

Financial analysis of finishing lambs fed a tropical grass hay-based diet containing rehydrated corn silage inoculated with autochthonous microorganisms

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Received: July 8, 2025
Accepted: April 30, 2026

How to cite: Soares, D. F. V.; Sedlmayer, T. G. S. C.; Moraes, N. S. L.; Ruas, L. P. A. C.; Martins Júnior, V. S.; Sá, H. C. M.; Souza, B. M. S.; Duarte, E. R. and Lima, L. S. 2026. Financial analysis of finishing lambs fed a tropical grass hay-based diet containing rehydrated corn silage inoculated with autochthonous microorganisms. Revista Brasileira de Zootecnia 55:e20250116. <https://doi.org/10.37496/rbz5520250116>

Editors:
Marcio de Souza Duarte
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ABSTRACT - We evaluated the effects of adding fungal inoculants composed of *Rhodotorula mucilaginosa* and *Trichoderma longibrachiatum* to rehydrated corn silage fed to lambs receiving a tropical grass hay-based diet and their impact on financial viability. The effects of combined inoculation on dry matter intake (DMI) and weight gain were analyzed. A total of 22 male Dorper × Santa Ines crossbred lambs, with an average body weight of 14.20 ± 1.74 kg, were randomly assigned to two treatments: (1) control (CTL), without inoculant and receiving only the culture medium; and (2) inoculated (INO), with the addition of *Rhodotorula mucilaginosa* and *Trichoderma longibrachiatum*. The experimental diets were formulated to meet the nutritional requirements of finishing lambs. The animals were fed a total mixed ration offered *ad libitum*, with 20% orts, containing 500 g/kg of dry matter (DM) as Tifton hay. The lambs were housed in individual cages equipped with feeders, drinkers, and a funnel to direct excreta. The combination of microorganisms reduced DMI ($P < 0.05$), with values of 102.51 g/kg $BW^{0.75}/d$ in the control group and 91.79 g/kg $BW^{0.75}/d$ in the treatment group. However, lambs fed INO and CTL diets showed similar feed-to-gain ratios and final body weights after 63 days in the feedlot, with values of 30.50 and 31.39, respectively ($P > 0.05$). In addition, lambs fed INO showed better overall profit (4.54 US\$/head or 0.29 US\$/kg BW) than those fed CTL ($P < 0.05$). Feeding finishing lambs with rehydrated corn silage inoculated with *Rhodotorula mucilaginosa* and *Trichoderma longibrachiatum* improves financial viability by reducing feed costs.

Keywords: feed-to-gain ratio, intake, production cost, revenue, total benefit, weight gain

1. Introduction

As in any other livestock system, feeding accounts for the majority of production costs in sheep production. Particularly in the tropics, the use of grains should be strategic, prioritizing categories with

higher nutritional requirements, such as finishing lambs, to maximize productive performance without excessively increasing costs. This strategy is necessary because tropical forages, although characterized by high dry matter production, generally contain higher concentrations of neutral detergent fiber (NDF), acid detergent fiber (ADF), and lignin, as well as lower levels of crude protein and non-fibrous carbohydrates, resulting in lower digestibility and nutritional value than temperate forages (Riaz et al., 2025). Therefore, strategies that improve nutrient utilization and reduce feed costs are highly desirable.

Ensiling rehydrated corn grain has become an important strategy for improving starch digestibility and reducing field losses and damage caused by insects and rodents (Daniel et al., 2022). As with other types of corn silage, researchers have investigated various additives, such as inoculants, to improve fermentation and reduce spoilage in rehydrated corn silage (Silva et al., 2019). In addition, inoculants can alter the microbial profile of silages (Xu et al., 2019) and may remain active in the rumen after ingestion by animals (Weinberg et al., 2016). Thus, rehydrated corn silage could also be used as a vehicle for delivering live microorganisms to sheep, potentially improving animal performance.

In our previous study (Soares et al., 2025), we observed that rehydrated corn silage inoculated with *Rhodotorula mucilaginosa* and *Trichoderma longibrachiatum* reduced fiber content and dry matter intake in tropical hay-based diets, without affecting body weight gain. Similarly, Martins Júnior et al. (2022) showed that lambs supplemented with a yeast (*Rhodotorula mucilaginosa*) isolated from sheep rumen fluid had greater dry matter intake (DMI) when fed a diet containing low-quality forage. In another study, Magaço et al. (2020) evaluated the performance of lambs fed low-quality hay supplemented with a strain of the fungus *Trichoderma longibrachiatum* isolated from the gastrointestinal tract of sheep. The authors observed an increase in average daily gain which were 1.86 kg greater than those of unsupplemented lambs, after 42 days of confinement. However, the effects of the combined use of these two microorganisms in sheep diets have not been investigated, particularly regarding their effects on both animal performance and financial viability.

Based on our previous findings that rehydrated corn silage inoculated with *Rhodotorula mucilaginosa* and *Trichoderma longibrachiatum*, which reduced dry matter intake without affecting final body weight in finishing lambs (Soares et al., 2025), we hypothesized that this feeding strategy may also improve the financial viability of the finishing phase in feedlot systems. Thus, the present study was conducted to evaluate the effects of combined inoculation with *Rhodotorula mucilaginosa* and *Trichoderma longibrachiatum*, isolated from the gastrointestinal tract of sheep, on the financial viability of finishing lambs fed a tropical grass hay-based diet.

2. Material and methods

All animal care and handling procedures were approved by the Animal Care and Use Committee of the Universidade Federal de Minas Gerais, Brazil (protocol no. 251/2021).

2.1. Ensiling

Corn grain was ground in a hammer mill with a 2-mm screen. Before ensiling, the ground corn was rehydrated with chlorine-free water in a horizontal helical mixer to achieve a final moisture concentration of 350 g/kg. For each treatment, 700 kg of rehydrated corn were ensiled in polyethylene bags (200 µm, 51 × 110 cm, 60 L; Silo Plast, Maringá, Brazil) using an electric silage bagger and compactor (Do Campo Agrícola, Rio Grande do Sul, Brazil). After ensiling (packing and sealing), the silos were weighed to calculate silage density (925 kg/m³) and stored for at least 45 days.

During corn rehydration, treatments were defined as: (1) control (CTL), without inoculant and receiving only the culture medium (Sabouraud broth; KASVI®, Teramo, Italy). The medium contained 10 g of peptone and 20 g of dextrose per liter and was added at 14.7 mL/kg of rehydrated corn; and (2) inoculated (INO), with the addition of *Rhodotorula mucilaginosa* and *Trichoderma longibrachiatum* (GenBank KX463453.1) at 1×10⁹ CFU/kg. The microorganisms were isolated from the ruminal fluid

of healthy sheep fed tropical forages (Freitas et al., 2012; Magaço et al., 2020; Martins et al., 2022; Martins Júnior et al., 2022). The experimental dose was defined based on previous studies (Diaz et al., 2018; Magaço et al., 2020; Martins Júnior et al., 2022).

2.2. Animals, experimental design, and diets

A total of 22 intact male Dorper × Santa Inês lambs (approximately 3 months of age; 14.20 ± 1.74 kg BW) from the same herd were housed in individual metabolic cages (1.0×2.0 m) located in a covered barn equipped with exhaust fans. The cages were equipped with feeders, drinkers, and a funnel for collecting excreta. At the beginning of the experiment, all lambs were individually identified using numbered ear tags, weighed (after a 16-h fast), and dewormed with ivermectin 1% (0.2 mg/kg BW, subcutaneously; Vallée, Minas Gerais, Brazil) and albendazole (Aldazol®, 10 mg/kg BW, orally; Vallée, Minas Gerais, Brazil). In addition, they received an anticoccidial treatment with toltrazuril (Isocox®, 20 mg/kg BW, orally; Ouro Fino, São Paulo, Brazil) and were vaccinated against clostridiosis (Poli-Start; Vallée, Minas Gerais, Brazil), according to the manufacturer's instructions.

Lambs were fed a standard diet for a 14-day adaptation period. Afterward, lambs were randomly assigned to one of the two treatments (CTL and INO) for 63 days. The experimental diet was formulated to meet the nutritional requirements of finishing lambs (target average daily gain of 250 g), with a maturity level of 0.6 (early-maturing genotype), according to the NRC (2007). The diet comprised Tifton hay, rehydrated corn silage, soybean meal, and a mineral supplement (Table 1). Throughout the experiment, animals were fed twice daily (08:00 and 16:00 h) a total mixed ration offered ad libitum (allowing for 20% refusals on an as-fed basis), and feed intake was recorded daily. Lambs were weighed every seven days to monitor weight gain and adjust the feed allowance. On Days 1 and 63 of the experimental period, the animals were weighed after a 16-h feed withdrawal to obtain the initial and final body weights (IBW and FBW, respectively). Samples of the diet, rehydrated corn silage, and orts were collected weekly and stored at -20 °C to form composite samples every three weeks.

Table1 - Ingredient and chemical composition of the experimental diet and rehydrated corn

Item	Total mixed diet	Rehydrated corn silage	
		Control	Inoculant
Ingredient (g/kg DM)			
Tifton hay	500.4		
Rehydrated corn	248.7		
Soybean meal	220.8		
Mineral supplement ¹	15.0		
Limestone	12.6		
Dicalcium phosphate	2.5		
Chemical composition			
Dry matter (g/kg)	810.5	622.8	631.9
Organic matter (g/kg DM)	906.9	987.5	984.2
Ash (g/kg DM)	93.1	12.5	15.8
Crude protein (g/kg DM)	186.9	97.9	98.0
Ether extract (g/kg DM)	27.1	42.8	38.9
Neutral detergent fiber (g/kg DM)	453.2	134.8	89.9
Non-fibrous carbohydrates (g/kg DM) ²	237.7	712.0	757.4
Total digestible nutrient (g/kg DM) ³	660.0	660.0	660.0

¹ Composition (per kg of MN): sodium (147 g/kg), calcium (110 g/kg), phosphorous (87 g/kg), sulfur (18 g/kg), zinc (3,800 mg/kg), manganese (2,000 mg/kg), fluorine (870 mg/kg), copper (590 mg/kg), molybdenum (300 mg/kg), iodine (50 mg/kg), selenium (20 mg/kg), chromium (20 mg/kg), cobalt (15 mg/kg).

² Calculated according to Hall (2000) as: NFC (g/kg DM) = $1000 - (\text{CP} + \text{EE} + \text{NDF} + \text{Ash})$.

³ Estimated using food values published in the NRC (2007).

2.3. Chemical analysis

Composite samples were dried in a air-forced oven at 55 °C for 72 h and ground through a 1-mm screen in a Wiley mill. Dry matter (DM) was determined using method 934.01 (AOAC, 1990). Ash was determined by combustion in a muffle furnace (method 942.05; AOAC, 1990), and organic matter was calculated as the difference between DM and ash. Total nitrogen (N) was determined using a Tecnal TE-036/1 (Tecnal, Piracicaba, SP, Brazil) following method 988.05 (AOAC, 1990), and crude protein (CP) was estimated as $N \times 6.25$. Ether extract (EE) was determined according to Detmann et al. (2012). Neutral detergent fiber, including residual ash (aNDF), was determined using heat-stable α -amylase, as described by Mertens (2002). Non-fibrous carbohydrates (NFC) were estimated according to Hall (2000) using the equation: $NFC \text{ (g/kg DM)} = 1000 - (CP + EE + \text{neutral detergent fiber} + \text{ash})$.

2.4. Financial analysis

The economic evaluation was conducted according to the methodological approaches proposed by Pereira et al. (2013) and Rozanski et al. (2019), with adaptations to reflect the actual revenue structure of finishing lamb production systems. Financial indicators were calculated to assess the economic efficiency of the feeding strategies using production costs, revenue, and the benefit-to-cost ratio.

The following variables were used as inputs for the financial analysis: purchase price of lambs, daily dry matter intake (DMI), diet cost, body weight gain, selling price of lambs, and final body weight. Brazilian average market prices for the years 2021 and 2022 were adopted for all economic inputs, based on data from the Center for Advanced Studies on Applied Economics (CEPEA, 2023). Productive performance variables, including dry matter intake (DMI), body weight gain (BW gain), and average daily gain (ADG), were obtained from Soares et al. (2025). The cost of the marginal factor (CMF) was defined as the daily feeding cost per lamb (US\$/lamb/day) and calculated as:

$$CMF = DMI \times \text{Feed cost}$$

in which DMI is daily dry matter intake (kg DM/lamb/day) and Feed cost is the cost of the diet per kilogram of dry matter (US\$/kg DM). The total cost of the marginal factor (US\$/lamb) was obtained by:

$$\text{Total CMF} = CMF \times \text{Days}$$

in which Days represents the duration of the finishing period (days). The purchase price for lambs (US\$/lamb) was calculated as:

$$\text{Purchase price} = \text{Initial body} \times \text{Market price at purchase}$$

The total cost (TC) considered in the analysis was defined as the sum of the purchase price for lambs and the total cost of the marginal factor:

$$TC = \text{Purchase price} + \text{Total CMF}$$

Other indirect production costs, such as labor, infrastructure, and equipment depreciation, were not included in the analysis, as they were assumed to be similar across treatments. The revenue of the marginal factor (RMF) was defined as the realized revenue at slaughter (US\$/lamb) and calculated as:

$$RMF = \text{Final body weight} \times \text{Market selling price}$$

in which Final body weight is the body weight at the end of the finishing period and Market selling price corresponds to the average market price for lambs. Although animals were marketed only at slaughter, RMF was used as an economic indicator to enable comparison among feeding strategies, without imputing daily revenues. Net income (NI), equivalent to gross profit, was calculated as:

$$NI = RMF - (\text{Total CMF} + \text{Purchase price})$$

Net income was also expressed per kilogram of body weight (US\$/kg BW) to standardize economic performance relative to animal size:

$$\text{NI kg BW} = \frac{\text{NI}}{\text{Final body weight}}$$

The benefit-to-cost ratio (BCR), representing the overall economic efficiency of the production system, was calculated as:

$$\text{BCR} = \frac{\text{RMI}}{\text{TC}}$$

In addition, the benefit-to-cost ratio of the marginal factor (BCRMF), which reflects the efficiency of feeding costs alone, was calculated as:

$$\text{BCRMF} = \frac{\text{RMF}}{\text{Total CMF}}$$

2.5. Statistical analysis

All results were analyzed using the R software (R Core Team, 2021). The normality and homogeneity of variances of the residues between treatments were assessed using the Shapiro-Wilk and Bartlett tests, respectively. Data were analyzed as a completely randomized design with the following model:

$$Y_{ij} = \mu + T_i + \beta (X_{ij} - \bar{X}_{...}) + \varepsilon_{ij},$$

in which Y_{ij} , the dependent variable; μ , overall mean; T_i , the fixed effect of treatment ($i = 1$ to 2); β , the regression coefficient of Y over X ; X_{ij} , average observation of the covariate (initial BW); $\bar{X}_{...}$, the overall mean for covariate X ; and ε_{ij} , the random residual error. Results were presented as means and their standard error. Data were analyzed using analysis of variance (ANOVA), and P-values are presented in the tables. Statistical significance was declared at $P \leq 0.05$ and tendencies at $0.05 < P \leq 0.10$.

3. Results

The chemical composition of the rehydrated corn silages (Table 1) showed that the inoculated silage had lower neutral detergent fiber (NDF; 89.9 vs. 134.8 g/kg DM) and higher non-fibrous carbohydrates (NFC; 757.4 vs. 712.0 g/kg DM) compared with the control. Total digestible nutrients were similar between treatments (660 g/kg DM).

Growth performance data (Table 2) have been previously reported and discussed in detail in our preliminary studies (Soares et al., 2025). Briefly, lambs fed the INO diet showed lower total DMI ($P = 0.003$), ADG ($P = 0.031$), and total BW gain ($P = 0.032$) than those fed CTL (Table 2). No treatment effect was observed for the final BW ($P = 0.666$) or feed-to-gain ratio ($P = 0.178$). These performance parameters were used as inputs for the economic evaluation conducted in the present study.

Table 2 - Dry matter intake and body weight gain of finisher lambs fed a tropical grass hay-based diet containing rehydrated corn silage inoculated with *Rhodotorula mucilaginosa* + *Trichoderma longibrachiatum*

Item	Treatment		SEM	P-value
	Control	Inoculant		
Dry matter intake (g/kg BW ^{0.75} /d)	102.51a	91.79b	2.219	0.0027
Initial body weight (kg)	14.43	15.08	0.806	0.1778
Final body weight (kg)	31.39	30.50	1.423	0.6660
Average daily gain (kg/day)	0.252a	0.230b	0.0073	0.0307
Total body weight gain (kg)	17.80a	16.26b	0.531	0.0320
Feed-to-gain ratio (kg)	4.607	4.492	0.0893	0.1765

SEM - standard error of the mean.

Means within a row with different letters differ at $P \leq 0.05$.

Purchase and selling prices were standardized on a live body weight basis to ensure comparability between treatments. Lambs were purchased at a fixed price corresponding to their initial body weight (US\$ 38.38 per lamb; approximately US\$ 2.60-2.70/kg BW) and marketed according to final live weight, generating total revenue of US\$ 68.18 and US\$ 66.49 per lamb for the CTL and INO groups, respectively. These values were used to calculate gross profit per lamb and per kilogram of body weight gain. Daily and total feed costs (Table 3) were lower for lambs fed the INO diet than for those fed the CTL diet (US\$ 0.39 vs. US\$ 0.423 per lamb/day, $P = 0.005$; and US\$ 23.92 vs. US\$ 26.22 per lamb, $P = 0.004$, respectively). No treatment effect was observed for total revenue ($P = 0.1182$). However, gross profit, expressed as US\$/kg BW and US\$/lamb, was greater ($P = 0.011$ and $P = 0.025$, respectively) for lambs fed the INO diet than for those fed the CTL diet. Despite the lower feed costs, final body weight did not differ between groups, supporting the economic interpretation.

Additionally, the cost of the marginal factor (CMF) (Table 4) was lower in INO ($P = 0.005$), while the revenue of the marginal factor (RMF) did not differ between treatments ($P = 0.118$). Although the overall benefit-to-cost ratio (BCR) was similar between treatments ($P = 0.977$), the benefit-to-cost ratio of the marginal factor (BCRMF) was greater in lambs fed INO ($P = 0.006$).

Table 3 - Financial analysis of finisher lambs fed a tropical grass hay-based diet containing rehydrated corn silage inoculated with *Rhodotorula mucilaginosa* + *Trichoderma longibrachiatum*

Item	Treatment		SEM	P-value
	Control	Inoculant		
Purchase price of lambs	\$38.38	\$38.38	0.0001	0.185
Feed cost (US\$/lamb.d)	\$0.423a	\$0.390b	0.010	0.005
Feed cost (US\$/lamb)	\$26.22a	\$23.92b	0.641	0.004
Total revenue (US\$/lamb)	\$68.18	\$66.49	1.041	0.118
Gross profit ¹ (US\$/lamb)	\$4.47b	\$4.54a	0.0001	0.025
Gross profit ¹ (US\$/kg BW)	\$0.26b	\$0.29a	0.009	0.011

SEM - standard error of the mean.

¹ Total revenue - (Feed cost + Purchase price for lambs).

Means within a row with different lowercase letters differ at $P \leq 0.05$.

Table 4 - Economic indicators of finisher lambs fed a tropical grass hay-based diet containing rehydrated corn silage inoculated with *Rhodotorula mucilaginosa* + *Trichoderma longibrachiatum*

Item	Treatment		SEM	P-value
	Control	Inoculant		
CMF (US\$/lamb/day)	\$0.423a	\$0.390b	0.020	0.005
Total cost of the marginal factor (US\$/lamb)	\$26.22a	\$23.92b	0.641	0.004
RMF (US\$/lamb)	\$68.18	\$66.49	1.040	0.118
Net income (US\$/lamb)	\$4.47b	\$4.54a	0.0001	0.025
Net income (US\$/kg BW)	\$0.26b	\$0.29a	0.009	0.011
Benefit-to-cost ratio (BCR)	\$1.06	\$1.07	0.012	0.977
Benefit-to-cost ratio of the marginal factor (BCRMF)	\$2.59b	\$2.75a	0.0468	0.006

CMF - cost of marginal factor; RMF - revenue of the marginal factor; SEM - standard error of the mean.

Means within a row with different lowercase letters differ at $P \leq 0.05$.

4. Discussion

In the present study, the combined inoculation of *Rhodotorula mucilaginosa* (RM) and *Trichoderma longibrachiatum* (TL) in rehydrated corn silage reduced DMI in lambs. The lower DMI observed in lambs fed the INO diet may be associated with greater ruminal starch availability resulting from the

ensiling of inoculated rehydrated corn. During ensiling, proteolysis of the protein matrix surrounding starch granules can occur, increasing starch accessibility to ruminal microorganisms and potentially enhancing ruminal starch fermentation. This effect may be related to the hydrolytic activity of the inoculated microorganisms. Although high proteolytic activity is relatively uncommon in yeasts (Rodarte et al., 2011), previous studies have reported that fungi such as *Trichoderma* spp. are prolific producers of hydrolytic enzymes, including proteases (Lopes et al., 2012). Greater ruminal starch fermentability has been associated with reduced DMI in ruminants (Swingle et al., 1999; Parsons et al., 2007). This phenomenon is attributed to the hepatic oxidation theory, which posits that the satiety and hunger of ruminants are regulated by the energy status of hepatocytes (Allen et al., 2009). Greater ruminal fermentation of starch increases propionate production, which, after absorption and metabolism in the liver, stimulates hepatic oxidation and promotes satiety, thereby reducing feed intake (Junges et al., 2017). Although ruminal fermentation characteristics were not measured in the present study, the reduction in DMI suggests that inoculation may have increased starch availability compared with the conventional ensiling process used in the CTL treatment.

The increased fermentability of corn grain may also be attributed to the fibrolytic activity of RM and TL. Lee et al. (2015) documented a significant reduction in NDF content and an improvement in rice straw silage quality when inoculated with anaerobic fungi exhibiting cellulolytic activity. Similarly, Wang et al. (2019) reported enhanced silage quality and fiber degradation rates after introducing the fungus *Piromyces* sp. nov. from the rumen into corn silage. Consequently, the increased fiber degradation during silage fermentation likely intensified the grain's susceptibility to breakdown in our study. This hypothesis is corroborated by the lower acid detergent fiber (aNDF) concentration observed in inoculated rehydrated corn silage (89.9 g/kg DM) compared to the control (134.8 g/kg DM).

The lower DMI observed in lambs fed INO can reasonably explain their reduced average daily gain (ADG). However, previous studies evaluating these microorganisms individually have reported different responses. Martins Júnior et al. (2022) supplemented *Rhodotorula mucilaginosa* to weaned lambs fed low-quality tropical hay (*Urochloa decumbens*) and reported increased DMI and ADG. Similarly, Magaço et al. (2020) supplemented *Trichoderma longibrachiatum* to weaned lambs receiving the same forage source and found no effect on DMI but an increase in ADG. These contrasting results suggest that using these microorganisms as silage inoculants may elicit different responses than their direct dietary supplementation. However, the lower DMI and ADG observed in the present study did not appear to compromise productive performance, as lambs fed the INO and CTL diets exhibited similar feed-to-gain ratios and final body weights after 63 days in the feedlot. From an economic perspective, lambs fed the INO diet generated greater gross profit (US\$/head and US\$/kg BW) than those fed the CTL diet. Similarly, Magaço et al. (2020) reported a 13.35% reduction in the cost of body weight production (US\$/kg BW) when *T. longibrachiatum* was included in lamb diets. The economic value of improvements in feed efficiency relative to ADG depends largely on feed costs and market conditions (Allen et al., 2009). Accordingly, the lower feeding costs observed for lambs fed the INO diet were primarily responsible for the greater economic return. Because sheep producers have limited influence over market prices (Raineri et al., 2015), improving feed efficiency and reducing feeding costs are key strategies for increasing profitability. Therefore, the present findings suggest that inoculating rehydrated corn silage with *R. mucilaginosa* and *T. longibrachiatum* may represent a practical approach to improving the economic sustainability of feedlot lamb production systems.

5. Conclusions

Feeding fattening lambs rehydrated corn silage inoculated with *Rhodotorula mucilaginosa* + *Trichoderma longibrachiatum* improves the financial feasibility of tropical hay-based diets.

Data availability

The entire dataset supporting the results of this study was published in the article itself.

Author contributions

Conceptualization: Duarte, E. R. and Lima, L. S. **Formal analysis:** Soares, D. F. V.; Moraes, N. S. L. and Souza, B. M. S. **Funding acquisition:** Sá, H. C. M.; Duarte, E. R. and Lima, L. S. **Investigation:** Soares, D. F. V.; Sedlmayer, T. G. S. C.; Moraes, N. S. L.; Ruas, L. P. A. C.; Martins Júnior, V. S.; Sá, H. C. M.; Souza, B. M. S. and Lima, L. S. **Methodology:** Martins Júnior, V. S. and Lima, L. S. **Project administration:** Sá, H. C. M.; Duarte, E. R. and Lima, L. S. **Resources:** Souza, B. M. S. **Software:** Sá, H. C. M. **Supervision:** Sá, H. C. M. and Duarte, E. R. **Writing – original draft:** Soares, D. F. V. **Writing – review & editing:** Soares, D. F. V.; Sá, H. C. M.; Duarte, E. R. and Lima, L. S.

Conflict of interest

The authors declare no conflict of interest.

Acknowledgments

The Fundação de Amparo à Pesquisa de Minas Gerais (FAPEMIG) funded this study. The authors express their gratitude to the CARAPRETA – GRUPO A.R.G. for lending the lambs used in the present study.

Financial support

This work was funded by the Fundação de Amparo à Pesquisa de Minas Gerais (FAPEMIG) and the CARAPRETA – GRUPO ARG.

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