



Pequi (*Caryocar brasiliense* Camb.) by-product for lambs: Performance, feed intake, and nutrient digestibility

*Subproducto de pequi (*Caryocar brasiliense* Camb.) para corderos: Desempeño, consumo y digestibilidad de nutrientes*

*Subproduto de pequi (*Caryocar brasiliense* Camb.) em cordeiros: Desempenho, consumo e digestibilidade dos nutrientes*

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Abstract

Background: The use of pequi by-product as animal feed is an appealing alternative to reduce overall production costs. However, little is known regarding its effects on animal performance as well as the ideal inclusion level in the diet. **Objective:** To evaluate performance, intake, and digestibility of confined lambs receiving diets containing different levels of pequi by-product as a partial substitute for corn silage. **Methods:** The experiment was conducted in Curvelo, Brazil, using twenty-five crossbred Santa Inês male lambs (17.83 ± 1.73 kg) aged six months for 92 days. Increasing levels of pequi by-product (0, 6, 12, 18, and 24%) replacing corn silage were evaluated in a completely randomized design. Analysis of variance and regression were performed, with 5% significance level. **Results:** Inclusion of pequi by-product did not influence ($p > 0.05$) average daily gain, total weight gain, or feed conversion ratio. No effect ($p > 0.05$) was also observed on intake of dry matter, organic matter, ether extract, crude protein, neutral detergent fiber, total carbohydrates, and total digestible nutrients. However, a linear decrease was observed ($p < 0.05$) in the apparent digestibility of dry matter, organic matter, ether extract, crude protein, neutral detergent fiber, total carbohydrates, and total digestible nutrients with increasing inclusion of pequi by-product. **Conclusion:** Pequi by-product is a potential substitute for corn silage in lamb diets because it does not influence animal performance and feed intake. However, digestibility decreases with increasing dietary inclusion levels of pequi by-product.

Keywords: *Alternative feedstuff; animal performance; feed intake; fruit by-product; fruit residue; lamb; digestibility; pequi; sheep; weight gain.*

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Resumen

Antecedentes: la inclusión de subproductos de pequi en alimentación animal es una estrategia atractiva para reducir los costos de producción. Sin embargo, todavía se sabe poco sobre el efecto de este subproducto en el rendimiento de los animales, así como su nivel ideal de inclusión en la dieta. **Objetivo:** evaluar el rendimiento, consumo y digestibilidad en corderos confinados recibiendo dietas con subproducto de pequi en reemplazo parcial del ensilado de maíz. **Métodos:** el experimento se realizó en Curvelo, Brasil, utilizando 25 corderos machos cruzados de raza Santa Inês ($17,83 \pm 1,73$ kg) y 6 meses de edad, durante 92 días. Se evaluaron niveles crecientes del subproducto de pequi (0, 6, 12, 18 y 24%) para sustituir el ensilado de maíz siguiendo un diseño completamente aleatorio. Los análisis de varianza y regresión se llevaron a cabo usando un nivel de significancia del 5%. **Resultados:** la inclusión del subproducto de pequi no influyó ($p > 0,05$) en la ganancia de peso diaria, ganancia de peso total, ni conversión alimenticia. No se observó efecto ($p > 0,05$) en la ingesta de materia seca, materia orgánica, extracto etéreo, proteína bruta, fibra detergente neutra, carbohidratos totales y nutrientes digestibles totales. Sin embargo, se observó una reducción lineal ($p < 0,05$) en la digestibilidad aparente de materia seca, materia orgánica, extracto etéreo, proteína bruta, fibra detergente neutra, carbohidratos totales y nutrientes digestibles totales con el aumento del nivel de inclusión del subproducto. **Conclusión:** el subproducto de pequi puede utilizarse como sustituto parcial del ensilado de maíz, ya que no afecta la ganancia de peso ni la ingesta de nutrientes. Sin embargo, la digestibilidad disminuye al aumentar el nivel de inclusión del subproducto en la dieta.

Palabras clave: *cordero; digestibilidad; ganancia de peso; ingesta; oveja; pequi; piensos alternativos; rendimiento animal; residuos de fruta; subproducto de fruta.*

Resumo

Antecedentes: o uso de subprodutos do pequi na alimentação animal é uma estratégia atraente que busca a redução dos custos de produção. Entretanto, pouco ainda se sabe sobre o efeito desse subproduto no desempenho animal assim como qual seria o nível ideal da sua inclusão na dieta. **Objetivo:** avaliar o desempenho, consumo e digestibilidade em cordeiros confinados recebendo dietas contendo subproduto de pequi em substituição à silagem de milho. **Métodos:** o experimento foi conduzido em Curvelo, Brasil, utilizando 25 cordeiros machos cruzados da raça Santa Inês ($17,83 \pm 1,73$ kg) com 6 meses de idade durante 92 dias. Níveis crescentes do subproduto de pequi (0, 6, 12, 18 e 24%) foram avaliados em substituição à silagem de milho em um delineamento inteiramente casualizado. A análise de variância e regressão foram conduzidas adotando 5% como nível de significância. **Resultados:** a inclusão do subproduto de pequi não influenciou ($p > 0,05$) o ganho de peso médio diário, o ganho de peso total e a conversão alimentar. Também não foi observado efeito ($p > 0,05$) no consumo de matéria seca, matéria orgânica, extrato etéreo, proteína bruta, fibra em detergente neutro, carboidratos totais e nutrientes digestíveis totais. Entretanto, foi observada redução linear ($p < 0,05$) na digestibilidade aparente da matéria seca, matéria orgânica, extrato etéreo, proteína bruta, fibra em detergente neutro, carboidratos totais e nutrientes digestíveis totais com o aumento da inclusão do subproduto. **Conclusão:** o subproduto de pequi pode ser utilizado como substituto parcial à silagem de milho uma vez que não influenciou o desempenho animal ou o consumo de nutrientes. No entanto, a digestibilidade diminuiu com o aumento do nível de inclusão do subproduto na dieta.

Palavras-chave: *alimentos alternativos; consumo; subproduto de fruta; cordeiro; desempenho animal; digestibilidade; ganho de peso; ovino; pequi; resíduo de fruta.*

Introduction

The use of alternative feeds from plant by-products in animal diets can reduce the environmental impact of the livestock industry (Lousada Junior *et al.*, 2005; Salami *et al.*, 2019) and feeding cost (Lousada Junior *et al.*, 2005), as well as the competition with human food (Lousada Junior *et al.*, 2005; Salami *et al.*, 2019). Previous studies indicated the feasibility of using different fruit by-products as feed for small ruminants (Almeida *et al.*, 2019; Almeida *et al.*, 2015). However, many by-products are wasted due to lack of knowledge about its potential use. Pequi by-product is an example of a plant by-product with potential to be used in ruminant feeding.

Pequi is the fruit of the “pequizeiro” (*Caryocar brasiliense* Camb.), which is a native tree present in tropical areas of Latin America. The main economic interest of pequi lies in the extraction of its core (pyrene: internal mesocarp, thorny endocarp, and edible almond), which represents between 17.9 to 22.5% of the fruit (Alves *et al.*, 2014; Soares Júnior *et al.*, 2010). In contrast, the shell (exocarp and external mesocarp), which represents between 76.0 to 82.1% of the fruit (Alves *et al.*, 2014; Soares Júnior *et al.*, 2010), has a latent interest and is the main by-product of pequi. In 2019, 3.28 million tons of pequi were commercialized in the four main producing states in Brazil (CEASA-GO, 2020). The extraction of the fruit’s core would result in 2.49 to 2.69 million tons of byproducts that could be incorporated in ruminant diets, potentially reducing overall production costs and increasing the environmental sustainability of the activity.

The use of pequi by-product in ruminants has received little attention in the literature. While evaluating the ruminal degradation kinetics of pequi shell in goats, Geraseev *et al.* (2011) reported a high potential degradability of its dry matter (DM; 93.95%), crude protein (CP; 88.16%), and neutral detergent fiber (NDF; 82.39%). They also reported a linear increase in potential degradability of DM and NDF with

increasing levels of the by-product as a partial substitute for elephant grass. Nevertheless, further studies are required to evaluate its suitability for different animal species in combination with different roughage sources.

Therefore, the objective of this study was to evaluate performance, intake, and digestibility of diets with increasing levels of pequi by-product as a partial substitute for corn silage in lambs.

Materials and Methods

Ethical considerations

The Ethics Committee on the Use of Animals from Universidade Federal dos Vales do Jequitinhonha e Mucuri (UFVJM) approved the experimental procedures used in this study (26/June/2013, Protocol n° 008/2013).

Experiments

The experiment was conducted in the Ruminants Laboratory at the Experimental Farm of Moura (EFM) of UFVJM, located in Curvelo – MG, Brazil. Bromatological analyses were carried out in the Food Analysis Laboratory of UFVJM – JK Campus, Diamantina – MG.

Animals and study design

The pequi by-product was collected in a fruit-processing cooperative located in the city of Japonvar – MG. The by-product consisted of pequi shells (exocarp and external mesocarp), resulting from extraction of the fruit core (pyrene: internal mesocarp, thorny endocarp, and edible almond). The byproduct was transported to the EFM, placed on black plastic canvas forming 5-cm thick layers, exposed to the sun for drying and turned three times a day. The by-product was ground on 5-mm sieve when it reached a dry and crumbly aspect.

The experiment length was 92 days -between August 13 and November 11, 2012. After a 10-days adaptation, followed by three 28-day periods, the last one being 26 days for data collection. Twenty-five non-castrated male

crossbred Santa Inês lambs, averaging 17.83 ± 1.73 kg body weight (BW) and six months of age were used. Lambs were kept in 1.5 x 1.0 m individual metabolic cages equipped with individual feeder and drinker. The cages were cleaned daily. All animals were orally dewormed against endoparasites at the beginning of the experiment.

The animals were fed a total-mixed ration with a 50:50 forage to concentrate ratio (dry matter basis). The concentrate was formulated with ground corn, soybean meal, urea, and mineral mix (Table 1). Diets were balanced for 200 g daily weight gain, according to the requirements for 20 kg BW animals, as recommended by the NRC (2007). The diet contained approximately 16% CP and 70% total digestible nutrients (TDN).

Table 1. Ingredients composition of the experimental diets offered to confined lambs.

Item*	Pequi by-product levels (%)				
	0	6	12	18	24
Ground corn	31.0	31.0	31.0	31.0	31.0
Soybean meal	16.0	16.0	16.0	16.0	16.0
Urea	1.35	1.35	1.35	1.35	1.35
Ammonium sulfate	0.15	0.15	0.15	0.15	0.15
Mineral mixture	1.50	1.50	1.50	1.50	1.50
Corn silage	50.0	44.0	38.0	32.0	26.0
Pequi by-product	0.00	6.00	12.0	18.0	24.0

*Values are expressed on dry matter basis (g/100 g of dry matter).

Five levels of inclusion of pequi by-product were evaluated as follow based on percentage of dry matter content: Treatment 1 = corn silage (50%) and concentrate (50%) (control); Treatment 2 = corn silage (44%), pequi by-product (6%), and concentrate (50%); Treatment 3 = corn silage (38%), pequi by-product (12%), and concentrate (50%); Treatment 4 = corn silage (32%), pequi by-product (18%), and concentrate (50%); Treatment 5 = corn silage (26%), pequi by-product (24%), and concentrate (50%).

The mixture of roughage and concentrate was done right before the animals were fed. It was provided *ad libitum* two times a day at 08h00

am and 04h00 pm, allowing approximately 10% leftovers. The animals had *ad libitum* access to water and mineral mixture.

The chemical composition of pequi by-product, corn silage, and experimental diets obtained from samples collected over the entire experimental period are shown in Table 2.

Forage and concentrate offered were daily recorded throughout the experiment to measure individual consumption. Diet and leftovers were daily sampled, placed in plastic bags, and stored in the freezer for future analyses. Animals were weighed at the beginning and the end of each period for assessing total body weight and average daily gain. Nutrient intake was calculated as percentage of body weight (% BW), relation to metabolic weight (g/BW^{0.75}), and in kilograms per day (kg/day). Average daily gain (ADG) was calculated as the difference between initial and final BW over the number of days evaluated. Feed conversion ratio (FCR) was obtained from the relationship between average dry matter intake and average BW gain.

Digestibility trials were carried out from the 11th to the 18th day of the second experimental period (eight consecutive days) to estimate apparent digestibility of nutrients. The total amount of feces produced was collected using nappa leather bags (83% polyester and 17% cotton) attached to the animal during the 1st and 7th days of the trial. Before the morning feeding, the feces were weighed, sampled (about 10% of the total), and kept frozen at -20 °C for later analyses.

Laboratory analysis and measurements

Corn silage, pequi by-product, concentrate and dried leftovers samples were ground in a Wiley mill (Thomas Model 4 Wiley® Mill; Thomas Scientific, Swedeboro, NJ, USA) to pass through a 1-mm stainless steel curved round-hole sieve. Samples were analyzed for dry matter (DM), organic matter (OM), crude protein (CP), ether extract (EE), and ash content according to the AOAC (1997). The NDF values were obtained according to Mertens (2002),

without sodium sulphite, but using heat-stable alpha-amylase (Novo A/S, Hellerup, Denmark). We used the Ankom® NDF determination system with non-woven fabric bags (5.0 x 5.0 cm, 100 micrometres porosity, TNT 100g/m²). Contents of ADF, ADIN, INND, and lignin

(72% sulfuric acid) were obtained by sequential method (Robertson and Van Soest, 1981), and presented as suggested by Licitra *et al.* (1996). Analysis of condensed tannins was conducted only for the pequi by-product using the hot water method according to Trugilho *et al.* (2003).

Table 2. Chemical composition of pequi by-product, corn silage, and experimental diets.

Item	Pequi by-product	Corn silage	Pequi by-product levels (%)				
			0	6	12	18	24
DM*	89.46	24.65	53.62	57.52	61.86	65.74	69.63
OM*	94.32	94.74	94.42	94.37	94.31	94.28	94.26
Ash*	5.68	5.26	4.07	4.12	4.18	4.21	4.23
EE*	2.93	2.75	2.91	2.92	2.93	2.94	2.95
CP*	4.54	8.79	16.99	16.92	16.90	16.63	16.36
NDFap*	28.62	61.23	40.90	38.93	37.11	35.21	33.32
ADFap*	19.14	30.63	15.17	14.70	14.25	13.77	13.29
AIAD*	0.29	0.42	0.27	0.26	0.25	0.24	0.23
AIND*	0.62	1.47	0.45	0.43	0.41	0.39	0.36
ADIN**	29.11	9.95	4.98	6.12	7.26	8.40	9.54
INND**	51.38	40.01	20.01	20.69	21.37	22.05	22.77
Lignin*	5.95	3.46	3.66	3.82	3.99	4.14	4.29
NFC*	62.12	23.19	38.19	40.11	42.39	44.51	46.64
TCHO*	86.85	83.20	76.02	76.03	75.97	76.21	76.44
Tannin*	9.80	---	0.00	0.58	1.17	1.76	2.35

*Values are expressed on dry matter basis (g/100 g of dry matter). **Values are expressed on total nitrogen basis (g/100 g of total nitrogen). Dry matter (DM), organic matter (OM), ether extract (EE), crude protein (CP), neutral detergent fiber corrected for ash and protein (NDFap), acid detergent fiber corrected for ash and protein (ADFap), ashes insoluble in acid detergent (AIAD), ash insoluble in neutral detergent (AIND), Acid detergent insoluble nitrogen (ADIN), insoluble nitrogen in neutral detergent (INND), non-fibrous carbohydrate (NFC), total carbohydrates (TCHO).

Fecal samples were analyzed for DM, OM, CP, EE, and ash, according to AOAC (1997), and NDF according to Mertens (2002).

Non-fiber carbohydrates (NFC) in leftovers and feces were estimated with the Van Soest *et al.* (1991) equation, using the formula: $NFC = 100 - (CP + EE + Ash + NDFap)$, where: NFC = estimated content of non-fibrous carbohydrates (%); CP = crude protein content (%); EE = ether extract content (%); Ash = ash content; and NDFap = neutral detergent fiber corrected for ash and protein (%).

Non-fiber carbohydrates (NFC) of concentrate feeds were estimated according to Hall and Akinyode (2000), using the formula: $NFC = 100 - [(CP_{total}\% - CP_{pura}\% + urea\%) + NDFap\% + EE\% + Ash\%]$.

Total digestible nutrients (TDN) were calculated using the NRC (2001) equation: $TDN = CP_d + 2.25 \times EE_d + NDFap_d + NFC$; where TDN = total digestible nutrients; CP_d = digestible crude protein; EE_d = digestible ether extract; NDFap_d = neutral detergent fiber corrected for ash and digestible protein, and NFC = non-fibrous carbohydrates.

Total carbohydrates (TCHO) were calculated as proposed by Sniffen *et al.* (1992): $TC = 100 - (CP\% + EE\% + Ash\%)$.

Similar to Valero *et al.* (2016), the apparent digestibility (AD) values of nutritional components of the diet were obtained using the following equation:

$$AD (\%) = \frac{(DM \text{ intake} \times \text{nutrient}\%) - (DM \text{ excreted} \times \text{nutrient}\%)}{DM \text{ intake} \times \text{nutrient}\%} \times 100$$

Agro-industrial by-products used in animal diets are usually obtained after intensive processing. It often implies an intense reduction in particle size, which is associated with the physical effectiveness of fiber. Therefore, we measured the particle size on a 500-g sample of the pequi by-product using granulometric sieves of 1.00, 1.18, 1.40, 2.36, 2.80, 3.35, 4.00, and 4.75 mm. The sieves were sorted in descending order and stirred until complete passage of particles. Subsequently, portions retained on each sieve were weighed to determine the percentage of each fraction of particle sizes of the pequi by-product.

Statistical analysis

The experiment was conducted in a completely randomized design with five treatments and five replicates. The results were submitted to analyses of variance, with initial BW as a covariate, and regression considering 5% probability or lower for type I error using the SAS software, version 9.0 (SAS, 2002).

Results

Pequi by-product showed higher amounts of lignin than corn silage. Based on dry matter, pequi by-product had 5.95% while corn silage had 3.46% lignin (Table 2). Consequently, the higher the inclusion of pequi by-product, the more lignin was included in the diet. However, the difference between the highest and lowest lignin content in the diet was only about 0.63% (Table 2).

There was no effect ($p > 0.05$) of pequi by-product as replacement of corn silage on intake of DM, OM, CP, EE, NDFap, NFC, TCHO, and TDN, regardless of how they were expressed: %BW, g/BW^{0.75}, or kg/day (Table 3). In addition, there was no change on NDF and NFC intake (Table 3), despite the reduction of NDF and increase of NFC in the diets with the inclusion of pequi by-product (Table 2).

More than 60% of the pequi by-product measured 1.18mm or above, as presented in Table 4.

There was a negative ($p < 0.01$) linear effect on the apparent digestibility of nutritional constituents with the inclusion of pequi by-product (Table 5). The absolute digestibility value of DM, OM, EE, CP, NDFap, NFC, and TDN, decreased linearly (11.67, 12.35, 23.41, 17.92, 12.64, 9.24, and 6.77%, respectively) between zero and 24% inclusion of pequi by-product (Table 5). Decreased ($p < 0.01$) digestibility of TDN was expected since it was calculated based on digestible CP, EE, NDFap, and NFC, where a reduction in digestibility ($p < 0.01$) was also observed (Table 5).

No significant effect ($p > 0.05$) was observed of treatments on average daily gain and days to reach 30 kg of BW (Table 6). The animals gained 224 g/day on average. No effect ($p > 0.05$) on feed conversion rate was expected since the feed conversion ratio was calculated based on total intake and total weight gain, which in turn were not statistically significant ($p > 0.05$). The average number of days to reach 30 kg was 65.38 and no effect ($p > 0.05$) of pequi by-product was observed.

Discussion

We evaluated the partial replacement of corn silage by increasing levels of pequi by-product in diets fed to lambs and its effect on animal performance, feed intake, and nutrient digestibility to assess the suitability of this by-product as a potential feed source for ruminants.

Table 3. Nutritional intake of lambs fed diets with increasing levels of pequi by-product.

Item*	Pequi by-product levels (%)					SEM	Regression	p-value	CV (%)
	0	6	12	18	24				
<i>% BW</i>									
DM	4.01	3.95	4.31	4.15	3.83	0.10	$\hat{y} = 4.05$	0.40	16.69
OM	3.81	3.75	4.08	3.92	3.62	0.09	$\hat{y} = 3.83$	0.39	16.66
EE	0.11	0.11	0.12	0.11	0.10	0.003	$\hat{y} = 0.11$	0.25	16.27
CP	0.83	0.79	0.84	0.76	0.69	0.02	$\hat{y} = 0.78$	0.06	17.34
NDFap	1.56	1.48	1.55	1.57	1.38	0.03	$\hat{y} = 1.15$	0.31	15.87
NFC	1.30	1.35	1.56	1.46	1.42	0.04	$\hat{y} = 1.42$	0.36	18.84
TCHO	2.86	2.84	3.11	3.03	2.81	0.04	$\hat{y} = 2.93$	0.24	16.56
TDN	2.80	2.63	2.71	2.65	2.29	0.08	$\hat{y} = 2.62$	0.21	16.68
<i>g/BW^{0.75}</i>									
DM	89.79	88.14	97.17	92.41	85.11	2.23	$\hat{y} = 90.52$	0.39	16.64
OM	85.40	83.57	92.01	87.37	80.48	2.12	$\hat{y} = 85.77$	0.38	16.62
EE	2.57	2.50	2.80	2.62	2.38	0.07	$\hat{y} = 2.57$	0.25	16.72
CP	18.67	17.80	19.06	17.13	15.50	0.50	$\hat{y} = 17.63$	0.06	17.17
NDFap	34.95	33.11	34.97	34.95	30.86	0.76	$\hat{y} = 33.77$	0.32	15.61
NFC	29.20	30.14	35.16	32.66	31.74	0.90	$\hat{y} = 31.78$	0.34	17.95
TCHO	64.15	63.26	70.14	67.61	62.60	0.93	$\hat{y} = 65.55$	0.22	16.49
TDN	62.77	58.60	61.13	59.18	51.01	1.86	$\hat{y} = 58.54$	0.22	16.75
<i>kg/day</i>									
DM	1.00	0.97	1.11	1.02	0.93	0.03	$\hat{y} = 1.01$	0.39	17.41
OM	0.96	0.92	1.05	0.96	0.88	0.03	$\hat{y} = 0.95$	0.39	17.38
EE	0.03	0.02	0.03	0.02	0.02	0.001	$\hat{y} = 0.02$	0.26	18.91
CP	0.21	0.19	0.21	0.19	0.17	0.01	$\hat{y} = 0.19$	0.10	17.70
NDFap	0.39	0.36	0.40	0.38	0.34	0.01	$\hat{y} = 0.37$	0.37	16.09
NFC	0.32	0.33	0.40	0.35	0.35	0.01	$\hat{y} = 0.35$	0.32	19.00
TCHO	0.72	0.70	0.80	0.74	0.69	0.01	$\hat{y} = 0.73$	0.22	17.28
TDN	0.70	0.65	0.70	0.65	0.56	0.02	$\hat{y} = 0.65$	0.29	17.84

*Values are expressed on dry matter basis (g/100 g of dry matter). Dry matter (DM), organic matter (OM), ether extract (EE), crude protein (CP), neutral detergent fiber corrected for ash and protein (NDFap), non-fibrous carbohydrate (NFC), total carbohydrates (TCHO), total digestible nutrients (TDN), standard error of the mean (SEM), coefficient of variation (CV).

Table 4. Proportion of particle sizes of pequi by-product using granulometric sieves on a 500 g sample.

mm	Particle Size								
	<1	>1	>1.18	>1.4	>2.36	>2.8	>3.35	>4	>4.75

The DM intake (4.05% BW) was higher than the 2.97% BW presented by NRC (2007) based on the requirements of finishing lambs weighing 20 kg BW and 200 g/day expected weight gain. While evaluating the performance of goats

fed increasing levels of pequi by-product as a partial substitute of elephant grass, Ribeiro Junior *et al.* (2009) reported no effect of the by-product inclusion on DM intake ($p > 0.05$) with an average of 58.3 g/BW^{0.75}, and 0.512 kg/day,

which were lower than the values reported in the present study (Table 3). Additionally, Almeida *et al.* (2019) evaluated the effect of replacing 75% of sorghum silage offered to finishing lambs by different fruit by-products (pineapple, banana, mango, or passion fruit), and reported DM intake ranging from 3.4 to 3.7% BW, which

is similar to our study. Voluntary intake may change depending on the quality and type of feed and the physiological status of the animal (NRC, 2007). It also may change according to feed digestibility, since its ability to be more or less digestible implies meeting physical energy requirement and satiety (NRC, 2007).

Table 5. Nutritional intake of lambs fed diets with increasing levels of pequi by-product.

Item*	Pequi by-product levels					SEM	Regression	p-value	R ²	CV (%)
	0	6	12	18	24					
DMD	72.72	70.81	66.75	68.31	64.23	0.74	$\hat{y} = 72.46 - 0.39X$	0.009	0.41	4.92
OMD	72.28	70.15	66.13	67.43	63.35	0.76	$\hat{y} = 71.99 - 0.37X$	0.006	0.44	5.01
EED	78.75	76.68	73.12	69.17	60.31	1.64	$\hat{y} = 77.71 - 0.76X$	< 0.001	0.78	5.64
CPD	76.41	72.63	67.41	68.01	62.67	0.81	$\hat{y} = 75.84 - 0.59X$	< 0.001	0.68	4.63
NDFapD	62.69	59.83	53.30	57.14	54.76	1.14	$\hat{y} = 61.87 - 0.32X$	0.005	0.24	11.2
NFCD	84.71	81.14	77.82	79.14	76.88	1.08	$\hat{y} = 83.51 - 0.31X$	0.01	0.34	4.55
TDND	74.56	73.16	70.53	71.08	69.51	0.79	$\hat{y} = 73.86 - 0.21X$	0.002	0.43	2.77

*Values are expressed in Kg. Dry matter digestibility (DMD), organic matter digestibility (OMD), ether extract digestibility (EED), crude protein digestibility (CPD), digestibility of neutral detergent fiber corrected for ash and protein (NDFapD), non-fibrous carbohydrate digestibility (NFCD), digestibility of total digestible nutrients (TDND), standard error of mean (SEM), coefficient of determination (R²), coefficient of variation (CV).

Table 6. Productive performance of lambs fed diet with increasing levels of pequi by-product replacing corn silage.

Item	Pequi by-product levels (%)					SEM	Regression	p-value	CV (%)
	0	6	12	18	24				
Initial weight*	18.13	17.90	18.16	17.34	17.62	0.47	$\hat{y} = 17.83$	0.25	9.84
Final weight*	32.52	31.52	33.40	31.65	31.15	0.47	$\hat{y} = 32.05$	0.85	7.40
Average daily gain**	0.234	0.214	0.248	0.224	0.200	0.01	$\hat{y} = 0.224$	0.81	23.53
Total weight gain*	14.38	13.62	15.23	14.30	13.53	0.49	$\hat{y} = 14.21$	0.85	19.55
Days to reach 30 kg	63.20	66.40	63.20	64.20	69.80	2.56	$\hat{y} = 65.38$	0.91	19.01
Feed conversion ratio	4.43	4.76	4.74	4.49	4.86	0.18	$\hat{y} = 4.43$	0.45	24.14

*Values are expressed in kilograms. **Values are expressed in grams. Standard error of the mean (SEM), coefficient of variation (CV).

No significant difference in nutrient intake indicates no preference for corn silage compared to pequi by-product. The NDF intake expressed as the percentage of BW found in this study (1.15% BW) was similar to the values proposed by Van Soest (1994): between 0.8 and 1.2% BW. In addition, NDF intake expressed as grams of metabolic weight ($\text{g/BW}^{0.75}$) and kg per day (kg/day) in this study (Table 3) were 1.41 and 1.76 times higher, respectively, than the intakes reported by Ribeiro Junior *et al.* (2009). Even though NFC was higher on diets with greater

inclusion of pequi by-product compared to the control diet, no change on NFC intake was observed, which was similar to that observed by Almeida *et al.* (2019) using mango by-products. Perhaps the presence of tannins in pequi by-product may have reduced its acceptability due to its reduced palatability caused by hydrogen bonds with saliva protein and mucous (Guimarães-Beelen *et al.*, 2006).

Most of the particle size of the pequi by-product was above the minimum particle size

(1.18 mm) necessary to ensure the maintenance of rumination, salivation, and therefore the ruminal pH buffering (hydrogen potential) for growing lambs (Cardoso *et al.*, 2006).

Reduction of CP apparent digestibility may have been the result of tannins present in pequi by-product. Feed tannin concentration is considered high or moderate if it is 6 to 12% or 2 to 4% of DM, respectively (Frutos *et al.*, 2002). Even though the concentration of tannins in the diets was lower than the high threshold, factors such as molecular weight, monomer composition (Lascano *et al.*, 2001), and the spatial form (Rosales, 1999) of the tannin molecule can affect food consumption and digestibility. In addition, tannins can bond with proteins forming a complex which makes them unavailable for animals (Patra and Saxena, 2010; Van Soest, 1994).

Changes in cellulolytic activity and growth of fibrolytic bacteria might be the reason for the decreased digestibility of NDFap in the present study. Condensate tannin extract of different native forages from the Brazilian northeastern semiarid region showed bacteriostatic effects on *Ruminococcus flavefaciens* FD1 (Guimarães-Beelen *et al.*, 2006). Furthermore, the growth of microorganisms depends on the ruminal digestion rate of structural carbohydrates and nitrogen (Russell *et al.*, 1992). Such situation was likely impaired due to reduced digestibility of CP (Table 5), reducing microorganism growth and consequently reduced lytic activity on NDFap.

Observed ADG was higher than expected. Diets were designed to supply enough nutrients for animals weighing 20 kg to gain 200 g/day (NRC, 2007), but 224 g/day ADG was observed. Ribeiro Junior *et al.* (2009) reported 39.3 g/day ADG, while Almeida *et al.* (2019) reported 168 g/day ADG, which were 5.7 and 1.3 times lower, respectively, compared to the present study. High dry matter intake (4.05% BW) could be the reason for the difference between expected and observed ADG. Sheep fed diets with different concentrations of metabolizable energy increase

their dry matter intake, increasing their average daily gain (Pereira *et al.*, 2010).

A reduced productive performance was expected because the inclusion of pequi by-product negatively affected diet digestibility. However, no effect of diet on animal performance was observed (Table 6). We hypothesized the occurrence of compensatory growth. Animals used in this study were bought from different farms and it was reasonable to believe they went through some kind of feed restriction before starting the experimental period. Especially because they were kept on grazing during the dry season, which is the season of forage shortage, leading to great DMI and weight gain during the experimental period. Compensatory gain has been observed in lambs. For instance, lambs maintained under moderate feed restriction (30% restriction) during 60 days showed higher feed intake and BW gain after the restriction period than non-restricted animals (Homem Junior *et al.*, 2007). However, the duration and severity of feed restriction used in our study is unknown, making it difficult to measure the length of the compensatory growth period.

Fruit by-products can be a source of bioactive compounds such as unsaturated fatty acids, phytochemicals, and vitamins (Salami *et al.*, 2019). Bioactive compounds in pequi by-product have anthelmintic properties in sheep, tested in vitro and in vivo (Nogueira *et al.*, 2012). It also has effect against gastrointestinal nematodes of cattle, tested in vitro (Fonseca *et al.*, 2014). Extract from pequi by-product has antimicrobial properties, potentially making it an alternative to ionophores for reducing enteric methane production (Oliveira *et al.*, 2014; Patra and Saxena, 2010). Such bioactive compounds were not evaluated in the present study; it is an area of active research.

As a conclusion, pequi by-product can substitute for corn silage up to 24% of the total DM of the diet since it does not affect animal performance or intake, despite reducing nutrient digestibility. The use of this by-product could potentially reduce the feeding cost of lambs.

Further research is needed to evaluate the potential benefits of the bioactive compounds present in pequi by-product.

Declarations

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Conflicts of interest

The authors declare they have no conflicts of interest with regard to the work presented in this report.

Author contributions

Janaina L Barbosa, Ana-Caroline M De-Castro, and Danilo O Alves conducted the experiment, collected samples, and conducted laboratory analysis. Darcilene M De-Figueiredo designed and supervised the experiment, sample collection, and laboratory analysis as well as the interpretation of statistical results. Janaina L Barbosa, Darcilene M De-Figueiredo, Marcela A Magalhães, Mário H F Mourthé, Marianne Schorer, and Gabriel M Dallago wrote, revised, and edited the manuscript. All authors read and approved the final manuscript.

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