


Suitability of different levels of sunflower cake from biodiesel production as feed ingredient for lamb production

Lidiane Fagundes da Silva Monteiro¹ , Aline Moreira Portella de Melo¹ ,
Martina Pérez Serrano^{2,3,4} , Roberto Germano Costa^{1*} , Valdi de Lima
Júnior¹ , Ariosvaldo Nunes de Medeiros¹ , José Manuel Lorenzo⁵ 

¹ Universidade Federal da Paraíba, Areia, PB, Brasil.

² Universidad de Castilla-La Mancha, Instituto de Investigación en Recursos Cinegéticos, Animal Science Techniques Applied to Wildlife Management Research Group, Campus Universitario, Albacete, Spain.

³ Universidad de Castilla-La Mancha, Instituto de Desarrollo Regional, Sección de Recursos Cinegéticos y Ganaderos, Campus Universitario, Albacete, Spain.

⁴ Universidad de Castilla-La Mancha, Escuela Técnica Superior de Ingenieros Agrónomos y Montes, Departamento de Ciencia y Tecnología Agroforestal y Genética, Campus Universitario, Albacete, Spain.

⁵ Centro Tecnológico de la Carne de Galicia, Parque Tecnológico de Galicia, San Cibrao das Viñas, Ourense, Spain.

*Corresponding author:
betogermano@hotmail.com

Received: December 15, 2019

Accepted: May 8, 2020

How to cite: Monteiro, L. F. S.; Melo, A. M. P.; Serrano, M. P.; Costa, R. G.; Lima Júnior, V.; Medeiros, A. N. and Lorenzo, J. M. 2020. Suitability of different levels of sunflower cake from biodiesel production as feed ingredient for lamb production. *Revista Brasileira de Zootecnia* 49:e20190269.
<https://doi.org/10.37496/rbz4920190269>

Copyright: This is an open access article distributed under the terms of the Creative Commons Attribution License (<http://creativecommons.org/licenses/by/4.0/>), which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.



ABSTRACT - The objective of this study was to evaluate performance traits, intake, nutrient apparent digestibility, and economic analysis of lambs fed diets containing different levels of sunflower cake (SFC) with a certain chemical composition. Thirty-six Santa Inês × Dorper lambs ($n = 9$ per treatment diet) with an average body weight (BW) of 19.5 ± 2.19 kg at the beginning of the study were randomly allocated to four isocaloric and isonitrogenous diets for 63 days. A control diet without SFC was compared with diets containing 5, 10, and 15% of dietary dry matter (DM) of SFC replacing soybean meal and corn. Growth performance and economic indicators were calculated. Moreover, individual faeces were collected using canvas bags to evaluate the apparent digestibility of nutrients between days 30 and 45 of study. The total BW gain linearly decreased with the inclusion of SFC in the lamb diet. However, no differences among treatments were observed for final BW, average daily gain, average daily feed intake, or feed conversion ratio. The inclusion of different levels of SFC in the diet reduced the intakes of DM as g/kg BW and non-fibre carbohydrates on DM basis. The apparent digestibility of all nutrients studied improved with the inclusion of 5% SFC but decreased with diets containing 10 or 15% of SFC. Moreover, the higher benefit:cost ratio was obtained for diet containing 5% SFC. Therefore, SFC from biodiesel production could be used at levels of 5% in lamb rations, reducing feeding costs without worsening productive performance, nutrient intake, and digestibility at the ages studied.

Keywords: digestibility, byproduct, consumption, economic analysis, performance traits

1. Introduction

In recent years, the use of agroindustrial byproducts in animal nutrition has been successfully adopted as alternative ingredients to traditional raw materials to reduce feeding costs and to cope with the

need to recycle waste material from the global biofuel industry (Vasta et al., 2008; Tufarelli et al., 2013). Reducing feed costs is particularly important for the intensive sheep industry (Guimarães et al., 2014). Generally, corn and soybean meal are the main ingredients used in feed rations of confined animal. However, price fluctuation and competition with diets for monogastric (mainly poultry and pork) are the main obstacles for the use of these raw materials in diets for lambs. As a consequence, it is necessary to evaluate the possibility of replacing them with lower cost alternative foods. In fact, the available information about the effects of including alternative nutrient sources in lamb diets on performance (Costa et al., 2016; Santos et al., 2016), intake (Costa et al., 2016), nutrient digestibility (Costa et al., 2016), and carcass (Cirne et al., 2016; Costa et al., 2016) and meat (Bezerra et al., 2016; De Melo et al., 2020) quality is extensive.

A possibility is the use of sunflower cake (SFC), a biodiesel agroindustry coproduct, as source of nutrients for lamb diets (Moura et al., 2015; Lima et al., 2018a). The SFC is free of antinutritional factors (Lima et al., 2018a) and can be included in diets for ruminants as an energy source based on its high lipid content [18.2% as average on dry matter (DM) basis], but also as alternative protein source with an average crude protein (CP) content of 25.3% DM (Lima et al., 2018a; Monção et al., 2018). However, the high content of lipids, which is associated with the amount and quality of fibre in SFC, can decrease animal intake and affect the digestibility and performance due to interference with fibre digestion or diet palatability (Fernandes Júnior et al., 2013; Alves et al., 2016). Some authors have observed a decrease of body weight (BW) gain (Fernandes Júnior et al., 2015), intake (Lima et al., 2018a), and nutrient digestibility (Lima et al., 2018a) when they included SFC in lamb diets. However, most of the studies have shown benefits of the inclusion of SFC in lamb diets (Fernandes Junior et al., 2013; Moura et al., 2015) without affecting the sensory attributes of meat (Lima et al., 2018b), or even improving lamb meat tenderness (De Melo et al., 2020).

The variability observed among the studies mentioned above for the results obtained in lambs fed diets containing SFC (Fernandes Júnior et al., 2013, 2015; Moura et al., 2015; Lima et al., 2018a; Lima et al., 2018b; De Melo et al., 2020) could have different causes such as different inclusion levels in the diet or the variability in the nutrient composition of the SFC used. In fact, the chemical composition of this byproduct is highly variable (Al-Masri, 2005; Weinberg et al., 2008), resulting mainly from different origins and varieties, the press model, or the setting used (Goes et al., 2010). The main hypothesis to be tested is that the percentage of SFC inclusion in the diet cannot be recommended without knowing its specific nutritional composition since it is highly variable. The SFC inclusion percentage in the diet can be higher the more protein and less fiber it has.

Therefore, it is necessary to evaluate the effects of the SFC inclusion in the total mixed rations (TMR) for lambs considering the specific chemical composition of the byproduct available in each particular case. The objective of this study was to evaluate performance traits, intake, nutrient apparent digestibility, and economic analysis of lambs fed diets containing different levels of SFC with a determined chemical composition.

2. Material and Methods

Research was conducted according to the institutional committee on animal use (case number 2305/14). The study was conducted in Parnamirim, Rio Grande do Norte (5° 54'57" S, 35° 15'56"W and altitude of 53 m), specifically, in the metropolitan region of Natal.

A total of 36 Santa Inês × Dorper male lambs, six months of age and average initial BW of 19.5±2.19 kg, were randomly assigned to four treatments (nine lambs per treatment). Lambs were housed in individual pens (1.6 × 1 m) equipped with slatted concrete floors and fitted with a drinker and a feeder. Water was available ad libitum through the experiment. After an adaptation period of 10 days to diets and facilities, the experiment started and lasted 63 days. During the adaptation period, all animals were treated for internal and external parasites with ivermectin (Ivomec gold, Merial, São Paulo, Brazil) and vaccinated against clostridiosis (Sintoxan, Merial, São Paulo, Brazil).

To prevent lambs from selecting feed, four pelleted total mixed rations, including forage and concentrate, were used. Forage (hay Tifton-85, *Cynodon* spp.) was ground to 25 mm length. Then, it was mixed to concentrate and steam-pelleted (8 mm diameter) to preserve the integrity of the fibrous components to reduce differences in physical form. The TMR were supplied to lambs twice daily at 08:00 and 16:00 h in two equal meals.

Three experimental TMR replaced corn and soybean meal with 5, 10, and 15% of SFC. These diets were compared with a control TMR containing corn and soybean meal as main ingredients without SFC. The SFC was obtained from a sunflower press factory near the experimental site. The SFC used in the diets was the product of the extraction of the oil from the sunflower grain through mechanical gripping (heated steam rollers). The analysis of the SFC was carried out by means of a single component, eliminating a portion of each bag in a total of 40 bags with 50 kg of SFC each. Each SFC sample was analysed by triplicate. The determined chemical composition and calculated metabolisable energy (ME) content of the TMR ingredients are shown in Table 1 according to FEDNA (2016) recommendations. The TMR were formulated to be isocaloric (2.74 Mcal/kg DM of ME on average) and isonitrogenous (18.0% of CP) (Table 2) and meet or exceeded the nutritional requirements for lambs with average daily gain (ADG) of 200 g according to the NRC (2007).

At the beginning of the study, lambs were individually identified, weighed (initial BW), and distributed in the experimental pens so that the initial average live BW was the same for the four experimental groups. Afterwards, lambs were weighed weekly and the day before slaughter to obtain the final BW. In all cases, lambs were weighed in the morning after 12 h of fasting and before the first feeding. Data obtained were used to calculate the total BW gain and ADG. The average daily feed intake (ADFI) was determined by the daily control of the feed supplied minus the daily feed refused. Feed refusals were collected daily, weighed, and individually bulked for analysis. Data of ADG and ADFI were used to calculate the feed conversion ratio (FCR). The nutrient intake was estimated based on the difference between the total of each nutrient contained in the TMR offered and the amount in the refusals.

The apparent digestibility of nutrients was determined between days 30 and 45 of the experiment using the total collections of faeces during this period. For collection of faeces, appropriate canvas bags were attached to the lambs using nylon strips as previously indicated by Lima et al. (2018a). After a period of four days of adaptation to the canvas bags, two daily faecal collections were made (09:00 and 15:00 h) from all experimental animals. Each collected sample was subsequently analysed individually by duplicate. The direct method was used to determine the apparent digestibility of nutrients by evaluating the nutrient content in TMR samples and faeces using the following formula: $[(\text{nutrient consumed} - \text{nutrient in faeces}) / (\text{nutrient consumed})] \times 100$.

Table 1 - Determined chemical composition and calculated metabolisable energy (ME)¹ content of the total mixed ration ingredients [% as dry matter (DM) basis, unless otherwise indicated]

Composition	Ingredient			
	Corn	Soybean meal	Sunflower cake	Tifton-85 hay
DM	87.6	88.6	92.5	89.9
Organic matter	98.5	93.7	95.3	93.4
Mineral matter	1.55	6.32	4.75	6.64
Crude protein	9.11	48.8	34.5	9.65
Ether extract	4.07	1.71	6.31	1.65
Neutral detergent fibre	14.0	14.6	37.5	79.9
Acid detergent fibre	4.08	9.86	27.9	39.0
Acid detergent lignin	1.16	1.33	10.7	5.35
Hemicellulose	9.92	4.74	9.6	40.9
Cellulose	2.92	8.53	26.8	33.7
Non-fibrous carbohydrates	71.3	28.6	16.9	2.2
ME (Mcal/kg DM)	2.83	2.95	1.83	1.21

¹ According to FEDNA (2016) recommendations.

Table 2 - Ingredients, determined chemical composition, and energy content of the experimental total mixed rations [% as dry matter (DM) basis, unless otherwise indicated]

Item	Sunflower cake level (%)			
	0	5	10	15
Ingredients				
Corn	40.4	39.0	38.4	36.6
Soybean meal	16.6	13.0	8.60	5.40
Sunflower cake	0.00	5.00	10.0	15.0
Vitamin-mineral premix ¹	2.00	2.00	2.00	2.00
Tifton-85 hay	41.0	41.0	41.0	41.0
Determined chemical composition (% DM)				
DM	91.2	91.4	91.5	91.7
Organic matter	86.8	87.0	87.2	87.4
Mineral matter	4.4	4.4	4.3	4.3
Crude protein	18.0	18.1	17.8	18.2
Ether extract	3.0	3.3	3.6	3.9
Neutral detergent fibre	46.6	48.9	50.9	53.4
Acid detergent fibre	22.0	23.6	25.0	26.8
Acid detergent lignin	3.3	3.9	4.5	5.2
Hemicellulose	24.6	25.3	25.9	26.7
Cellulose	18.7	20.2	21.6	23.3
Non-fibrous carbohydrates	41.6	41.0	40.6	39.9
Metabolisable energy (Mcal/kg DM)	2.76	2.75	2.72	2.72
Net energy (Mcal/kg DM)	1.77	1.74	1.71	1.68

¹ Supplied per kg of diet: 70 g of P, 140 g of Ca, 148 g of Na, 12 g of S, 1.32 mg of Mg, 700 mg of F, 4.70 mg of Zn, 3.69 mg of Mn, 2.20 mg of Fe, 140 mg of Co, 61 mg of I, 15 mg of Se, and 100 mg of monensin sodium salt.

Samples of ingredients, TMR, waste, and faeces were identified, weighed, and stored in plastic bags at -10°C immediately after collection. At the end of the experimental period, the collected samples were defrosted and dried in a forced-air ventilation oven at 55°C for 72 h. Then, samples were ground using a 1-mm sieve and packaged in identified containers for laboratory analysis. Chemical composition of ingredients, TMR, leftovers, and faeces was determined in triplicate as described by AOAC (2005) for DM (method AOAC 934.01), mineral matter (MM; method AOAC 942.05), CP (Kjeldahl method, method AOAC 984.13), and ether extract (EE; method AOAC 920.39). Data obtained were used to calculate the organic matter (OM) content. Neutral detergent fibre (NDF) and acid detergent fibre (ADF) were analysed according to Van Soest et al. (1991). Acid detergent lignin (ADL) was determined according to method 973.18 (AOAC, 2002). Hemicellulose content was calculated by the difference between NDF and ADF. Non-fibrous carbohydrates (NFC) content was calculated as: $\text{NFC (\%)} = 100 - (\text{MM, \%} + \text{CP, \%} + \text{EE, \%} + \text{NDF, \%})$.

The production cost was estimated using the operational cost (OC) proposed by Matsunaga et al. (1976), considering the costs of acquisition of animals (10.4 euros per kg of BW), hired labour, diet, sanitary (vaccines and vermifuge), tools and utensils, and slaughter. The hired labour was calculated as the salary of a worker in force in the region, reflecting a total of the remuneration dedicated to the activity. The local market prices of the ingredients included in the experimental TMR were considered to calculate the diet cost. The gross income (benefit) was calculated as: $\text{final BW (kg)} \times 1.35 \times 17.0$ (price of meat) + 40.0 (not edible constituent of carcass per animal) + 8.0 (skin), with all values representing the price paid in the local market. In addition, the gross margin per treatment and day and per animal and day were calculated. Finally, the ratio between benefit and OC was analysed.

The experiment was conducted in a completely randomized design with four treatments. The experimental unit was the lamb individually allocated. Prerequisites to run each test were checked, and data normality was tested with the Shapiro-Wilk test. All data were normally distributed. Data

were analysed using the regression procedure at the 5% probability level using the following model procedure:

$$Y_{ij} = \mu + s_i + e_{ij}, \quad (1)$$

in which Y_{ij} is the observed value, μ is the overall mean, s_i is the effect of SFC level, and e_{ij} is the experimental error (SPSS Inc., Chicago, IL). The polynomial contrasts were used to determine the linear (L) and quadratic (Q) effects of the diet SFC inclusion level when significant differences among diets were detected. The standard error of the mean was obtained as the standard deviation divided by the square root of the sample size. Significance was set at $P < 0.05$.

3. Results

The SFC used in the experimental diets had 34.5% CP, 6.31% EE, 37.5% NDF, 10.7% ADL, and 1.83 Mcal ME/kg (as average on DM basis; Table 1). Determined nutrient contents of the experimental TMR were similar to expected values (Table 2).

The inclusion level of SFC in the TMR did not affect final BW, ADG, ADFI, and FCR (Table 3). However, total BW gain decreased 0.03 g per every 1% of SFC included in the TMR (L; $P = 0.048$). Although the NDF contents in the experimental TMR increased with the SFC level, they did not affect the intakes of DM, OM, CP, EE, and NDF (Table 4). However, SFC inclusion decreased the DM intake per kg BW ($P = 0.040$ and 0.042 for L and Q effects, respectively) and NFC intake ($P = 0.018$ for L effect).

The inclusion of SFC up to 5% (10 and 15%) of the TMR decreased the apparent digestibility of all nutrients studied comparing with diets containing 10 and 15% of SFC ($P < 0.05$ for L and Q effects for all nutrients except for EE; Table 5).

Table 3 - Growth performance of lambs fed diets containing different levels of sunflower cake

Item	Sunflower cake level (%)				Regression	R ²	SEM	P-value ¹
	0	5	10	15				
Initial BW (kg)	18.6	19.7	20.0	19.8	$\hat{y} = 18.8$	-	0.45	0.280
Final BW (kg)	32.7	32.7	31.0	31.9	$\hat{y} = 32.7$	-	0.53	0.401
Total BW gain (kg)	14.6	13.0	11.0	12.1	$\hat{y} = 14.8 + 0.03x$	0.234	0.54	0.048
ADG (g/day)	229.2	209.2	184.9	192.6	$\hat{y} = 224$	0.126	8.82	0.101
ADFI (kg/day)	1.15	1.11	1.08	1.08	$\hat{y} = 1.14$	-	0.023	0.290
FCR	5.18	5.46	5.98	5.17	$\hat{y} = 5.09$	-	0.151	0.432

BW - body weight; ADG - average daily gain; ADFI - average daily feed intake; FCR - feed conversion ratio; R² - coefficient of determination; SEM - standard error of the means.

¹ Linear effect because quadratic effect was not significant for any trait studied.

Table 4 - Daily nutrient intake of lambs fed diets containing different levels of sunflower cake [kg/day as dry matter (DM) basis, unless otherwise indicated]

Item	Sunflower cake level (%)				Regression	R ²	SEM	P-value	
	0	5	10	15				L	Q
DM	1.09	1.10	1.02	0.99	$\hat{y} = 0.842$	-	0.035	0.235	0.473
DM (g/kg BW)	44.8	42.8	41.8	42.3	$\hat{y} = 45 - 0.56x + 0.03x^2$	0.261	0.47	0.040	0.042
DM (g/kg BW ^{0.75})	100.9	96.6	94.2	95.2	$\hat{y} = 99.6$	-	1.19	0.100	0.103
Organic matter	1.02	1.04	0.96	0.93	$\hat{y} = 1.04$	-	0.033	0.235	0.163
Mineral matter	0.066	0.068	0.063	0.060	$\hat{y} = 0.068$	-	0.0023	0.221	0.420
Crude protein	0.18	0.17	0.16	0.15	$\hat{y} = 0.18$	-	0.006	0.101	0.228
Ether extract	0.029	0.025	0.028	0.032	$\hat{y} = 0.027$	-	0.0011	0.260	0.100
Neutral detergent fibre	0.40	0.44	0.40	0.42	$\hat{y} = 0.412$	-	0.014	0.928	0.972
Non-fibrous carbohydrates	0.42	0.40	0.38	0.33	$\hat{y} = 0.42 - 0.001x$	0.246	0.014	0.018	0.113

BW - body weight; R² - coefficient of determination; SEM - standard error of the means; L and Q - linear and quadratic effects, respectively.

The TMR containing 15% SFC had the lowest OC (432.9 vs. 428.2 vs. 423.5 vs. 418.8 euros for TMR including 0, 5, 10 and 15% of SFC, respectively. Table 6). However, TMR containing 15% of SFC presented the lowest gross income and the lowest gross margin (455.6 vs. 452.7 vs. 435.8 vs. 426.8 euros and 22.7, 24.5, 12.2, and 8.0 euros for diets including 0, 5, 10, and 15% of SFC, respectively).

4. Discussion

The chemical composition of SFC is based on cell wall components such as lignocellulosic fibres (around 40% DM), protein fractions (around 30% DM), and other components (around 30% DM), many of which are water-soluble. The lack of homogeneity for the nutritional composition has been reported for SFC (Al-Masri, 2005; Weinberg et al., 2008). The EE content of the SFC used in current study was similar to the value reported by Qwele et al. (2013) but had more CP and less EE and hemicellulose comparing with the SFC used in other studies (Moura et al., 2015; Lima et al., 2018a; Monção et al., 2018). In fact, an important variability for the EE content of SFC has been observed with values ranging from 3.2% DM (Geneau-Sbartai et al., 2008) to more than 23% DM (Monção et al., 2018). The causes for this variability are unknown, but it might be due to differences in the extraction process used or even in variations of SFC composition among different origins.

Although no differences among diets were found for final BW and ADG, the inclusion of SFC in the TMR decreased the total BW gain of lambs, agreeing with previous results (Rodrigues et al., 2013;

Table 5 - Apparent digestibility of nutrients of lambs fed diets containing different levels of sunflower cake [% as dry matter basis]

Item	Sunflower cake level (%)				Regression	R ²	SEM	P-value	
	0	5	10	15				L	Q
Dry matter	72.1	77.7	67.2	60.5	$\hat{y} = 72.1 + 4.1x - 0.72x^2 + 0.03x^3$	0.692	1.58	0.001	0.000
Organic matter	73.9	78.8	69.2	62.9	$\hat{y} = 73.9 + 3.6x - 0.65x^2 + 0.024x^3$	0.675	1.49	0.001	0.000
Crude protein	70.6	78.1	65.9	64.0	$\hat{y} = 70.6 + 5.5x - 0.99x^2 + 0.04x^3$	0.540	1.57	0.024	0.019
Ether extract	62.6	69.7	43.1	57.2	$\hat{y} = 62.6 + 0.099x^3$	0.486	3.05	0.100	0.230
Neutral detergent fibre	61.3	68.4	57.0	52.3	$\hat{y} = 61.3 + 4.99x - 0.88x^2 + 0.03x^3$	0.618	1.59	0.002	0.000
Non-fibrous carbohydrates	88.2	90.7	85.1	75.7	$\hat{y} = 88.2 + 1.60x - 0.25x^2 + 0.006x^3$	0.548	1.58	0.006	0.002

R² - coefficient of determination; SEM - standard error of the means; L and Q - linear and quadratic effects, respectively.

Table 6 - Economic analysis of production of lambs fed diets containing different levels of sunflower cake (in euros, unless otherwise indicated)

Item	Sunflower cake level (%)			
	0	5	10	15
Operational cost				
Animal acquisition ¹	204.1	204.1	204.1	204.1
Hired labour	68.7	68.7	68.7	68.7
Feeding	93.7	89.0	84.3	79.6
Sanity	11.4	11.4	11.4	11.4
Tools and utensils	4.37	4.37	4.37	4.37
Slaughter cost	50.8	50.8	50.8	50.8
Total operational cost	439.9	428.2	423.5	418.8
Economic indicators				
Gross income	455.6	452.7	435.8	426.8
Gross margin (euros/treatment/day)	0.40	0.43	0.22	0.14
Gross margin (euros/animal/day)	0.07	0.07	0.04	0.02
Benefit:cost ratio	1.05	1.05	1.02	1.01

¹ 10.4 euros/kg of body weight.

Fernandes Júnior et al., 2015; Lima et al., 2018a; Monção et al., 2018). Rodrigues et al. (2013) found a linear reduction of 0.06 kg for total BW gain per every 1% of SFC included in the diet, similarly to the reduction of 0.03 kg found in the current study.

The inclusion of this byproduct did not limit the intake, which agrees with previous results obtained by Fernandes Júnior et al. (2015) and by Moura et al. (2015), assessing the good acceptability of diets containing SFC by lambs. In addition, there were no differences among treatments for the FCR according to Rodrigues et al. (2013) and Monção et al. (2018). Current results agree with those of Louvandini et al. (2007), who did not find differences for FCR of lambs when assessing diets containing sunflower meal as a substitute for soybean meal.

Based on performance traits, Rodrigues et al. (2013) recommended SFC inclusion levels from 21 to 28% of the diet. Similarly, Fernandes Júnior et al. (2015) replaced up to 80% cotton meal with SFC in lamb diets and concluded that lambs responded as expected up to the replacement levels of 20% and 40%, impairing animal performance from the 60% substitution. In general, SFC inclusion level did not influence growth performance. Therefore, TMR containing 15% of SFC supposes a possibility of using this byproduct in diets for lambs in confinement.

Dry matter (as kg/day) and OM intakes did not change with the inclusion of SFC in the TMR, which agrees with results obtained by Moura et al. (2015) for lambs and by Agy et al. (2012) for DM intake (kg/day) of goats. In addition, these results were expected since there were almost no differences in diet composition for these nutrients. Similar results for DM intake were found by Medeiros et al. (2003) for sheep receiving diets of up to 66% soybean meal replaced by sunflower meal. However, a decrease of DM intake expressed as g/kg BW was observed for diets containing SFC. Possibly, the intake limitation observed in current study occurred due to the physical action of fibre in the rumen, since, by including the SFC, the NDF of the diet increased by up to 4%. Also, digestion of the diet can be effective on feed intake. Diet digestibility has a positive correlation with intake. In the current study, feed intakes were similar, but differences were detected for nutrient digestibility among treatments. The cause for these results is unknown but it might be due to the fact that diets were isocaloric but contained different percentages of fibre.

The highest NFC intake was observed for the control diet based on corn and soybean meal. In fact, these two ingredients have high levels of NFC of rapid ruminal degradation. In particular, the NFC intake decreased 1 g (as average) for each unit of SFC added to the TMR. The reduction in the NFC intake observed in the current study with SFC inclusion was probably due to the reduction of the levels of this fraction in the diets which, in turn, is directly related to the increase of the EE contents of TMR with higher levels of SFC.

Some authors have observed a decrease in the nutrient digestibility with sunflower inclusion in the diets for lambs (Alves et al., 2016). However, in the current study, the highest apparent digestibility of nutrients was observed for TMR containing 5% SFC decreasing with diets containing 10 or 15% SFC, probably as a consequence of the higher content of EE and fibre compounds of diets containing 10 or 15% of SFC. Similar to our results, Lima et al. (2018a) found a linear decrease of the DM apparent digestibility of lambs fed diets containing 10, 20, and 30% SFC. The high digestibility found in the current study for CP with the diet containing 5% of SFC confirms the results observed by Mupeta et al. (1997). In addition, Oliveira et al. (2007) found higher CP digestibilities when replacing 25 and 50% of soybean and corn by SFC than with diets without SFC. Similarly to current results, a quadratic response was found by Garcia et al. (2004), when evaluating the EE digestibility of sunflower meal in diets for dairy cattle. Notably, the apparent digestibility of EE may be overestimated for the biosynthesis of lipids by microorganisms in the rumen and cecum in diets with low EE content, such as the control diet (Moura et al., 2015). Regarding fibre digestibility, the SFC fibre has low digestibility due to its high content of lignin. However, Santos et al. (2014) evaluated the digestibility of oilseed byproducts in lamb diets and found that the digestibility of total carbohydrates was 76% for SFC diet, similarly to that obtained for diets containing soybean and peanut pie. Differences reported among studies for apparent digestibility of nutrients could be attributed to differences in chemical composition among batches of SFC used, resulting in difference in digestibility or ruminal fermentation characteristics.

The major purpose of replacing soybean meal with alternative sources such as SFC is to reduce animal production costs (Monção et al., 2018). Sunflower is one of the four major predominant oleaginous cultures in the world, widely cultivated in the five continents (USDA, 2016). Therefore, SFC could be an alternative raw material globally available.

In the economic evaluation, the OC decreased with the inclusion of SFC compared with the control diet. In fact, diet containing 15% of SFC presented the lowest OC and the lowest gross revenues due to the substitution of corn and soybean meal by SFC. Therefore, and despite the reduction in diet costs, and consequently in total OC, the inclusion of SFC in lamb diets did not generate the best profitability. Moreover, current results showed that the benefit:cost ratio was positive for all treatments with the TMR including 5% of SFC having the same benefit:cost ratio than the control diet, standing out as the best option of profitability. Similarly, Monção et al. (2018) concluded that the inclusion up to 10% SFC in the diet of feedlot lambs increased the economic viability of the activity with a higher net revenue for marketing live or slaughtered animals. Therefore, inclusion level of 5% of SFC in lamb diets could be recommended under the economical point of view.

5. Conclusions

According to current results, sunflower cake with the chemical composition used in this study can be included in diets for confined lambs in up to 15% without damage to slaughter body weight, feed intake, or feed conversion ratio. However, an inclusion level of 5% of sunflower cake is recommended if the apparent digestibility of nutrients and the benefit:cost ratio are considered, thus being an alternative to corn and soybean meal in lamb diets.

Author Contributions

Conceptualization: L.F.S. Monteiro, A.M.P. Melo and J.M. Lorenzo. Data curation: A.N. Medeiros. Formal analysis: M.P. Serrano, R.G. Costa and A.N. Medeiros. Funding acquisition: J.M. Lorenzo. Investigation: V. Lima Júnior and J.M. Lorenzo. Methodology: R.G. Costa and A.N. Medeiros. Project administration: L.F.S. Monteiro and J.M. Lorenzo. Supervision: A.M.P. Melo. Validation: A.M.P. Melo. Writing-original draft: M.P. Serrano. Writing-review & editing: L.F.S. Monteiro, A.M.P. Melo, R.G. Costa, V. Lima Júnior, A.N. Medeiros and J.M. Lorenzo.

Conflict of Interest

The authors declare no conflict of interest.

References

- Agy, M. S. F. A.; Oliveira, R. L.; Ribeiro, C. V. D. M.; Ribeiro, M. D.; Bagaldo, A. R.; Araújo, G. G. L.; Pinto, L. F. B. and Ribeiro, R. D. X. 2012. Sunflower cake from biodiesel production fed to crossbred Boer kids. *Revista Brasileira de Zootecnia* 41:123-130. <https://doi.org/10.1590/S1516-35982012000100019>
- Al-Masri, M. R. 2005. Nutritive value of some agricultural wastes as affected by relatively low gamma irradiation levels and chemical treatments. *Bioresource Technology* 96:1737-1741. <https://doi.org/10.1016/j.biortech.2004.12.032>
- Alves, F. J. L.; Ferreira, M. A.; Urbano, S. A.; Andrade, R. P. X.; Silva, A. E. M.; Siqueira, M. C. B.; Oliveira, J. P. F. and Silva, J. L. 2016. Performance of lambs fed alternative protein sources to soybean meal. *Revista Brasileira de Zootecnia* 45:145-150. <https://doi.org/10.1590/S1806-92902016000400001>
- AOAC - Association of Official Analytical Chemists. 2002. Official methods of analysis of AOAC. 17th ed. AOAC, Washington, D.C., USA.
- AOAC - Association of Official Analytical Chemists. 2005. Official methods of analysis of AOAC. 18th ed. AOAC, Arlington, VA, USA.
- Bezerra, L. S.; Barbosa, A. M.; Carvalho, G. G. P.; Simonato, J. I.; Freitas Jr, J. E.; Araújo, M. L. G. M. L.; Pereira, L.; Silva, R. R.; Lacerda, E. C. Q. and Carvalho, B. M. A. 2016. Meat quality of lambs fed diets with peanut cake. *Meat Science* 121:88-95. <https://doi.org/10.1016/j.meatsci.2016.05.019>

- Cirne, L. G. A.; Silva Sobrinho, A. G.; Almeida, F. A.; Santana, V. T.; Endo, V.; Zeola, N. M. B. L. and Almeida, A. K. 2016. Carcass characteristics of lambs fed diets with mulberry hay. *Semina: Ciências Agrárias* 37:2737-2748. <https://doi.org/10.5433/1679-0359.2016v37n4Supl1p2737>
- Costa, J. B.; Oliveira, R. L.; Silva, T. M.; Ribeiro, R. D. X.; Silva, A. M.; Leão, A. G.; Bezerra, L. R. and Rocha, T. C. 2016. Intake, digestibility, nitrogen balance, performance, and carcass yield of lambs fed licuri cake. *Journal of Animal Science* 94:2973-2980. <https://doi.org/10.2527/jas.2015-0143>
- De Melo, A. M. P.; López-Pedrouso, M.; Costa, R. G.; Franco, D.; Moura, A. A. A. N.; Silva, T. A.; Moreno, F. B. M. B.; Lima Júnior, V.; Monteiro-Moreira, A. C. O.; Medeiros, A. N.; Moreira, R. A. and Lorenzo, J. M. 2020. Proteome changes in lamb *semimembranosus* muscles associated with the inclusion of sunflower cake in their diet. *International Journal of Food Science and Technology* 55:995-1001. <https://doi.org/10.1111/ijfs.14328>
- FEDNA - Fundación Española para el Desarrollo de la Nutrición Animal. 2016. Tablas FEDNA de composición de alimentos. Valor nutritivo. Available at: <<http://www.fundacionfedna.org/ingredientes-para-piensos>>. Accessed on: Sept. 12, 2019.
- Fernandes Júnior, F.; Ribeiro, E. L. A.; Mizubuti, I. Y.; Silva, L. D. F.; Barbosa, M. A. A. F.; Prado, O. P. P.; Pereira, E. S.; Pimentel, P. G. and Constantino C. 2013 Características de carcaça e qualidade da carne de cordeiros Santa Inês alimentados com torta de girassol em substituição ao farelo de algodão. *Semina: Ciências Agrárias* 34:3999-4014. <https://doi.org/10.5433/1679-0359.2013v34n6Supl2p3999>
- Fernandes Júnior, F.; Ribeiro, E. L. A.; Castro, F. A. B.; Mizubuti, I. Y.; Silva, L. D. F.; Pereira, E. S.; Pinto, A. P.; Barbosa, M. A. A. F. and Koritiaki, N. A. 2015. Desempenho, consumo e morfometria *in vivo* de cordeiros Santa Inês alimentados com rações contendo torta de girassol em substituição ao farelo de algodão. *Arquivo Brasileiro de Medicina Veterinária e Zootecnia* 67:483-491. <https://doi.org/10.1590/1678-7071>
- Garcia, J. A.; Vieira, P. F.; Cecon, P. R.; Melo, G. M. P.; Martins, A. S. and Setti, M. C. 2004. Digestibilidade aparente do farelo de girassol na alimentação de bovinos leiteiros em fase de crescimento. *Ciência Animal Brasileira* 5:123-129.
- Geneau-Sbartai, C.; Leyris, J.; Silvestre, F. O. and Rigal, L. 2008. Sunflower cake as a natural composite: composition and plastic properties. *Journal of Agricultural and Food Chemistry* 56:11198-11208. <https://doi.org/10.1021/jf8011536>
- Goes, R. H. T. B.; Souza, K. A.; Patussi, R. A.; Cornelio, T. C.; Oliveira, E. R. and Brabes, K. C. S. 2010. Degradabilidade *in situ* dos grãos de cambre, girassol e soja, e de seus coprodutos em ovinos. *Acta Scientiarum. Animal Sciences* 32:271-277. <https://doi.org/10.4025/actascianimsci.v32i3.7913>
- Guimarães, G. S.; Silva, F. F.; Silva, L. L.; Galvão, L. M. G.; Santos, L. M. and Alencar, A. M. 2014. Intake, digestibility and performance of lambs fed with diets containing cassava peels. *Ciência e Agrotecnologia* 38:295-302. <https://doi.org/10.1590/S1413-70542014000300010>
- Lima, A. G. V. O.; Silva, T. M.; Bezerra, L. R.; Pereira, E. S.; Barbosa, A. M.; Ribeiro, R. D. X.; Rocha, T. C.; Trajano, J. S. and Oliveira, R. L. 2018a. Intake, digestibility, nitrogen balance, performance and carcass traits of Santa Inês lamb fed with sunflower cake from biodiesel production. *Small Ruminant Research* 168:19-24. <https://doi.org/10.1016/j.smallrumres.2018.09.003>
- Lima, A. G. V. O.; Oliveira, R. L.; Silva, T. M.; Barbosa, A. M.; Nascimento, T. V. C.; Oliveira, V. S.; Ribeiro, R. D. X.; Pereira, E. S. and Bezerra, L. R. 2018b. Feeding sunflower cake from biodiesel production to Santa Inês lambs: physicochemical composition, fatty acid profile and sensory attributes of meat. *PLoS ONE* 13:e0188648. <https://doi.org/10.1371/journal.pone.0188648>
- Louvandini, H.; Nunes, G. A.; Garcia, J. A. S.; McManus, C.; Costa, D. M. and Araújo, S. C. 2007. Desempenho, características de carcaça e constituintes corporais de ovinos Santa Inês alimentados com farelo de girassol em substituição ao farelo de soja na dieta. *Revista Brasileira de Zootecnia* 36:603-609. <https://doi.org/10.1590/S1516-35982007000300013>
- Matsunaga, M.; Bemelmans, P. F.; Toledo, P. E. N.; Dulle, R. D.; Okawa, H. and Pedroso, I. A. 1976. Metodologia de custo de produção utilizada pelo IEA. *Agricultura em São Paulo* 23:123-139.
- Medeiros, O. N.; Honório, F. O. and Lisboa, O. C. 2003. Desempenho de cordeiros Santa Inês alimentados com farelo de girassol. In: *Anais da 40ª Reunião Anual da Sociedade Brasileira de Zootecnia*, Santa Maria.
- Monção, F. P.; Oliveira, E. R.; Araújo Gabriel, A. M.; Gandra, J. R.; Araki, H. M. C.; Almeida Nascimento, F.; Rodrigues, G. C. G. and Pereira, T. L. 2018. Economic feasibility of producing feedlot lambs fed on sunflower cake. *Iranian Journal of Applied Animal Science* 8:629-634.
- Moura, E. S.; Silva, L. D. F.; Peixoto, E. L. T.; Bumbieris Junior, V. H.; Ribeiro, E. L. A.; Mizubuti, I. Y. and Fortaleza, A. P. S. 2015. Sunflower cake in diets for lambs: intake, digestibility, nitrogen balance and rumen parameters. *Semina: Ciências Agrárias* 36:2247-2258. <https://doi.org/10.5433/1679-0359.2015v36n3Supl1p2247>
- Mupeta, B.; Weisbjerg, M. R.; Hvelplund, T. and Madsen, J. 1997. Digestibility of amino acids in protein rich tropical feeds for ruminants estimated with the mobile bag technique. *Animal Feed Science and Technology* 69:271-280. [https://doi.org/10.1016/S0377-8401\(97\)81641-0](https://doi.org/10.1016/S0377-8401(97)81641-0)
- NRC - National Research Council. 2007. Nutrient requirements of small ruminants: sheep, goats, cervids, and new world camelids. National Academy Press, Washington, DC, USA.
- Oliveira, M. D. S.; Mota, D. A.; Barbosa, J. C.; Stein, M. and Borgonovi, F. 2007. Composição bromatológica e digestibilidade ruminal *in vitro* de concentrados contendo diferentes níveis de torta de girassol. *Ciência Animal Brasileira* 8:629-683.

- Qwele, K.; Hugo, A.; Oyedemi, S. O.; Moyo, B.; Masika, P. J. and Muchenje V. 2013. Chemical composition, fatty acid content and antioxidant potential of meat from goats supplemented with Moringa (*Moringa oleifera*) leaves, sunflower cake and grass hay. *Meat Science* 93:455-462. <https://doi.org/10.1016/j.meatsci.2012.11.009>
- Rodrigues, D. N.; Cabral, L. S.; Lima, L. R.; Zervoudakis, J. T.; Galati, R. L.; Oliveira, A. S.; Costa, D. P. B. and Geron, L. J. V. 2013. Desempenho de cordeiros confinados, alimentados com dietas à base de torta de girassol. *Pesquisa Agropecuária Brasileira* 48:426-432. <https://doi.org/10.1590/S0100-204X2013000400011>
- Santos, V. C.; Ezequiel, J. M. B.; Morgado, E. S.; Fávoro, V. R.; D'Áurea, A. P. and Sousa Junior, S. C. 2014. Desempenho e digestibilidade de componentes nutritivos de dietas contendo subprodutos de oleaginosas na alimentação de cordeiros. *Semina: Ciências Agrárias* 35:1577-1586. <https://doi.org/10.5433/1679-0359.2014v35n3p1577>
- Santos, R. C.; Alves, K. S.; Mezzomo, R.; Oliveira, L. R. S.; Cutrim, D. O.; Gomes, D. I.; Leite, G. P. and Araújo, M. Y. S. 2016. Performance of feedlot lambs fed palm kernel cake-based diets. *Tropical Animal Health and Production* 48:367-372. <https://doi.org/10.1007/s11250-015-0960-y>
- Tufarelli, V.; Introna, M.; Cazzato, E.; Mazzei, D. and Laudadio, V. 2013. Suitability of partly destoned exhausted olive cake as by-product feed ingredient for lamb production. *Journal of Animal Science* 91:872-877. <https://doi.org/10.2527/jas.2012-5541>
- USDA - United States Department of Agriculture. 2016. Oilseeds: world market and trade. Available at: <<http://apps.fas.usda.gov/psdonline/circulars/oilseeds.pdf>>. Accessed on: Sept 12, 2019.
- Van Soest, P. J.; Robertson, J. B. and Lewis, B. A. 1991. Methods for dietary fiber, neutral detergent fiber, and nonstarch polysaccharides in relation to animal nutrition. *Journal of Dairy Science* 74:3583-3597. [https://doi.org/10.3168/jds.S0022-0302\(91\)78551-2](https://doi.org/10.3168/jds.S0022-0302(91)78551-2)
- Vasta, V.; Nudda, A.; Cannas, A.; Lanza, M. and Priolo, A. 2008. Alternative feed resources and their effects on the quality of meat and milk from small ruminants. *Animal Feed Science and Technology* 147:223-246. <https://doi.org/10.1016/j.anifeedsci.2007.09.020>
- Weinberg, Z. G.; Chen, Y. and Weinberg, P. 2008. Ensiling olive cake with and without molasses for ruminant feeding. *Bioresource Technology* 99:1526-1529. <https://doi.org/10.1016/j.biortech.2007.04.022>