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NUTRITIONAL AND METABOLIC PARAMETERS OF SHEEP FED EXTRUDED ROUGHAGE

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ABSTRACT - The search for technologies to increase productivity of the herds, without increasing production costs, brings a positive highlight to extruded feeds, since these products act to maximize digestive efficiency. The objective was to evaluate the effect of using different levels of inclusion of extruded roughage to replace corn silage on nutritional and metabolic parameters in sheep. For this, 20 ewes aged over three years were used, housed in metabolic cages, distributed in a completely randomized design in four treatments, which consisted of different levels of inclusion of extruded roughage to replace corn silage (20%, 40%, 60% and 80%). Dry matter intake (DMI) and water intake were calculated by the difference between what was offered and what was left over. Blood glucose and energy and protein metabolites were obtained through blood collection by jugular venipuncture and subsequent laboratory analyses, and feeding behavior by observation every 5 min. for 24 h. DMI and water intake increased linearly with the inclusion of extruded roughage in the diet. The greater inclusion of extruded roughage reduced the total chewing time, consequently increasing the efficiency of ingestion, rumination and total chewing. The inclusion of extruded roughage in the diet of sheep increases the dry matter intake, without reducing the digestibility of nutrients, reducing the time spent on chewing.
Keywords: digestibility, energetic, feeding behavior, proteic.

PARÂMETROS NUTRICIONAIS E METABÓLICOS DE OVINOS ALIMENTADOS COM VOLUMOSO EXTRUSADO

RESUMO - A busca por tecnologias para aumentar a produtividade dos rebanhos, sem onerar os custos de produção, traz destaque positivo para os alimentos extrusados, uma vez que esses produtos atuam na maximização da eficiência digestiva. Objetivou-se avaliar o efeito da utilização de diferentes níveis de inclusão de volumoso extrusado em substituição a silagem de milho sobre os parâmetros nutricionais e metabólicos em ovinos. Para isso utilizou-se 20 ovelhas com idade superior a três anos, alojadas em gaiolas metabólicas, distribuídas em delineamento inteiramente casualizado em quatro tratamentos, que consistiram de diferentes níveis de inclusão de volumoso extrusado em substituição à silagem de milho (20%, 40%, 60% e 80%). O consumo de matéria seca (CMS) e consumo de água foram calculados pela diferença entre o ofertado e as sobras. A glicemia e os metabólitos energéticos e proteicos foram obtidos através de coleta de sangue por venopunção jugular e posteriores análises laboratoriais, e o comportamento ingestivo por observação a cada 5 min., durante 24 h. O CMS e o consumo de água aumentaram linearmente com a inclusão do volumoso extrusado na dieta. A maior inclusão do volumoso extrusado reduziu o tempo de mastigação total, consequentemente aumentou-se a eficiência de ingestão, ruminação e mastigação total. A inclusão de volumoso extrusado na dieta de ovinos aumenta o consumo de matéria seca, sem reduzir a digestibilidade dos nutrientes, reduzindo o tempo de mastigação, além de manter o metabolismo energético e proteico.
Palavras-chave: comportamento ingestivo, digestibilidade, energético, proteico.

INTRODUCTION

Proper nutritional management has a great importance on sheep production system, since feed costs are the highest (RAMOS et al., 2010). Therefore, there are alternatives to optimize this animal production, such as food processing, which are used to improve the nutrients use by animals with responses on their intake and productivity (OLIVEIRA et al., 2018). Among these procedures, we can mention the extrusion process, which, through the application of heat, humidity and pressure in the food, can cause modifications (SILVA et al., 2015), providing improvements in the digestibility of starch, proteins and fibers and, consequently, higher productive performance.

The use of corn silage in animal feed is very common in ruminant production systems, but complications during planting, compaction and silo sealing can compromise the nutritional quality of total feed and

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consequently harm the herd's diet. Therefore, the use of extruded feed that can replace corn silage has advantages in terms of storage, time of use and feed handling, in addition to reducing selection by animals (SILVA et al., 2021).

Despite the advantages of using extruded feed, little is known about the inclusion level of these products in ruminant diets. In this case, as they are products that include starch in their composition, it is necessary to carry out further studies to identify the maximum inclusion levels that can be used without compromising the nutritional, metabolic and productive parameters.

The animals' productive response depends on the intake, digestibility and metabolism of the ingested nutrients. The use of nutrients, such as energy and protein, is necessary to meet maintenance and production needs (MEDEIROS et al., 2015). Feed digestibility is defined by the ability that allows the animal using the nutrients in the feed to a greater or lesser extent, and this ability is expressed by the nutrient digestibility coefficient (SILVA et al., 1979). Another way of analyzing feed quality is by evaluating the animals' feeding behavior, which is defined by the distribution of defined periods of activities, such as intake, rumination and resting to adjust the feeding management of the animals to the characteristics of the ration (CIRNE et al., 2014; OLIVEIRA et al., 2020).

In addition, the nutritional quality of the diet can be obtained by evaluating the blood metabolic profile of the animals. Changes in the concentrations of some blood metabolites can occur in situations of nutritional imbalance, so one of the ways to know if the diet meets the nutritional needs of the animals is through the evaluation of the metabolic profile (SILVA et al., 2020a).

The extruded roughage can bring advantages in relation to intake, digestibility and metabolism, in addition, little is known about the maximum level of incorporation of this extruded feed in ruminant diets. Therefore, the hypothesis would be that the extruded material can, in addition to bringing all these advantages, replace corn silage in the production system. In this sense, the objective of this study was to evaluate the effect of inclusion levels of extruded roughage, in replacement of corn silage, on nutritional and metabolic parameters in sheep.

MATERIAL AND METHODS

The experiment was carried out in the Goat and Sheep Sector, at the Capim Branco Experimental Farm, belonging to the Universidade Federal de Uberlândia (UFU), during January 2017. Twenty non-pregnant Santa Inês ewes were used, with 3±0.5 years and average body weight of 54.5 kg. These animals remained individually in metabolic cages for metabolism tests, with dimensions of 1.30 x 0.80 m, equipped with a feeder, drinker, salt shaker, slatted floor and equipment for separation of feces and urine. The experiment lasted 20 days, with 15 days for adaptation of the animals to the feed and cages and 5 days for data collection (feces, urine, leftover feed and water). Food was provided twice a day, at 08:00 am and 4:00 pm. The animals had free access to water and mineral salt.

The treatments consisted of inclusion levels of extruded roughage, with concentrations of the product Foragge® 52.5% (F) and corn silage (S), being T1 = 20% F + 80% S, T2 = 40% F + 60 % S, T3 = 60% F + 40% S and T4 = 80% F + 20% S. Foragge® 52.5% (Nutratta®, Itumbiara, Goiás) is an extruded feed, composed of 52.5% *Urochloa brizantha* grass, corn starch and minerals (Masterfós®, mineral salt for sheep), with a dry matter content of 90% (Table 1).

TABLE 1 - Chemical composition of Foragge® 52,5%, corn silage and treatments.

Nutrients (%)	Foragge® 52,5%*	Corn Silage**
Dry Matter	90.0	31.2
Crude Protein	7.1	8.0
Starch	25.1	NA
Mineral Matter	3.7	10.3
Neutral Detergent Fiber	42.3	57.1
Acid Detergent Fiber	26.3	36.2

	Relation between Foragge® and Corn Silage			
	20:80	40:60	60:40	80:20
Dry Matter	43.0	54.7	66.5	78.2
Crude Protein	7.8	7.6	7.5	7.3
Mineral Matter	9.0	7.7	6.3	5.0
Neutral Detergent Fiber	54.2	51.2	48.2	45.3
Acid Detergent Fiber	34.2	32.2	30.3	28.3

*Values provided by manufacturer Nutratta®. NA: not analised. **Values obtained by laboratorial analisys at Laboratório de Nutrição Animal da Universidade Federal de Uberlândia.

The feed leftovers in the troughs were measured daily and whenever there were no leftovers, the amount offered was increased by 10%, until reaching a surplus equivalent to 10% of the offered amount. The calculation of dry matter intake (DMI) of the ration was obtained through the difference between what was offered and the leftovers. The feces produced by the animals were collected daily, at 09:00 am and weighed on a Toledo® electronic scale, with a precision of 5 g, determining the dry matter content, allowing the calculation of feed digestibility, based on dry matter (DMD), through Equation 1.

$$DMD = (DMI-FW)/DMI \qquad \text{(Equation 1)}$$

Where:
DMI = dry matter intake (kg day^{-1});
PF = feces weight on dry matter basis (kg day^{-1}).

The determination of the dry matter content of leftover food and feces was performed at the Laboratorio de Nutrição Animal (LABAN) at Universidade Federal de Uberlândia, using the INCT-CA method, G-003/1 (DETMANN et al., 2012). The fecal score was evaluated daily, during the collection period, before weighing, according to the scale proposed by Gomes et al. (2012), where, on scale 1, the stools were classified as dry and opaque, on scale 2 as normal, on scale 3, slightly smoothed, on scale 4, softened, losing shape and glued (grape clusters), on scale 5, as soft and unformed (pig feces) and in the scale 6, as diarrheal.

Water was supplied every day in the morning, at 08:00 am, in plastic buckets, in the amount of six liters per animal, and also in the afternoon, when necessary (checking was done every day at 3:00 pm), the remaining water was measured the following day in plastic graduated cylinders with a precision of 20 mL. Another bucket was also used, in order to measure the amount of water that evaporated. The same evaporation bucket received 6 L of water in the morning, where, the next morning, the amount of water that still remained was measured, in order to know the value of the evaporated, being deducted from the total water intake. The calculation of the water intake offered in the bucket was based on the difference between what was offered, the leftovers and the evaporated water. The total water intake was calculated by adding the water present in the feed to the water consumed in the bucket by the animals.

For the urine total collection, plastic buckets covered with screens were used to avoid contamination with fur, feed and feces, the buckets being allocated below the metabolism cages. In each bucket, 100 mL of 2N sulfuric acid (H_2SO_4) was added to avoid nitrogen (N) volatilization as well as possible microbial fermentation present in the environment. Urine collection was performed daily in the morning at 09:30 am. The total volume of urine was measured using a graduated cylinder (plastic) with a precision of 20 mL and the urine density was determined using a Megabrix® manual refractometer.

For the measurement of feeding behavior, the animals were subjected to visual observation by six trained people (one evaluator every 4 h), arranged so as not to disturb the animals, once during the collection period, for 24 h. At night, the shed where the metabolism cages were located remained under artificial lighting and the lights were kept on for 5 days, before the evaluations, to promote the adaptation of the animals to the lighting. Notes were taken every 5 min., observing whether the animal was feeding (FED), ruminating (RUM), or resting (REST), according to the methodology proposed by Fischer et al. (1998). Activity calculations were made in min day^{-1}, assuming that within 5 min. of each observation, the animal remained in the same activity. The total time spent chewing (CHEW) was determined by adding the time spent eating (FED) and ruminating (RUM). The feeding (FEf), chewing (CEf) and rumination (REf) efficiencies were obtained, according to equations 2, 3 and 4 (POLLI et al., 1996):

$$FEf\ (g\ min^{-1}) = DMI / FT \qquad \text{(Equation 2)}$$

$$CEf\ (g\ min^{-1}) = DMI / CT \qquad \text{(Equation 3)}$$

$$REf\ (g\ min^{-1}) = DMI / RT \qquad \text{(Equation 4)}$$

Where:
DMI = dry matter intake (g DM day^{-1}),
FT = time spent on feeding (min day^{-1}),
CT = time spent on chewing (min day^{-1}) and
RT = time spent on rumination (min day^{-1}).

Blood samples were collected on the 1st, 3rd and 5th days of the collection period, always before the first feeding (at 07:30 am), with the animal fasting. To evaluate the biochemical components, blood samples were collected by venipuncture of the jugular vein, with 10 mL Vacutainer® tubes, without anticoagulant and identified for each animal. The biochemical components for determination of energy metabolism were triglycerides and cholesterol and for determination of protein metabolism, total protein, urea, albumin, uric acid and creatinine.

The glycemic avaliation was performed on the sixth day, immediately after the data collection period, at 08:00 am (before the first meal), 11:00 am, 2:00 pm, 5:00 pm and 8:00 pm. On the day of the glycemic assessment, the second meal was only offered after the 8:00 am collection. Samples were collected by venipuncture of the jugular vein, with 5 mL Vacutainer® tubes, containing fluorine and EDTA and identified for each animal.

The collected blood samples were centrifuged at 3000 r.p.m. for 10 min and the serum separated into aliquots, inside microtubes and stored in a freezer at -5ºC for later laboratory analysis. All samples were processed in an automated biochemical analyzer (Bioplus® 2000, Barueri, SP, Brazil), using a commercial kit (Lab Test®, Lagoa Santa, MG, Brazil).

The experimental design was completely randomized, with four treatments (T1 = 20% F + 80% S, T2 = 40% F + 60% S, T3 = 60% F + 40% S and T4 = 80% F + 20% S) and five replications and for glycemia split plots were used. The SAEG 9.0 program was used for a regression study and 5% probability of error was used in order to compare means. Fecal score data were analyzed by non-parametric statistics, using the Kruskal and Wallis (1952) and Conover (1980) test. All responses were previously tested for normality and homoscedasticity.

RESULTS AND DISCUSSION

Table 2 shows an increasing linear effect of the inclusion level of extruded roughage on dry matter intake (P<0.05), that is, as the proportion of Foragge® increases and corn silage decreases, there was an increase in dry matter intake (DMI) in relation to animal's body and metabolic weight. According to NRC (2007), the average DMI for adult sheep in maintenance is approximately 1.83% of body weight, 83% lower than that found in the present study.

TABLE 2 - Relation between Foragge®:corn silage on dry matter intake (DMI) and dry matter digestibility (DMD) in sheep.

	Foragge®:Corn silage (%)				*P*	Y	R^2 (%)	Mean	CV (%)
	20:80	40:60	60:40	80:20					
DMI (kg day^{-1})	1.65	1.64	1.91	2.27	0.0257	1.338300 + 0.010679x	88.05	1.87	11.56
DMI (%BW)	2.99	2.96	3.57	3.91	0.0247	2.522900 + 0.016784x	88.05	3.36	8.68
DMI ($BW^{0,75}$)	81.67	80.83	96.47	108.07	0.0258	68.052500 + 0.474254x	88.29	91.76	8.52
DMD (%)	64.91	58.60	59.98	60.12	0.1293			60.90	8.57

BW: body weight; CV = coefficient of variation.

The effect of inclusion levels in extruded roughage on dry matter intake can be explained by the fact that the feed extrusion process alters the matrix of nutrients, such as starch, proteins and fibers, making them more digestible, that is, they are fermented faster in the rumen. In addition, as the forage particle is smaller than 2 mm, this leads to less volume in the rumen, in addition to increasing the feed passage rate and, consequently, intake by the animal. Also, the extruded feed facilitates the apprehension by the animal, as it is presented in the form of pellets. In this sense, it can be inferred that the lower rumen volume in animals fed diets with higher levels of extruded roughage may have been the main cause of the significant increase in DMI (MACEDO JÚNIOR et al., 2017). Silva et al. (2021) and Rodrigues et al. (2022) also observed an increase in DMI for sheep, as the inclusion of extruded roughage in the diet increased.

The effect of including extruded feed on dry matter digestibility coefficient (P>0.05) was not verified. It is known that, in ruminants, the higher the DMI of the animal, the lower the digestibility of the feed (FERREIRA et al., 2013) and, according to Silva (2013), the retention of food for a longer time in the gastrointestinal tract will allow it to be digested the maximum as possible. However, in the present study, DMI in relation to body weight was high, 83% higher than recommended by the NRC (2007), however, no negative effect was observed on dry matter digestibility, with presented similar values to corn digestibility (SANTOS et al., 2010). A factor that may have contributed to this result is the extrusion process itself, since the application of heat and humidity in the feed manufacturing process results in a final product with better digestibility and fermentability by ruminal microorganisms. In addition, Foragge® contains 25.1% of starch, which undergoes gelatinization after the extrusion process (ROKEY et al., 2010), resulting in improvements in the digestibility of the final product. Silva et al. (2021) and Siqueira et al. (2022) also found no difference in DMS, working with extruded roughage material in substitution of corn silage for sheep, with mean values of 56.95% and 63.78%, respectively.

Table 3 shows a linear increasing effect of the inclusion level of extruded roughage on water intake (P<0.05). Water can be obtained by animals from three sources: drinking water, water contained in the feed and metabolic water derived from the catabolism of nutrients (ESMINGER et al., 1990). As the extrudes roughage contains about 90% dry matter, it requires the highest water intake per kilogram of feed consumed. Confirming this theory, it is possible to observe that there was no difference in the total water intake, which is the sum of the water intake in the diet with the voluntary water intake, that is, the higher the extruded roughage content in the diet as well as the total diet, the greater the voluntary water intake of these animals. In fact, studies carried out by Kume et al. (2010) and Souza et al. (2010) found that voluntary water intake is higher with the increase in feed dry matter.

The average observed for the total water intake of the animals was 4.15 L of water day^{-1}. According to the equation proposed by the NRC (2007), the estimated water intake would be 6.22 L day^{-1}. In this way, it can be verified that the animals ingested less than the recommended amount of water. Confirming this result, a relationship was established between drinking water intake and the amount of dry matter ingested by sheep, which should be 2 or 3 times higher than the DMI, thus observing that the average water intake was 1.38 times higher than DMI, value below the recommended. However, even with water intake below the recommended amount, the DMI was 83% above the recommended level and with the DMD within the reference values, that is, the dynamics of ruminal fermentation of these animals was not affected.

A positive linear effect was observed in the level of extruded roughage on feces weight, expressed in natural matter and dry matter in kg day^{-1}, which can be explained by the increase in dry matter with the inclusion of extruded forage in the diet. It is interesting to note that the increase in DMI with consequent greater fecal excretion of the animals treated with a higher proportion of extruded roughage did not modify the dry matter digestibility of the diet, indicating that its use by the animal is similar to that of corn silage. There was no effect of inclusion of extruded roughage on fecal dry matter, fecal score and urinary volume (P>0.05). The volume of urine excreted by the animals is within the range recommended by Reece (2006), which should be 100-400 mL for every 10 kg of body weight. As the average weight of the animals was

54.5 kg, the daily urinary excretion should be between 545-2180 mL. Mean daily urinary excretion was 845 mL, close to the recommended lower limit for urinary excretion, related to water intake below the recommended level. Urinary density showed a quadratic behavior, with a higher value at the level of greater inclusion of the extruded roughage (80F: 20S), due to the higher DMI presented by the animals that received this diet. The sheep had normal limits (1.015-1.045 g mL^{-1}) in all treatments, according to Carvalho (2008) and Reece (2006).

TABLE 3 - Relation between Foragge®:corn silage on water intake (CH_2O), feces and urine excretion in sheep

	Foragge®:Corn silage (%)				*P*	Y	R^2 (%)	Mean	CV (%)
	20:80	40:60	60:40	80:20					
CH_2O (L day^{-1})	1.12	2.40	3.41	3.71	0.0085	0.471200 + 0.043896x	93.87	2.66	39.25
CH_2O Total (L day^{-1})	3.35	4.32	4.49	4.45		-	-	4.15	29.28
CH_2O/DMI	0.66	1.45	1.79	1.61	0.0487	-0.632850 + 0.076886x – 0.000609x^2	99.66	1.38	38.69
Urine (L day^{-1})	0.681	0.993	1.202	0.504	0.2697	-	-	0.845	33.83
Urine (g mL^{-1})	1.0294	1.0252	1.0212	1.0390	0.0003	1.05000 – 0.001251x + 0.000014x^2	86.68	1.0287	0.85
Feces NM (kg day^{-1})	1.92	2.14	2.56	3.24	0.0368	1.372700 + 0.021947x	94.52	2.47	30.28
Feces DM (kg day^{-1})	0.584	0.680	0.773	0.903	0.0147	0.473200 + 0.005246x	99.36	0.735	21.06
Fecal DM (%)	30.79	32.31	31.08	29.06	0.4178	-	-	30.81	14.28
Fecal score	2.52	2.48	2.64	2.92	0.3698	-	-	2.64	-

*Non-parametric statistics used for score fecal Variable; NM: natural matter; DM: dry matter; CV = coefficient of variation.

In Table 4, it was verified that there was no effect of the inclusion of extruded roughage on the periods of feeding and rumination in sheep (P>0.05), with effect on periods of rest and chewing. The animals remained resting longer, as the inclusion of roughage extruded in the diet increased, due to the characteristic of the extruded feed, with a higher dry matter content than that of corn silage, in addition to better apprehension of the product, shorter ingestion time and consequently, longer rest periods.

The ewes reduced the chewing time due to the addition of roughage extruded feed (P<0.05), which shows that the feed, being easy to apprehend, in addition to having a smaller particle size (2 mm), resulted in a reduction of total chewing time and increased resting time. Several authors verified the effect of reducing the size of particles over the chewing time (HADJIGEORGIOU et al., 2003; OLIVEIRA et al., 2018).

TABLE 4 - Relation between Foragge®:corn silage on feeding behavior in sheep.

	Foragge®:Corn silage (%)				*P*	Y	R^2 (%)	Mean	CV (%)
	20:80	40:60	60:40	80:20					
Feeding (min day^{-1})	245	274	252	218	0.3671	-	-	247.25	29.69
Rumination (min day^{-1})	492	512	413	390	0.2789	-	-	471.75	17.93
Resting (min day^{-1})	703	654	775	832	0.0021	614.000 + 2.5400x	69.94	741.00	12.62
Chewing (min day^{-1})	737	786	665	608	0.0120	826.000 – 2.5400x	69.94	699.00	13.68
Feeding efficiency (g min^{-1})	6.78	6.20	8.79	10.60	0.0058	4.582100 + 0.070314x	81.68	8.09	24.52
Rumination efficiency (g min^{-1})	3.39	3.21	4.95	6.04	0.0009	1.98260 + 0.048461x	86.43	4.40	24.13
Chewing efficiency (g min^{-1})	2.26	2.10	2.90	3.83	0.0074	2.761250 – 0.040779x + 0.000685x^2	98.14	2.77	15.99

CV = coefficient of variation.

The feeding and rumination efficiencies had an increasing linear response, with the inclusion of extruded feed in the diet (P<0.05). It is important to emphasize that an increase in rumination efficiency will not necessarily have a positive effect, since a reduction in rumination can be detrimental to the functioning of the rumen. In the present work, it was verified that the greater efficiency in the intake and rumination occurred with the inclusion of extruded roughage, without causing deleterious effects to the ruminal environment, since the DMI increased, without harming the DMD.

Figure 1 shows a quadratic effect for the energy metabolite glucose in relation to the time of collection, with high glycemic levels between 11:00 am and 2:00 pm, approximately 3 to 6 h after feeding the animals. In ruminants, the peak glucose concentration occurs in this period after feeding, since glucose is synthesized in the liver from propionate, glucogenic amino acids and other precursors (ARAÚJO et al., 2020a). In addition, the roughage extrudate used had 25.1% of starch in its composition, a gelatinized ingredient, due to the extrusion process, with high digestibility and rapidly fermented in the rumen, causing this glucose peak at times closer to the first feeding. The blood glucose values of the animals in the present study (Figure 1) were within the range recommended by Silva et al. (2020a).

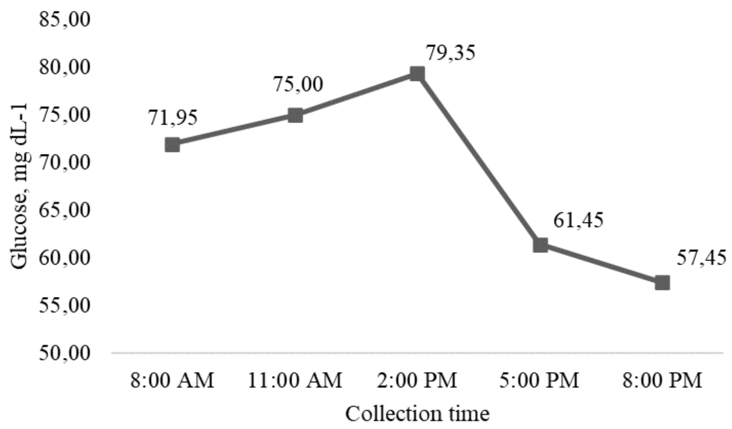

FIGURE 1 - Collection time on glucose concentration in sheep fed with relations between Foragge® and corn silage. $Y=37.545079 + 6.659444x – 0.288492x^2$, R^2=80.48% (P = 0.0036).

Table 5 shows that the inclusion of extruded roughage on the blood concentration of energy and protein metabolites was not significant, except for uric acid and urea. The energy metabolites evaluated remained within the reference values proposed by Silva et al. (2020a). Triglycerides are the main form of energy storage in the animal organism and synthesized in almost all tissues, especially in the liver and adipose tissue. The biosynthesis of triglycerides is made from circulating glucose and glycerol, so their concentrations are directly related to those of glucose (VARANIS et al., 2021; SIQUEIRA et al., 2022). Cholesterol is biosynthesized in the small intestine and adipose cells, being synthesized from acetyl-CoA originating from acetic acid produced in the rumen and resulting from the fermentation of dietary fiber (SILVA et al., 2020a).

TABLE 5 - Relation between Foragge®:corn silage on blood parameters in sheep.

	Foragge®:Corn silage (%)				*P*	Y	R^2 (%)	Mean	CV (%)	RV
	20:80	40:60	60:40	80:20						
Energetic Metabolites										
Triglycerides (mg dL^{-1})	31.73	32.00	28.73	17.19	0.6325	-		27.41	37.66	5-71
Cholesterol (mg dL^{-1})	84.20	86.16	70.66	88.39	0.5698	-		82.35	20.07	14-126
Glucose (mg dL^{-1})	67.80	63.32	74.32	70.72	0.2510	-		69.04	15.43	30-94
Protein Metabolites										
Total Protein (g dL^{-1})	6.84	6.59	6.63	5.86	0.4789	-		6.48	23.22	3.1-10.7
Albumin (g dL^{-1})	2.64	3.17	2.75	3.02	0.4125	-		2.89	21.22	1.1-5.2
Uric Acid (mg dL^{-1})	0.08	0.18	0.15	0.07	0.0489	$0.09100 + 0.011390x – 0.000118x^2$	96.92	0.12	38.10	0-1.7
Urea (mg dL^{-1})	17.73	18.93	25.33	17.26	0.0421	$6.897500 + 0.604095x – 0.005791x^2$	54.02	19.81	24.42	10-92
Creatinine (mg dL^{-1})	0.65	0.63	0.61	0.57	0.5378			0.62	15.87	0.4-1.7

*RV = reference values according to Silva et al. (2020a), CV = coefficient of variation.

Among the protein metabolites, albumin and total protein reflect on the nutritional status of the animal, as well as on the amount of protein in the diet (GONZÁLEZ et al., 2000), therefore, low circulating levels may indicate metabolic protein deficiency. The values of these metabolites are within the normal range for the sheep species (SILVA et al., 2020a), reflecting that the correct amount of protein was provided to the animals.

There was a quadratic effect of the use of extruded roughage replacing corn silage on the concentration of uric acid in the blood, so that the animals that received 40% of extruded roughage (40F:60S) had a higher serum concentration of this metabolite, that which may be related to a greater microbial balance in the rumen due to the association of microbial protein production with purine derivatives. The concentration of uric acid is positively correlated with the amount of microbial protein available for intestinal digestion in animals (COSTA, 2021), allowing to infer that animals fed with 40% of extruded forage had greater production of microbial protein to be used in the small intestine.

A quadratic effect of the use of extruded roughage on the blood concentration of urea was also observed, where the animals that received 60% of extruded roughage had the highest concentrations of this metabolite. According to Santos (2011) part of the protein that reaches the rumen is transformed into ammonia, so that it can be used by the ruminal flora in the production of microbial protein. When there is a lack of carbohydrates in the diet for the complete use of this ammonia, it is absorbed by the ruminal wall and taken to the liver where it is transformed into urea. Therefore, the increase in urea concentration may be directly related to the lack of synchronization in carbohydrate and protein degradation in the rumen (SOCREPPA, 2020).

Several studies with extruded roughage (ARAÚJO et al., 2020b; SILVA et al., 2020b; SILVA et al, 2021; SIQUEIRA et al., 2022) elucidate the change in dry matter intake, as the amount of extruded roughage in the diet, without altering the dry matter digestibility and metabolic profile of the animals.

CONCLUSIONS

The greater inclusion of extruded roughage material reduced the total chewing time, consequently increasing the feeding, rumination and total chewing efficiencies.

The inclusion of extruded roughage in the diet of sheep increases dry matter intake without reducing nutrient digestibility, reducing chewing time, in addition to maintaining energy and protein metabolism.

ETHICS COMMITTEE APPROVAL

The experiment was approved by the Commission for Ethics and Animal Use, of the Universidade Federal de Uberlândia, under protocol number 092/16.

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