo transhumant goats during the last third of gestation. We recommend 550 g/day of an 80:20 mixture of corn:soy expeller supplementation during late gestation.

Keywords: Digestibility, Energy, Crude protein, Grazing, Criollo, Argentina

Introduction

The Criollo goat is a dual-purpose breed, producing both meat and cashmere, and is found mainly in northern Patagonia, Argentina. In this area, there are approximately 450,000 Criollo goats, typically managed in small flocks within transhumant low-input production systems (Lanari et al. 2005, 2009) where this local breed is highly adapted to the harsh environment (Lanari et al. 2004; Easdale et al. 2020; Perez Leon et al. 2020). The main products of these systems are meat for self-consumption and the sale of young animals to local markets (Zimerman et al. 2008), while fibre extraction (cashmere) is an incipient innovation (Easdale and Aguiar 2018).

Herds graze and breed across two different rangeland types according to the season: shrub steppes during the winter (750–1400 m.a.s.l.) and grass steppes during the

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summer (1500–2000 m.a.s.l.). Winter rangelands differ from summer rangelands in the amount and quality of available fodder, with the former being the less productive (Villagra et al. 2013; Hendrickson and Moffet 2020; Baranova et al. 2019). Nevertheless, these winter rangelands are critical to the reproductive cycle of Criollo goats (Lanari et al. 2005, 2009; Villagra et al. 2015). In such cold areas, low forage quality rather than quantity is a limiting factor (Hendrickson and Moffet 2020), and animals are subject to sudden environmental changes which may affect their reproductive performance (Fielding 1985; Bøe and Ehrlenbruch 2013; Joy et al. 2020). Poor reproductive performance is one of the major factors influencing the efficiency of goat production and is considered a principal limiting factor in achieving optimal production systems (Mokhtari et al. 2019). In arid areas under extensive conditions, goats may suffer severe nutritional restrictions during gestation which lead to significant reproductive losses in the form of abortions and perinatal losses (Mellado et al. 2014). A shortage of energy or protein during pregnancy causes toxaemia, ketosis or foetal development compromise, especially towards the end of pregnancy when the foetal growth rate is highest (Rook 2000; Dore et al. 2015, Dunlap et al. 2015; Herring et al. 2018). Energy is the main limiting factor in animal production, and its availability affects the animal's adaptation to its environment, as well as behaviour and feeding strategy (Mellado 2016; Lachica and Aguilera 2005). Throughout the phases of their reproductive cycle, goats choose a feeding pattern in response to seasonal variations in forage quality (Mellado 2016; Egea et al. 2014). These diets differ in terms of parts of plants, plant species, forage digestibility and nutrient concentration. The evaluation of these variables is useful for determining whether the goats' nutritional requirements are met (Egea et al. 2014). Subsequently, if supplementary food is necessary, innovative management strategies should be proposed to address this nutritional deficit (Egea et al. 2019).

There are previous studies on the diet selection of free-ranging Criollo goats in the Argentinian Monte Desert (Allegretti et al. 2012; Egea et al. 2019), as well as of goats, sheep and cattle in the Patagonian steppe (Villagra et al. 2013), that aimed to determine the botanical composition of their diets. A rapid increase in body weight is expected during the last third of gestation. However, when goats select a diet that does not meet their gestational nutritional requirements, a decrease in body weight is observed, accompanied by poor body condition, resulting in foetal losses (Mellado 2016; Villagra et al. 2015).

This study aims to evaluate to what extent the winter rangelands of northern Argentine Patagonia satisfy the nutritional requirements needed by Criollo transhumant goats during late gestating according to the National Research Council's Committee on the Nutrient Requirements of Small Ruminants (NRC, 2007). Furthermore, the evolution of the weight and body condition of the goats will be studied as indicators of their nutritional status to determine the composition, digestibility, metabolizable energy and crude protein in winter rangeland. Finally, if necessary, the amount of supplemental energy and protein needed to meet the nutritional requirements of the goats in the last third of gestation will be established.

The results of this study will contribute to the generation of management recommendations towards a reduction in the productive losses of grazing goats in arid winter rangelands.

Study area

The study area is located in Neuquén province, northern Patagonia, Argentina (Fig. 1). Winter rangelands are located at 1045 m.a.s.l. (37° 30′ 53″ S and 70° 02′ 06″ W; Fig. 1). The average annual rainfall in the region is less than 200 mm, and the average annual temperature is between 13 and 14 °C. The vegetation corresponds to the Monte phytogeographic province, and the predominant physiognomy is the medium shrub-steppe (shrubs 1 to 2 m high), representing 20 to 40% of vegetation cover. The main floristic components are *Larrea divaricata* (jarilla hembra), *Larrea cuneifolia* (jarilla macho), *Atriplex lampa* (zampa), *Prosopis alpataco* (alpataco) and *Schinus polygamus* (molle). The most common undershrub species are *Acantholippia seriphioides* (falso tomillo), *Hyalis argentea* (olivillo) and *Pappostipa speciosa* (coiron amargo). A wide ecotone is included within the Patagonian province, where the most common species are *Larrea nitida*, *Schinus polygamus* and *Pappostipa speciosa*.

Materials and methods

Management practices

A flock of 230 Criollo goats belonging to a household located in the study area was studied between June 2009 and June 2012. There were no modifications to the farmer's typical management, which was similar to that performed by many smallholders in the region (Lanari et al. 2004, Villagra et al. 2015, Easdale and Aguiar 2018). The pastures were not fenced, and goats grazed freely without nocturnal enclosure. Throughout the year, no forage, concentrate or mineral supplements were fed to the goats. Management consisted of daily rounds to prevent the goats from leaving the grazing area and to prevent neighbouring herds from entering. The stocking rate for the winter range was 4.51 ha/SLU (sheep livestock unit; Villagra et al. 2015). Water was available from waterholes. Female goats met Criollo males upon arrival to the winter pastures (3% males) from early April to early June

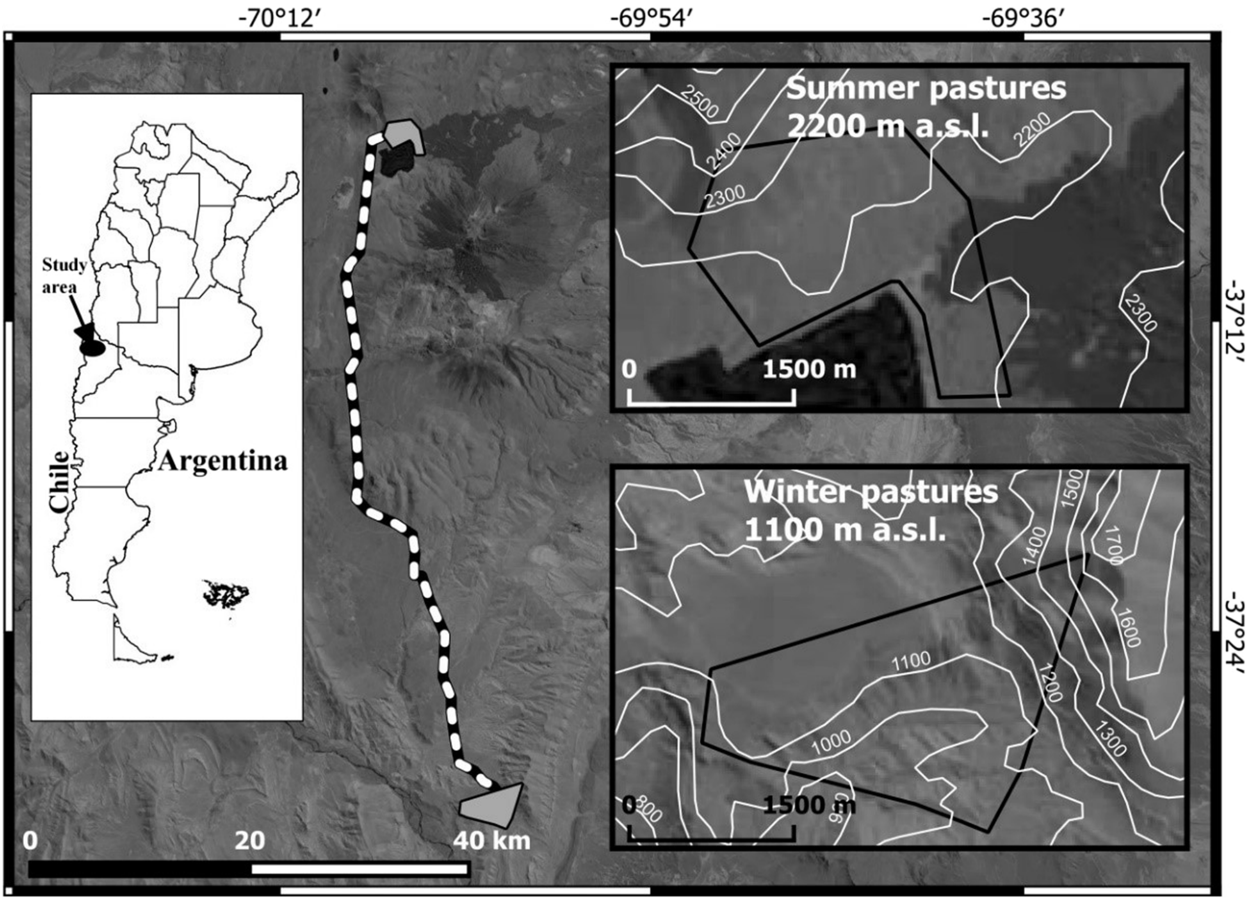

Fig. 1 Study area: Argentina (left); trans-human movement of goats (centre) and grazing areas (right)

(8 weeks). After the breeding season, males were separated until the next breeding season. Kidding took place between September 10th and November 10th each year.

Animal data collection: body weight (BW) and body condition score (BCS)

All animals were weighed, and BCS was evaluated both when they arrived at the winter rangelands and 1 month before the start of kidding (pre-kidding) to check if there were gains or losses of BW and assess the changes in BCS over the winter. Goats were identified with numbered tags when the study started. In order to carry out weighing, goats were enclosed in small paddocks in the afternoon and then weighed the following morning to ensure 12 h of fasting. An electronic scale (Balcopan inc.) with 0.1 kg accuracy was used. For BCS estimation, the 0 to 5 scale proposed by Jefferies (1961) was used. Only pregnant females were evaluated; the diagnosis was made via transrectal ultrasound with a 5-MHz linear array transducer (Honda HS-101V, Japan).

Diet composition estimation

Faecal samples were collected during weighing in order to estimate botanical diet composition. During July 2010, 2011 and 2012, 15 adult pregnant goats were randomly selected each year. From each goat, 10 faecal pellets were collected from the rectum to form a composite sample of 150 pellets. Faecal samples were treated following the procedure described by Sparks and Malechek (1968) and Williams (1969) modified by Latour and Pelliza Sbriller (1981), and microhistologically analysed according to Sparks and Malechek (1968), Holechek and Vavra (1981) and Holechek et al. (1982). Epidermal fragments (Sparks and Malechek 1968) and non-epidermal fragments (Sepúlveda Palma et al. 2004) were identified at the level of genus and species whenever possible. For each sample, the relative frequency (%) of forage items identified was determined according to Holechek and Gross (1982). Through these methods, the proportion of each forage species in the goats' diet was estimated. Fragments were identified by comparing the items with the reference collection of epidermal tissues of Patagonian plants available at the Laboratory of Microhistology in the INTA Bariloche Experimental Station.

Forage quality and minimum requirements

The forage quality of the species identified in the diet of the goats, specifically metabolizable energy (ME: Mcal/kg of dry matter), crude protein (CP: %) and digestible dry-matter (digestibility: %), was based on previous studies by Somlo et al. (1997), Somlo (1992), Caballero and Fritz (2013) and Barría et al. (2017) (Table 1). The methodology for determining plant quality reported by the authors was as follows: On samples previously dried in an oven at 60 °C and ground in a Willey mill through a 1-mm sieve, the following laboratory determinations were made: dry matter and organic matter according to Van Soest (1967), dry matter digestibility (D%) according to Van Soest (1969) and crude protein (CP) according to AOAC (2007). Digestible energy (DE) was calculated by means of equations according to Moir (1961) and metabolizable energy (ME) according to NRC (2007). We estimated the ME, CP and digestibility of the winter rangeland each year as the sum of the contributions of each forage species weighted by its proportion in the diet (Table 2). In order to calculate the requirements of ME (Mcal/day of dry matter) and CP (g/day of dry matter) for Criollo goats in this stage of gestation, the assumption was that goats' intake was 2.9% of BW (National Research Council, Committee on the Nutrient Requirements of Small Ruminants, Board on Agriculture, Division on Earth,, and Life Studies 2007) (Table 5). To estimate the quality of possible supplements to be used by the goats in the last third of gestation, samples (200 g) of alfalfa, corn grain and soybean expellers were taken from local stores and stored at − 20 °C. These samples were pooled and sub-sampled for chemical composition analysis. The feed samples were analysed by the Forage and Feed Quality Laboratory INTA EEA Bordenave. Dry matter (DM) % was determined in a forced air oven at 105 °C until a constant weight was reached); crude protein (CP) was determined by the Kjeldahl method (AOAC, 2007), metabolizable energy (ME) according to NRC (2007) and dry matter digestibility (D%) according to Van Soest (1969).

Table 1 Forage quality: metabolizable energy, crude protein and digestible dry matter of forage calculated from the diet botanical composition of pregnant goats

	ME, Mcal/kg DM	CP, g/kg DM	Digestibility, %
Grasses			
Alopecurus sp.	1.93	91	53.92
Bromus sp.	2.35	152	65.40
Distichlis sp.	1.62	27	44.80
Panicum sp.	1.93	91	53.92
Poa sp.	2.34	80	64.70
Rytidosperma sp.	2.36	152	65.40
Sporobolus sp.	1.16	57	34.00
Pappostipa sp.	1.73	81	49.20
Trisetum sp.	1.93	91	53.92
Shrubby			
Acantholippia sp.	1.53	65	43.70
Adesmia campestris	2.35	82	65.20
Anarthrophyllum sp.	1.59	107	44.00
Atriplex sp.	2.17	175	60.00
Chuquiraga sp.	1.45	64	40.10
Cyclolepis sp.	1.71	47	48.50
Discaria nana	1.67	90	48.11
Ephedra sp.	1.53	49	42.40
Hyalis argentea	2.20	68	61.60
Junellia sp.[a]	1.89	109	52.40
Larrea sp.	2.13	171	59.70
Maihuenia sp.	1.09	16	30.10
Azorella prolífera	1.47	37	40.60
Nardophyllum sp.[b]	1.77	45	49.00
Nassauvia sp.	1.06	47	29.50
Prosopidastrum sp.	1.50	117	42.90
Prosopis denudans	1.34	108	38.90
Schinus sp.	1.61	83	45.80
Senecio sp.	1.67	234	71.50
Forbs			
Acaena sp.	1.93	59	53.50
Cerastium sp.	2.09	109	57.97
Erodium cicutarium	2.31	162	64.00
Perezia sp.	2.04	66	56.40
Rumex sp.	2.09	210	57.97

[a] Caballero and Fritz 2013

[b] Barría et al. 2017

Statistical analysis

Goats were grouped according to their teeth chronology: (a) adult, goats with four, six or eight permanent incisor teeth or "full mouth", and (b) old, goats with half or all of their permanent incisor teeth worn. BW and BCS of adult and old goats upon arrival to the winter rangelands and 1 month before the start of kidding (pre-kidding) were analysed with a year factorial model for 2010, 2011 and 2012. This analysis covered the period from April to June, determining the average daily gain (ADG) during this time. The results are averages of BW and BCS with the standard errors and the number of goats involved (Table 3). The software used for statistical analysis was Infostat (Di Rienzo et al. 2011).

Table 2 Botanical composition of the goats' diet and the proportion of relative frequency of each forage item. Metabolizable energy, protein content and digestibility in 2010, 2011 and 2012 winter

Species in diet	2010				2011				2012			
	Relative frequency of each forage item, %	ME, Mcal/kg DM	CP, %	Digestibility, %	Relative frequency of each forage item, %	ME, Mcal/kg DM	CP, %	Digestibility, %	Relative frequency of each forage item, %	ME, Mcal/kg DM	CP, %	Digestibility, %
Grasses												
Alopecurus sp.	0	0	0	0	4.39	0.08	0.40	2.37	0	0	0	0
Bromus sp.	1.42	0.03	0.22	0.93	2.70	0.06	0.41	1.77	0	0	0	0
Distichlis sp.	0	0	0	0	1.01	0.02	0.03	0.45	0	0	0	0
Panicum sp.	1.07	0.02	0.10	0.58	0	0	0	0	0	0	0	0
Poa sp.	6.41	0.15	0.51	4.15	20.61	0.48	1.65	13.33	5.92	0.14	0.47	3.83
Rytidosperma sp.	3.91	0.09	0.59	2.56	0.68	0.02	0.10	0.44	0.70	0.02	0.11	0.46
Sporobolus sp.	0	0	0	0	0	0	0	0	2.44	0.03	0.14	0.83
Pappostipa sp.	20.64	0.36	1.67	10.15	31.42	0.54	2.55	15.46	32.75	0.57	2.65	16.11
Trisetum sp.	0	0	0	0	3.04	0.06	0.28	1.64	0	0	0	0
Total grasses	***33.45***	***0.65***	***3.09***	***18.36***	***63.85***	***1.26***	***5.41***	***35.46***	***41.81***	***0.75***	***3.37***	***21.23***
Shrubs												
Acantholippia sp.	3.20	0.05	0.21	1.40	0	0	0	0	0.70	0.01	0.05	0.31
Adesmia campestris	0	0	0	0	1.69	0.04	0.14	1.10	0	0	0	0
Anarthrophyllum sp.	0	0	0	0	0.34	0.01	0.04	0.15	0	0	0	0
Atriplex sp.	16.73	0.36	2.93	10.04	0	0	0	0	0	0	0	0
Chuquiraga sp.	20.64	0.30	1.32	8.28	2.70	0.04	0.17	1.08	22.30	0.32	1.43	8.94
Cyclolepis sp.	1.42	0.02	0.07	0.69	0	0	0	0	0	0	0	0
Discaria nana	1.78	0.03	0.16	0.86	0	0	0	0	0	0	0	0
Ephedra sp.	3.56	0.05	0.17	1.51	13.18	0.20	0.65	5.59	3.48	0.05	0.17	1.48
Hyalis argentea	2.49	0.05	0.17	1.53	1.69	0.04	0.11	1.04	5.23	0.12	0.36	3.22
Junellia sp. *A*	0	0	0	0	1.69	0.03	0.19	0.89	0	0	0	0
Larrea sp.	6.76	0.14	1.16	4.04	1.01	0.02	0.17	0.60	9.76	0.21	1.67	5.83
Maihuenia sp.	0	0	0	0	0	0	0	0	4.53	0.05	0.07	1.36

Table 2 (continued)

Species in diet	2010				2011				2012			
	Relative frequency of each forage item, %	**ME, Mcal/kg DM**	**CP, %**	**Digestibility, %**	**Relative frequency of each forage item, %**	**ME, Mcal/kg DM**	**CP, %**	**Digestibility, %**	**Relative frequency of each forage item, %**	**ME, Mcal/kg DM**	**CP, %**	**Digestibility, %**
Azorella prolifera	0.36	0.01	0.01	0.15	0	0	0	0	0	0	0.	0
Nardophyllum sp. *B*	0	0	0	0	0	0	0	0	1.05	0.02	0.05	0.51
Nassauvia sp.	1.42	0.02	0.07	0.42	0	0	0	0	0.35	0	0.02	0.10
Prosopidastrum sp.	0	0	0	0	0	0	0	0	2.79	0.04	0.33	1.20
Prosopis denudans	0	0	0	0	1.35	0.02	0.15	0.53	0	0	0	0
Schinus sp.	7.83	0.13	0.65	3.59	11.15	0.18	0.93	5.11	7.32	0.12	0.61	3.35
Senecio sp	0	0	0	0	0.34	0.01	0.08	0.24	0	0	0	0
Total shrubs	***66.19***	***1.16***	***6.91***	***32.49***	***35.14***	***0.58***	***2.62***	***16.33***	***57.51***	***0.94***	***4.74***	***26.30***
Forbs												
Acaena sp.	0	0	0	0	0	0	0	0	0.35	0.01	0.02	0.19
Cerastium sp.	0	0	0	0	0.34	0.01	0.04	0.20	0	0	0	0
Erodium cicutarium	0	0	0	0	0.68	0.02	0.11	0.44	0	0	0	0
Perezia sp.	0.36	0.01	0.02	0.20	0	0	0	0	0	0	0	0
Rumex sp.	0	0	0	0	0	0	0	0	0.35	0.01	0.07	0.20
Total forbs	***0.36***	***0.01***	***0.02***	***0.20***	***1.02***	***0.02***	***0.15***	***0.63***	***0.70***	***0.01***	***0.09***	***0.39***
Total	**100.00**	**1.82**	**10.03**	**51.06**	**100.01**	**1.87**	**8.18**	**52.42**	**100.02**	**1.70**	**8.20**	**47.92**

Results

Body weight (BW) and body condition score (BCS)

For the 3 years evaluated, body weight losses were observed in pregnant goats between their arrival to the winter rangelands, which coincided with the start of mating, and pre-kidding. However, there were differences in BW loss depending on the year. The highest BW loss for adult and old goats was observed in 2010, with the lowest average pre-kidding BW values recorded at this time (Table 3). In 2011, the loss of BW in adult and old goats was relatively low. During the winter of 2012, the loss of BW was intermediate.

Changes in BCS were also observed (Table 4). In all cases, there was a decrease in both BW and BCS, affecting the general condition of the animals.

Table 3 Average body weight and average daily gain of goats at arrival to the winter rangelands and at pre-kidding

Winter rangeland		ABW (kg) at arrival	ABW (kg) at pre-kidding	ADG (g) between arrival and pre-kidding
2010	**Adult**	41.1 (0.5)	32.9 (0.8)	− 62.8 (5.4)
		n = *93*	*n* = *40*	*n* = *40*
	Old	40.8 (0.5)	33.2 (1.3)	− 59.3 (10.1)
		n = *64*	*n* = *10*	*n* = *10*
2011	**Adult**	36.0 (0.5)	34.0 (1.1)	− 2.2 (3.5)
		n = *74*	n = 17	*n* = *14*
	Old	39.1 (0.4)	38.7 (1.0)	− 8.4 (5.2)
		n = *122*	*n* = *29*	*n* = *28*
2012	**Adult**	41.1 (0.6)	38.3 (0.5)	− 30.1 (2.2)
		n = *88*	*n* = *87*	*n* = *79*
	Old	41.8 (0.6)	38.4 (0.5)	− 41.9 (2.9)
		n = *67*	*n* = *59*	*n* = *55*

The number of evaluated goats is in italics. The standard error of the mean is between the brackets.

ABW average body weight, *ADG* average daily gain

Botanical composition of the goats' diet

The botanical composition of the goats' diet and the proportion of food items ingested during the 3 years of the study were determined. Food items were grouped into three forage classes: grasses (Poaceae), shrubs and forbs. Pregnant goats showed differences in the botanical composition of their diets among the years.

The diets of goats in 2010 and 2012 were mainly composed of shrubs (66.19% and 57.51%, respectively), while grasses contributed 33.45% and 41.81% of the winter diet, respectively. However, in 2011, the proportion of these plants changed with grasses contributing 63.85% and shrubs 35.14%. Forbs always represented less than 1% of the winter diet.

The greatest contribution of ME and CP was provided by shrubs during the winters of 2010 and 2012, while the greatest source of ME and CP in 2011 came from the grasses. Predictably, the contribution of ME and CP by forbs was negligible.

The calculated average digestibility was low: 51.06%, 52.4% and 47.92% for 2010, 2011 and 2012, respectively.

Table 4 Average body condition score of goats at arrival to the winter rangelands and at pre-kidding and the average of the differences between them

Winter rangeland		BCS at arrival	BCS at pre-kidding	Difference in BCS between arrival and pre-kidding
2010 (216 days)	**Adult**	2.65 (0.03)	1.23 (0.05)	− 1.49 (0.06)
		n = *93*	*n* = *40*	*n* = *40*
	Old	2.43 (0.05)	1.20 (0.13)	− 1.48 (0.15)
		n = *64*	*n* = *10*	*n* = *10*
2011 (205 days)	**Adult**	2.88 (0.03)	2.76 (0.05)	− 0.09 (0.07)
		n = *74*	*n* = *17*	*n* = *14*
	Old	2.42 (0.04)	2.24 (0.08)	− 0.25 (0.06)
		n = *122*	*n* = *29*	*n* = *28*
2012 (90 days before kidding)	**Adult**	2.85 (0.02)	2.24 (0.04)	− 0.59 (0.03)
		n = *88*	*n* = *87*	*n* = *79*
	Old	2.70 (0.03)	2.00 (0.05)	− 0.67 (0.05)
		n = *67*	*n* = *59*	*n* = *55*

The number of goats evaluated is in italics. The standard error of the mean is between the brackets

BCS average body condition score

Discussion

Goats' requirements were calculated based on the average body weight (40 kg) of adult and old goats each year at the beginning of the breeding season (arrival at the winter rangelands; Table 5). According to National Research Council, Committee on the Nutrient Requirements of Small Ruminants, Board on Agriculture, Division on Earth,, and Life Studies (2007), a 40-kg non-dairy goat during the last third of gestation needs a minimum of 2.77 Mcal/day of ME and 153 g/day of CP. To meet these requirements, the goats would need to ingest 2.9% of their body weight through a diet with an average digestibility of 66% that provides 2.39 Mcal/kg of ME and 13% of CP (National Research Council, Committee on the Nutrient Requirements of Small Ruminants, Board on Agriculture, Division on Earth,, and Life Studies 2007) (Table 5).

In 2010, the winter rangeland provided 1.82 Mcal/kg of ME and 10.3% of CP, with 51.06% digestibility. According to intake capacity and digestibility, the diet selected by the goats during the winter was inadequate when considering their minimum requirements. The goats suffered a deficiency of 0.60 Mcal/day of ME and 30 g/day of CP in fulfilling their gestational dietary requirements with forage of 51.06% of digestibility (Table 5).

In 2011, winter rangelands provided 1.87 Mcal/kg ME and 8.18% of CP, with a digestibility of 52.42%, and were not able to meet the minimum requirements of a pregnant goat. Goats suffered a dietary deficiency of 0.77 Mcal/day of ME and 65.5 g/day of CP (Table 5).

In 2012, winter rangelands provided 1.70 Mcal/kg ME and 8.2% of CP, with a digestibility of 47.9%, and, once again, were not able to meet the minimum requirements of a pregnant goat. Goats suffered a dietary deficiency of 0.75 Mcal/day of ME and 55.4 g/day of CP (Table 5).

However, goats are not able to eat the volume that our calculations would require due to their limited rumen size during the advanced stages of gestation.

Given the deficiency of ME and CP in the available forage of the winter rangelands, we calculated the necessary supplementation. In this area, farmers usually supplement with 500 g of concentrates that are available in the local market. Table 6 shows the results for different food concentrates and their ability to satisfy the nutritional requirements of pregnant goats.

According to the data (Table 6), 500 g of any available concentrate in northern Neuquén is not enough. Nonetheless, a supplement of just 550 g/day concentrate based on a mixture of corn and soy expeller (80:20 ratio) might be enough to achieve the ME and CP requirements of pregnant goats. The contribution in gr. of crude protein and the amount of Mcal of ME provided by the soybean and corn concentrate supplement added to 610 g of pasture intake would meet the nutritional requirements of the goats with an intake of 1.16 kg of DM, which is the maximum allowed according to the National Research Council, Committee on the Nutrient Requirements of Small Ruminants, Board on Agriculture, Division on Earth,, and Life Studies (2007).

One of the most important factors affecting the nutrition and performance of goats is the available rangeland

Table 5 Characteristics of the nutritional contribution of winter rangeland and requirement achieve in goats

Year	Winter rangeland forage contibution			achieve in goats			
	ME (Mcal/kg)	CP (%)	Digestibility (%)	Average body weight (kg)	Capacity intake of rangeland[a] (kg)	ME (Mcal/day)	PC (g/day)
2010	*1.82*	*10.30*	*51.06*	*41*	*1.19*	*2.17*	*122.57*
2011	*1.87*	*8.18*	*52.42*	*37*	*1.07*	*2*	*87.52*
2012	*1.70*	*8.20*	*47.90*	*41*	*1.19*	*2.02*	*97.59*

NRC requirements goats: 2.77 Mcal/d ME; 153 g/day CP

NRC concentration in diet: 2.39 Mcal/Kg ME; 13% PC; 66% digestibility

[a] Intake: 2.9% BW (1.16 kg DM)

Table 6 Contribution of the different concentrates and their possibility to meet the nutritional requirements of pregnant goats

	Dry matter (kg/day)	CP (g)	ME (Mcal)	Composition of supplement	Nutritional requirements achieve
Pelleted alfalfa hay:corn (55:45)	0.5	*73*	*1.14*	Pelleted alfalfa hay:corn (55:45)	*No*
Brewers' spent grain:corn	0.7	100	1.53	Brewers' spent grain:corn (55:45)	*No*
Corn:soybean expeller	**0.55**	**148**	**1.98**	**Corn:soybean exp. (80:20)**	**Yes**

forage quality. Low crude protein and low energy are related to a high-fibre concentration and consequently low digestibility (Gudmundsson 2001). Our results showed that forage species had low to intermediate ME, CP and digestibility, as cited by other authors (Egea et al. 2019).

Our study involved pregnant goats in the last third of gestation. Taking into account ruminal capacity, the selected diet from rangeland plants failed to satisfy the minimum nutritional requirements determined by the NRC: 13% CP and 2.39 Mcal/kg ME with 66% of dry matter digestibility. On average, the winter rangeland contributed just 8.8% CP and 1.80 Mcal/kg of ME with 51% of digestibility.

Late-stage gestation causes a low ruminal capacity that directly affects the amount of dry matter intake, and, as a consequence, ME and CP intake in the diet are often below the requirements (Wang et al. 1997; Assouma et al. 2018; Chebli et al. 2020; Hendrickson and Moffet 2020; Mellado 2016). CP levels in rangeland forage were between 8 and 10%, not enough to produce the recycling of nitrogen and to meet the requirements of rumen microbes. This results in a decrease in forage digestibility and dry matter intake (Van Soest 1967; 1969). Due to this process, significant weight losses are observed in goats, even at advanced gestation (Table 3). This results in an important loss of fat reserves, evidenced in the loss of BCS (Table 4).

The analysis of goats' diet across several years supports the importance of opportunistic feeding behaviour for these animals, rather than being constrained to a specific feeding type, that is a typical browser or grazer (Egea et al. 2019). We found large differences in the botanical composition of their diets among the years. The percentage of grasses in 2011 was almost twice that found in 2010, while the percentage of shrubs decreased proportionally (Table 2); Chebli et al. (2020) and Mellado (2016) found similar results. However, the ME intake was similar among the years, and protein intake was only slightly higher in 2010 (Table 5). The analysis of the botanical composition of diets shows the ability of goats to cope with the changing conditions of the environment, demonstrating their great adaptive capacity and rusticity in the face of adversities (Allegretti et al. 2012). These results also support those obtained by Egea et al. (2019), who explored how goats modified their feeding behaviour in response to changes in their nutritional requirements (late gestation) and forage availability (i.e. winter).

In accordance with other authors, we observed that free grazing is the best option for enabling goats to choose food according to their energy and protein needs. They increase the CP in their diet at the end of pregnancy, performing adjustments that depend on available forage, but in this case, the rangeland forage quality failed to meet their minimum requirements (Allegretti et al. 2012). Characteristics of forage species significantly influence the voluntary intake of goats. This intake is directly related to dry matter and CP concentrations and mainly to digestibility (Rodríguez-Zamora and Elizondo-Salazar 2012) which affects the ruminal physical filling and causes a low year-round productivity of range livestock (Assouma et al. 2018). Based on these data, a strategic supplementation in late-stage pregnant goats is recommended, in order to develop their late gestation and subsequent lactation without losing weight.

Energy and/or protein deficiencies reduce foetal development during late gestation, the stage of highest foetal growth rate (Härter et al. 2016; Doré et al. 2015). The survival rate of offspring will also be impacted by low birth weight (Akingbade et al. 2002; Jockers et al. 2021). According to our results, kids' production and therefore farmers' profits may be seriously affected if actions are not taken to improve the nutrition of goats in the last third of gestation. Among the supplements considered, the minimum requirements of adult and old goats during the last third of gestation could be satisfied with 550 g DM per day of an 80% corn:20% soy expeller (Table 6). We believe that the results of this study raise the need for further and more in-depth studies on the quality of the diet consumed by pregnant goats. Also, future research should focus on more economical and environmentally friendly forms of dietary supplements than those currently used by farmers and evaluated in this work.

Conclusions

We conclude that in the arid areas of northern Neuquén in Argentina, forage quality in winter rangelands is not high enough to satisfy the nutritional requirements of Criollo goats during late gestation. This is a limitation that is reflected in the notable losses of BW and BCS and compromises the production of kids since mating, the last third of gestation and parturition all take place on these winter ranges. The low forage quality cannot be compensated with higher intake, since goats' rumen volume is smaller during the last third of gestation, limiting their intake capacity to only 2.9% of their BW (National Research Council, Committee on the Nutrient Requirements of Small Ruminants, Board on Agriculture, Division on Earth, and Life Studies 2007). According to our results and given the characteristics of the rangeland forage involved, the recommendation to satisfy the requirements of the goats during the last third of gestation is a supplementation of 550 g/day of a mixture of corn and soybean expeller in a ratio of 80:20 (16% CP and 3 Mcal EM/kg). This action would both improve the productivity of the herds and increase the income of the farmers.

Future studies should focus on describing more precisely the quality of the diet consumed by pregnant goats and testing more economical and environmentally friendly management to meet the requirements of pregnant goats.

Recommendations

According to our results and given the characteristics of the range forage involved, the recommendation to satisfy the requirements of the goats during the last third of gestation is a supplementation of 550 g/day of a mixture of corn and soybean expeller in a ratio of 80:20 (16% CP and 3 Mcal EM/kg). This action would both improve the productivity of the herds and increase the income of the farmers.

Abbreviations

ADG: Average daily gain; BSC: Body condition score; BW: Body weight; CP: Crude protein; DM: Dry matter; ME: Metabolizable energy; NRC: National Research Council's Committee.

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Authors' contributions

All authors have participated in the conception and design or analysis and interpretation of the data, drafting of the article or revising it critically for important intellectual content, and approval of the final version, and they agree with the content of the manuscript and submission in this journal.

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Availability of data and materials

The datasets used and/or analysed during the current study are available from the corresponding author on request.

Declarations

Ethics approval and consent to participate

Not applicable to this section.

Consent for publication

Not applicable to this section.

Competing interests

The authors declare that they have no competing interests.

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References

Akingbade, A.A., I.V. Nsahlai, D. Morris, and C., & Iji, P.A. 2002. Field activities and blood profile of pregnant south African indigenous goats after receiving dihydroxy pyridone-degrading rumen bacteria and grazing Leucaena leucocephala-grass or natural pastures. *Journal of Agricultural Science* 138 (1): 103. https://doi.org/10.1017/S0021859601001617.

Allegretti, L., C. Sartor, S.P. Lama, V. Egea, M. Fucili, and C. Passera. 2012. Effect of the physiological state of Criollo goats on the botanical composition of their diet in NE Mendoza, Argentina. *Small Ruminant Research* 103 (2-3): 152–157. https://doi.org/10.1016/j.smallrumres.2011.09.018.

Association of Official Analytical Chemists International (AOAC), Horwitz, W., and G.W. Latimer. 2007. *Official methods of analysis of AOAC International*. Gaithersburg: AOAC International.

Assouma, M.H., P. Lecomte, P. Hiernaux, A. Ickowicz, C. Corniaux, V. Decruyenaere, A.R. Diarra, and J. Vayssières. 2018. How to better account for livestock diversity and fodder seasonality in assessing the fodder intake of livestock grazing semi-arid sub-Saharan Africa rangelands. *Livestock Science* 216: 16–23. https://doi.org/10.1016/j.livsci.2018.07.002.

Baranova, A., J. Oldeland, S.L. Wang, and U. Schickhoff. 2019. Grazing impact on forage quality and macronutrient content of rangelands in Qilian Mountains, NW China. *Journal of Mountain Science* 16 (1): 43–53. https://doi.org/10.1007/s11629-018-5131-y.

Barría, M.E., M. Cretton, M.C. Gurin, M.E. Arce, E.J. Rost, and M. Mazzuca. 2017. Nutrient content of woody species in the Patagonian steppe, Argentina. *Bulletin of the Argentine Society of Botany* 52 (4): 663-674

Caballero, G.A., and M.A. Fritz. 2013. *Composición botánica y valor nutritivo de la dieta de cabras en un arbustal halófilo y un jarillal del oeste de la provincia de La Pampa* https://repo.unlpam.edu.ar/handle/unlpam/1439. Accessed 26 July 2022

Chebli, Y., S. El Otmani, M. Chentouf, J.L. Hornick, J. Bindelle, and J.F. Cabaraux. 2020. Foraging behavior of goats browsing in southern Mediterranean Forest rangeland. *Animals* 10 (2): 196. https://doi.org/10.3390/ani10020196.

Di Rienzo, J.A., F. Casanoves, M.G. Balzarini, L. González, M. Tablada, and Y.C. Robledo. 2011. *InfoStat versión 2011.* Argentina: Grupo InfoStat, FCA, Universidad Nacional de Córdoba. URL http://www.infostat.com.ar, Accessed 26 July 2022

Doré, V., J. Dubuc, A.M. Bélanger, and S. Buczinski. 2015. Definition of prepartum hyperketonemia in dairy goats. *Journal of Dairy Science*, 98(7): 4535-4543. https://doi.org/10.3168/jds.2014-9172.

Dunlap, K.A., J.D. Brown, A.B. Keith, and M.C. Satterfield. 2015. Factors controlling nutrient availability to the developing fetus in ruminants. *Journal of Animal Science and Biotechnology* 6 (1): 1–10. https://doi.org/10.1186/s40104-015-0012-5.

Easdale, M.H., and M.R. Aguiar. 2018. From traditional knowledge to novel adaptations of transhumant pastoralists the in face of new challenges in North Patagonia. *Journal of Rural Studies* 63: 65–73. https://doi.org/10.1016/j.jrurstud.2018.09.001.

Easdale, M.H., N. Perez Leon, and M.R. Aguiar. 2020. Strains in sustainability debates: Traditional ecological knowledge and Western science through the lens of extension agents in a pastoral region. *Rural Sociology* 85 (1): 57–84. https://doi.org/10.1111/ruso.12268.

Egea, A.V., L. Allegretti, S.P. Lama, D. Grilli, C. Sartor, M. Fucili, J.C. Guevara, and C. Passera. 2014. Selective behavior of creole goats in response to the functional heterogeneity of native forage species in the Central Monte desert, Argentina. *Small Ruminant Research* 120 (1): 90–99. https://doi.org/10.1016/j.smallrumres.2014.04.005.

Egea, Á.V., M.L. Bakker, L.I. Allegretti, S.A. Paez, D.J. Grilli, J.C. Guevara, and J.J. Villalba. 2019. Seasonal changes in feed intake, diet digestibility and diet composition by lactating and non-lactating goats browsing in a semi-arid rangeland of Argentina. *Grass and Forage Science* 74 (1): 115–128. https://doi.org/10.1111/gfs.12393.

Fielding, D. 1985. Environmental management in animal agriculture. *Tropical Animal Health and Production*, 17(3): 152. https://doi.org/10.1007/bf02355874.
Gudmundsson, O. 2001. Extensive sheep grazing in oceanic circumpolar conditions. *Russian collection of agricultural articles*, 162–190 https://www.google.com/search?q=EXTENSIVE+SHEEP+GRAZING+IN+OCEANIC+CIRCUMPOLAR+CONDITIONS+Olafur+Gudmundsson&rlz=1C1GCEU_esAR928AR928&oq=EXTENSIVE+SHEEP+GRAZING+IN+OCEANIC+CIRCUMPOLAR+8. Accessed 26 July 2022
Hendrickson, J.R., and C. Moffet. 2020. Forage systems for the temperate subhumid and semiarid areas. *Forages: The science of grassland. Agriculture* 2: 387–405. https://doi.org/10.1002/9781119436669.ch21.
Herring, C.M., F.W. Bazer, G.A. Johnson, and G. Wu. 2018. Impacts of maternal dietary protein intake on fetal survival, growth, and development. *Experimental Biology and Medicine* 243 (6): 525–533. https://doi.org/10.1177/1535370218758275.
Holechek, J.L., and B.D. Gross. 1982. *Evaluation of different calculation procedures for microhistological analysis*. https://doi.org/10.2307/3898248.
Holechek, J.L., and M. Vavra. 1981. The effect of slide and frequency observation numbers on the precision of microhistological analysis. *Rangeland Ecology & Management/Journal of Range Management Archives* 34 (4): 337–338.
Holechek, J.L., B. Gross, S.M. Dabo, and T. Stephenson. 1982. Effects of sample preparation, growth stage, and observer on microhistological analysis of herbivore diets. *The Journal of Wildlife Management* 46 (2): 502–505. https://doi.org/10.2307/3808666.
Jefferies, B.C. 1961. Body condition scoring and its use in management. *Tasmanian Journal of Agriculture* 32: 19–21.
Jockers, E.R., V.H. Medina, and E.S. Villagra. 2021. Influence of pre and postpartum maternal body condition score on the growth of Neuquén Criollo kids. *Small Ruminant Research*, 205: 106540.
Joy, A., F.R. Dunshea, B.J. Leury, I.J. Clarke, K. DiGiacomo, and S.S. Chauhan. 2020. Resilience of small ruminants to climate change and increased environmental temperature: A review. *Animals* 10 (5): 867. https://doi.org/10.3390/ani10050867.
Lachica, M., and J.F. Aguilera. 2005. Energy expenditure of walk in grassland for small ruminants. *Small Ruminant Research* 59 (2-3): 105–121. https://doi.org/10.1016/j.smallrumres.2005.05.002.
Lanari, M., M. Pérez Centeno, J. Arrigo, S. Debenedetti, and M. Abad. 2009. Razas locales y fibras caprinas, bases para un desarrollo rural del norte de la Patagonia Argentina. *Animal Genetic Resources Information*, 45: 55-59. https://doi.org/10.1017/S1014233909990320.
Lanari, M.R., E. Domingo, and M.J. Pérez Centeno. 2004. Aspectos socioecómicos culturales de la cría de animales autóctonos Argentina "El sistema rural de la cabra criolla neuquina en el norte de la Patagonia". *Sitio Argentino de Producción Animal. Series INTA EEA Bariloche*. https://produccion-animal.com.ar/produccion_caprina/produccion_caprina/155-cabra_criolla_neuquina.pdf Accessed 26 July 2022.
Latour, M.C., and A. Pelliza Sbriller. 1981. Clave para la determinación de la dieta de herbívoros en el N.O. de la Patagonia. *RIA (Revista Investigaciones Agropecuarias de Bs. As.)*. 16(1): 109-152.
Mellado, M. 2016. Dietary selection by goats and the implications for range management in the Chihuahuan Desert: A review. *The Rangeland Journal* 38 (4): 331–341. https://doi.org/10.1071/RJ16002.
Mellado, M., L. Gaytán, A. Rodríguez, U. Macías-Cruz, L. Avendaño-Reyes, and J.E. García. 2014. Nutritive content of aborted and non-aborted goat diets on rangeland. *Veterinarija ir Zootechnika* 67(89): 68–74. https://www.researchgate.net/publication/269280081.
Moir, R.J. 1961. A note on the relationship between the digestible dry matter and the digestible energy content of ruminant diets. *Australian Journal of Experimental Agriculture*, 1(1): 24-26.
Mokhtari, M.S., M. Asadi Fozi, and J.P. Gutierrez. 2019. Genetic and phenotypic aspects of early reproductive performance in Raeini Cashmere goats. *Tropical Animal Health and Production* 51: 2175–2180. https://doi.org/10.1007/s11250-019-01915-0.
National Research Council. 2007. *Nutrient Requirements of Small Ruminants: Sheep, Goats, Cervids, and New World Camelids*. Washington, DC: The National Academies Press. https://doi.org/10.17226/11654.
Perez Leon, N., O. Bruzzone, and M.H. Easdale. 2020. A framework to tackling the synchrony between social and ecological phases of the annual cyclic movement of transhumant pastoralism. *Sustainability* 12 (8): 3462. https://doi.org/10.3390/su12083462.
Rook, JS. 2000. Pregnancy toxemia of ewes, does, and beef cows. *The Veterinary clinics of North America. Food animal practice*. 16(2): 293-317, vi-vii. https://doi.org/10.1016/s0749-0720(15)30107-9. PMID: 11022342.
Sepúlveda Plama, L.S., A. Pelliza, and M. Manacorda. 2004. La importancia de los tejidos no epidérmicos en el microanálisis de la dieta de herbívoros. *Ecología Austral*, 14(1): 031–038.
Somlo, R. 1992. *Manejo Nutricional en condiciones extensivas. Area Recursos Naturales, Pastizales Naturales C. Tecnica N°5*, ed. INTA: Estacion Experimental Agropecuaria Bariloche. Institutional communication INTA EEA Bariloche Argentina.
Somlo, R.C., L. Cohen, B. Giorgetti, O. Montenegro, and G. Rodriguez. 1997. Tablas de valor nutritivo de especies forrajeras patagónicas (Monte Pampeano). *Comunicación técnica*, (6). Argentina: INTA EEA Bariloche.
Sparks, D.R., and J.C. Malechek. 1968. Estimating percentage dry weight in diets using a microscopic technique. *Rangeland Ecology & Management/Journal of Range Management Archives* 21 (4): 264–265.
Van Soest, P.J. 1967. Development of a Comprehensive System of Feed Analyses and Its Application to Forages. *Journal of Animal Science*, 26: 119–128.
Van Soest, P.J. 1969. Composition, Fiber Quality and Nutritive Value of Forages. *Advances in Chemistry*, 95: 262–278.
Villagra, E.S., A. Pelliza, P. Willems, G. Siffredi, and G. Bonvissuto. 2013. What do domestic livestock eat in northern Patagonian rangelands? *Animal Production Science* 53 (4): 360–367. https://doi.org/10.1071/AN11283.
Villagra, E.S., M.H. Easdale, C.G. Giraudo, and G.L. Bonvissuto. 2015. Productive and income contributions of sheep, goat, and cattle, and different diversification schemes in smallholder production systems of northern Patagonia, Argentina. *Tropical Animal Health and Production* 47 (7): 1373–1380. https://doi.org/10.1007/s11250-015-0873-9.
Wang, H.R., Z.C. Feng, D.X. Lu, J.K. Ren, H.R. Li, D.W. Peter, J. Lindsay, and D.B. Purser. 1997. Effects of seasonal nutritive changes with forage on dietary intake and growth performance of grazing goats. *Inner Mongolian Journal of Animal Sciences and Production S* 1: 143–150.
Williams, O. 1969. An improved technique for identification of plants fragments in herbivore feces. *Journal of Range Management* 22(1): 51–52. https://doi.org/10.2307/3896035.
Zimerman, M., E. Domingo, and M.R. Lanari. 2008. Carcass characteristics of Neuquén Criollo kids in Patagonia region, Argentina. *Meat Science* 79(3): 453–457. https://doi.org/10.1016/j.meatsci.2007.12.007.

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