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Intake, ingestive behavior, and digestibility in goats fed diets containing different lipid sources

Wilson Duarte Ferrari Junior[1],
Elenice Andrade Moraes[1],
Mário Adriano Ávila Queiroz[1],
Jairo José da Silva Santos[1],
Illa Carla Santos Carvalho[1],
Débora Cristine de Oliveira Carvalho[1]
and Glayciane Costa Gois[2]

[1] Universidade FeDeral do Vale do São Francisco, Campus Ciências Agrárias, Rodovia BR-407, Km 12, Lote 543, Projeto de Irrigação Nilo Coelho, s/nº, C1, CEP 56300-000 Petrolina, PE, Brazil. E-mail: wilsonduarteferrarijunior@gmail.com, elenice.moraes@univasf.edu.br, mario.queiroz@univasf.edu.br, jairojose1010@discente.univasf.edu.br, illlac@hotmail.com, debora.carvalho@univasf.edu.br

[2] Universidade Federal do Maranhão, Centro de Ciências de Chapadinha, BR-222, Km 04, s/nº, Boa Vista, CEP 65500-000 Chapadinha, MA, Brazil. E-mail: glayciane_gois@yahoo.com.br

✉ Corresponding author

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Abstract – The objective of this work was to evaluate the inclusion of lipid sources in diets for goats, regarding animal intake, ingestive behavior, and nutrient digestibility. Sixteen uncastrated male goats were distributed in a completely randomized experimental design, with the following four treatments: a control, with corn as an energy source; licuri cake; residual soybean oil; and calcium salts of long-chain fatty acids, i.e., inert fat. The experimental period lasted for 84 days. Goats subjected to the control and inert fat diets had a higher crude protein digestibility than those that received the diet containing licuri cake. The control diet provided a greater digestibility of nonfibrous carbohydrates. Goats that received inert fat diets had the highest digestibility of total digestible nutrients. The diet with licuri cake resulted in a higher rumination time and neutral detergent fiber rumination, as well as in a shorter idling time. The animals spent more time feeding and less time ruminating during the afternoon, whereas the longest idle time was observed during early evening. The use of fat lipid sources did not affect animal intake, showing similar results to that of the control diet. However, the inclusion of the licuri cake reduces the digestibility of crude protein and total digestible nutrients, causing a longer rumination.

Index terms: *Syagrus coronata*, agro-industrial by-product, energy demand, fat supplement, residual frying oil.

Consumo, comportamento ingestivo e digestibilidade em caprinos alimentados com dietas com diferentes fontes lipídicas

Resumo – O objetivo deste trabalho foi avaliar a inclusão de fontes lipídicas em dietas para caprinos, quanto ao consumo e ao comportamento ingestivo dos animais e à sua digestibilidade dos nutrientes. Dezesseis caprinos machos não castrados foram distribuídos em delineamento experimental inteiramente casualizado, com os seguintes quatro tratamentos: controle, milho como fonte energética; torta de licuri; óleo residual de soja; e sais de cálcio de ácidos graxos de cadeia longa, i.e., gordura inerte. O período experimental durou 84 dias. Cabras submetidas às dietas controle e de gordura inerte apresentaram maior digestibilidade da proteína bruta do que as que receberam dieta com torta de licuri. A dieta-controle proporcionou maior digestibilidade de carboidratos não fibrosos. Cabras que receberam dietas com gordura inerte apresentaram maior digestibilidade dos nutrientes digestíveis totais. A dieta com torta de licuri resultou em maior tempo de ruminação e ruminação com fibra em detergente neutro, bem como em menor tempo de ócio. Os animais passaram mais tempo se alimentando e menos tempo ruminando durante a tarde, enquanto o maior tempo ocioso foi observado no início da noite. A utilização de fontes lipídicas gordurosas não afetou a ingestão dos animais, tendo apresentado resultados semelhantes aos da dieta-controle. No entanto, a inclusão da torta de licuri reduz a digestibilidade da proteína bruta e os nutrientes digestíveis totais, o que causa uma ruminação mais prolongada.

Termos para indexação: *Syagrus coronata*, subprodutos agroindustriais, demanda energética, suplemento de gordura, óleo residual de fritura.

Introduction

Feed represents the highest cost item in the production system of small ruminant in confinement. This fact is directly related to the food supply, becoming a determining factor for the viability of the production system (Cavalcanti et al., 2022). To reduce costs with the purchase of concentrates, such as corn and soybeans, alternative ingredients from agro-industrial processing have been used in the composition of feeds, to improve the cost/benefit ratio and, at the same time, to improve the efficiency and competitiveness of production systems, making it sustainable (Silva et al., 2021; Ferreira et al., 2023).

Among the various by-products of agro-industry with the potential for use in the feeding of small ruminants, those obtained from the processing of oilseeds, such as cakes and meal, stand out. Licuri (*Syagrus coronate* Becc.) cake is a notable by-product obtained during the cold mechanical pressing process for oil extraction (Oliveira et al., 2022). It can be included as a supplement in the diet of ruminants, due to its good nutritional value, including a high content of crude protein (215.8 g kg^{-1} dry matter), neutral detergent fiber (627.7 g kg^{-1} dry matter), and ether extract (119.7 g kg^{-1} dry matter), which is rich in short and medium-chain fatty acids (Silva et al., 2022). According to Ferreira et al. (2023), licuri cake is commonly incorporated into goat diets, to replace corn and soybean meal by up to 100%. Another ingredient that can be incorporated into diets for small ruminants is vegetable oil from the frying process, such as residual soybean oil. This oil type slowly degrades in the environment, leading to environmental, social, and economic issues in its disposal. Thus, including it in animal feed represents an alternative to mitigate the environmental impact and increase energy density (Peixoto et al., 2017). It also serves as a source of polyunsaturated fats in the goat diet, improving the fatty acid profile in animal-derived products (Costa et al., 2023). Lerma-Reyes et al. (2018) reported that the inclusion of 20 mL per day of soybean oil in goat diets does not adversely affect their productive performance.

However, some studies emphasize that incorporating oil into the diet of small ruminants can lead to reduced voluntary consumption, besides affecting their productive performance, which is attributed to interference with fiber digestion, prevention of direct microbial attack, and alterations in diet palatability (Bezerra et al., 2021; Hamzaoui et al., 2021). To address these concerns, inert fat sources have been developed commercially. These sources aim to mitigate the detrimental effects of unsaturated fatty acids on ruminal fermentation, subsequently enhancing the fiber digestibility and dry matter intake (Rapetti et al., 2002; Ghasemi et al., 2021). Additionally, the incorporation of inert fat can help prevent issues such as ruminal acidosis and liver abscess (Ghoniem & Atia, 2020).

The diet supplementation with lipid sources for small ruminants is well-known, as it can modify the ruminal metabolism, digestive processes, and the ingested nutrients (Gomes et al., 2021). Therefore, incorporating inert fat into goat diets could enhance both the intake and digestibility of dry matter and neutral detergent fiber.

The objective of this work was to evaluate the inclusion of lipid sources in diets for goats, regarding animal intake, ingestive behavior, and nutrient digestibility.

Materials and Methods

The study was conducted at Universidade Federal do Vale do São Francisco (UNIVASF), in the municipality of Petrolina, in the state of Pernambuco, Brazil (9°23'55"S, 40°30'03"W, at 376 m of altitude). The research was approved and certified by the ethics committee on human and animal studies of UNIVASF, under protocol number 27091063.

Sixteen uncastrated male goats of undefined breed (25.0±4.5 kg body weight) were distributed in individual pens equipped with drinking fountains and feeders. A completely randomized experimental design in was carried out with four treatments and four animals per treatment. The initial weight was used to define the blocks.

The experimental period lasted for 84 days, preceded by 10 days to adapt the animals to the facilities, management, and experimental diets. At the beginning of the adaptation period, the animals were identified, weighed, treated against endo- and ectoparasites, and randomly allocated to the previously identified pens according to the treatments.

The treatments consisted of four experimental diets, as follows: control, using corn as an energy source (C); licuri cake (LC); residual soybean oil (RSO); and Megalac-E calcium salts of long-chain fatty acids (Química Geral do Nordeste, Nova Ponte, MG, Brazil), i.e., inert fat (IF). The diet formulation for gains at 100 g per day followed the recommendations of the National Research Council (NRC, 2007) and was composed of elephant grass (*Pennisetum purpureum* Schum) in natura, ground corn, soybean meal, and the Caprinofós mineral and vitamin mixture (Tortuga, São Paulo, SP, Brazil), in a 50:50 roughage:concentrate ratio (Table 1).

The diets were provided in the form of complete ration twice a day at 08:00 and 16:00, and water was offered ad libitum. Leftovers were collected and weighed to determine intake and to adjust dry matter (DM) intake, in order to allow of 15% leftovers. Feed and leftovers samples were collected weekly for further chemical analysis.

The animals were weighed at the beginning and at the end of the experimental period, as follows: weekly and after a 16-hour period of solid food deprivation (with access to water), respectively. Daily dry matter intake (DMI) was determined by the difference between the total DM of feed offered and the total DM present in the leftovers. Nutrient intake was determined as the difference between the total nutrients present in the feed intake and the total nutrients present in the leftovers, on a total DM basis.

A digestibility test was carried out between the sixty-ninth and seventy-sixth day of the experimental period, lasting for six days of collection. Feces were sampled using collection bags fixed to the animals before the sampling period. The bags were emptied twice a day, and the feces were weighed. The samples were stored in a freezer at -15°C for chemical analysis. The apparent digestibility coefficient (ADC) of DM and nutrients was calculated using the following equation (Silva & Leão, 1979): ADC = {[(ingested nutrients - excreted nutrients) /ingested nutrients] x 100}.

The ingestive behavior was evaluated at 26, 52, and 78 days of the experimental period. For the evaluation, all animals were visually observed for 24 hours, and observations were recorded at 5 min intervals. The times spent feeding, ruminating, and idling were recorded according to Johnson & Combs (1991). At nocturnal observation, the environment was kept under artificial light.

Table 1. Percentage and chemical composition of experimental diets.

Compostion	Diet			
(% dry matter)	Control	Licuri cake	Residual soybean oil	Inert fat
Ground corn	28.00	20.00	25.40	25.10
Soybean meal	20.90	10.00	21.60	21.60
Licuri cake	-	18.20	-	-
Residual soybean oil	-	-	2.00	-
Inert fat	-	-	-	2.30
Mineral and vitaminic mixture[(1)]	1.10	1.00	1.00	1.00
Elephant grass	50.00	50.00	50.00	50.00
Chemical composition				
Mineral matter	9.52	9.13	9.64	8.42
Crude protein	16.55	16.53	17.63	17.62
Ether extract	3.32	5.21	5.31	4.94
Neutral detergent fiber	48.72	50.83	44.21	45.12
Acid detergent fiber	27.70	30.50	24.81	25.32
Lignin	9.52	14.15	10.43	10.73
Nonfibrous carbohydrates	24.00	20.33	25.31	25.92
Total digestible nutrients	82.62	80.41	82.52	86.83

[(1)]Mixture composition: 70 g P, 200 g Ca, 5,000 mg Mg, 10 g S, 100 g Na, 340 mg Fe, 440 mg Cu, 3,010 mg Zn, 1,480 mg Mn, 48 mg I, 25 mg Co, 20 mg Se, 6 mg Cr, 250,000 UI vitamin A, 40,000 UI vitamin D3, and 350 UI vitamin E.

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Samples of ingredients, diets, leftovers, and feces were pre-dried in an oven, at 55ºC, for 72 hours, followed by grinding in the MA-580 Thomas-Wiley knife mill (Marconi: Equipamentos para Laboratórios Ltda., Piracicaba, SP, Brazil). The samples were analyzed according to Association of Official Analytical Chemists (AOAC) (Latimer Jr., 2016) for: DM, using method 967.03; mineral matter (MM), with method 942.05; organic matter (OM), as 100 - MM; and crude protein (CP), using method 981.10. Ether extract (EE) was analyzed using the ANKOM TX-10 fat extractor (Macedon, NY, USA) according to American Oil Chemists Society (AOCS, 2017). Neutral detergent fiber (NDF) and acid detergent fiber (ADF) analyses were performed according to Van Soest et al. (1963a), with modifications proposed by Senger et al. (2008), using an autoclave at 110°C for 40 min. Lignin was determined by solubilizing cellulose with sulfuric acid at 72% (Van Soest et al., 1963b).

Total carbohydrates (TC) were estimated according to Sniffen et al. (1992), as follows: TC = 100 - (%CP + %EE + %MM). Nonfibrous carbohydrates (NFC) were calculated according to Hall (2003), as follows: NFC = %TC - %NDF.

Total digestible nutrient (TDN) content was estimated according to the equation proposed by NRC (2001): TDN = {[digestible CP + (digestible EE × 2.25) + (digestible NFC + digestible NDF)] - 7}, where the value 7 refers to the metabolic fecal TDN.

The data were subjected to the analysis of variance by using the Sisvar, version 5.1, statistical software (Ferreira, 2011). Significant probability values were those below 5% probability by Tukey's test.

Results and Discussion

DM and nutrient intakes were not affected by diets with different lipid sources (Table 2), and the average intakes per day were the following: 1,399.48 g DM, 207.37 g CP, 814.06 g NDF, 40.5 g EE, 241.56 g NFC, and 1,100.75 g TDN, respectively. The fat supplementation in diets for ruminants has been related to the decrease of DM intake (Cavalcanti et al., 2022). Although the mechanisms by which fat supplementation reduces consumption are not well elucidated, they involve effects on rumen fermentation and in intestinal motility, and on the acceptability of rations, besides effects on the release of gut hormones and fat oxidation in the liver (Allen, 2000; Alba et al., 2021). From this information, the lack of difference between treatments can be explained by the EE of diets, since the higher level was 5.3% in the diet with residual soybean oil, which is below the limit of 7% recommended by the NRC (2007). Lipid levels above 7% in diets for small ruminants reduce the DM intake, due to the toxic effect on the ruminal microbiota.

Although the inclusion of lipid sources resulted in an increase of approximately 2% in the levels of EE in the diets, it did not appear to have a negative effect on the digestibility by the animals and, consequently, on their voluntary intake. The DM intakes were above 1 kg per day, which is higher than the 0.593 g per day reported by Gomes et al. (2021) and the 0.981 g per day reported by Sachin et al. (2018), when including soybean oil and inert fat, respectively, in diets for goats.

Regarding digestibility, it was possible to observe that goats that received the control and inert fat diets had greater CP digestibility than goats that received a diet containing LC. There was no difference for CP the goats that received a diet containing residual soybean oil (Table 2). The lower CP digestibility in goats that received a diet supplemented with LC, compared to that of the control and inert fat diets, is probably related to the higher lignin content of 141.5 g kg^{-1} DM present in the diet with LC (Table 1), which reduces the degradation rate of CP in diets. LC is rich in acid detergent insoluble nitrogen, which is a fraction that has low or no ruminal degradability according to Silva et al. (2022). These authors observed a reduction in the CP digestibility with increased LC levels in diets for cull cows, which is in alignment with the results of the present study. A negative correlation between lignin and CP digestibility was reported by Silva et al. (2023). Lignin inhibits the digestion of hydrolytic enzymes, limiting the activity of ruminal microorganisms and, consequently, reducing the effectiveness of microorganisms in the digestion process.

The goats subjected to the control diet showed a greater NFC digestibility than those that received diets containing residual soybean oil. There was no difference for the NFC digestibility between goats that received diets containing LC and inert fat (Table 2). The reduction of ground corn in the diet containing residual soybean oil likely caused a reduction of NFC digestibility in comparison with the control diet. Corn has fast fermentation carbohydrates in its nutritional composition, which contributes to the production of organic acids and reduction of ruminal pH (Cavalcanti et al., 2022). Thus, with the increase of the EE content in the residual soybean oil diet, there may have been a ruminal pH increase in the goats, and the NFC fermenting bacteria may have been reduced. Similar results were obtained by Maia et al. (2006) for the inclusion of oil sources in the diet of goats; these authors concluded that the use of vegetable oils reduced the NFC digestibility by approximately 18% in comparison with the control diet.

The highest TDN digestibility was obtained by goats that received diets containing inert fat than goats that received diets containing LC. There was no difference for TDN digestibility between goats that received the control diet and goats that received residual soybean oil diets. There was no effect of diets on DM, NDF, and EE digestibility.

There was no effect of the diets on the feeding times of the goats, and average values (in min per day) were the following: 243.24, for total feeding time; 0.23, for DM intake; and 0.43, for NDF intake. Diets containing LC resulted in longer total rumination time for the goats, NDF rumination, and shorter idling time in comparison with the other tested diets.

The greater time spent in rumination, provided by the diet containing LC, may be due to the higher content of NDF (508.3 g kg^{-1} DM), ADF (305.0 g kg^{-1} DM), and lignin (141.5 g kg^{-1} DM) in its composition (Table 1). The time spent in rumination is proportional to the cell wall content of the diet, that is, the higher is the fiber content of the ration, the longer will be the rumination time, and the shorter will be the idle time, according to Van Soest (1994). Therefore, it can be inferred that the LC diet, which had a higher fiber content than the other lipid supplements and the control diet, led to a longer retention time of digesta in the rumen.

Regarding the period, the goats spent more time feeding and less time ruminating during the afternoon (Table 3). The longest idle time was observed at 06:00. The food supply during the afternoon corresponded to the longer time the animals spent feeding, resulting in less time spent ruminating. The longest feeding

Table 2. Intake and digestibility of goats fed diets with different lipid sources[(1)].

Parameter	Diet				SEM	P-value
	Control	Licuri cake	Residual soybean oil	Inert fat		
Intake (g per day)						
Dry matter	1572.25	1356.66	1218.72	1450.28	213.04	0.6947
Crude protein	235.00	189.50	183.50	221.50	31.42	0.6123
Neutral detergent fiber	884.75	841.50	704.00	826.00	121.71	0.7520
Ether extract	40.25	42.25	36.00	43.50	5.79	0.8099
Nonfibrous carbohydrates	303.25	199.00	207.75	256.25	38.48	0.2478
Total digestible nutrients	1287.50	974.00	926.25	1215.25	194.17	0.4999
Digestibility (%)						
Dry matter	81.14	73.84	77.21	84.71	2.82	0.0853
Crude protein	88.49a	78.36b	81.86ab	88.39a	2.24	0.0177
Neutral detergent fiber	77.80	67.59	72.39	88.19	3.51	0.0588
Ether extract	76.50	77.86	83.94	87.13	3.66	0.1869
Nonfibrous carbohydrates	97.33a	91.76ab	90.24b	95.76ab	1.60	0.0282
Total digestible nutrients	81.53ab	75.08b	79.25ab	87.13a	2.42	0.0281
Ingestive behavior						
Feeding (min per day)	224.20	292.52	225.03	231.21	18.38	0.3015
Dry matter (min g^{-1})	0.23	0.29	0.20	0.19	0.03	0.3425
Neutral detergent fiber (min g^{-1})	0.46	0.50	0.39	0.37	0.08	0.6880
Ruminating (min per day)	313.33b	459.58a	294.17b	318.33b	27.99	0.0004
Dry matter (min g^{-1})	0.18	0.19	0.19	0.17	0.02	0.8453
Neutral detergent fiber (min g^{-1})	0.50b	0.77a	0.52b	0.51b	0.06	0.0180
Idling (min per day)	902.50a	687.91b	920.83a	890.42a	34.63	<0.001

[(1)]Means followed by equal letters, on the lines, do not differ by Tukey's test, at 5% probability. SEM, standard error of the mean.

Table 3. Ingestive behavior of goats fed diets with different lipid sources in different observation periods[1].

Parameter	Period				SEM	P-value
	Morning	Afternoon	Evening	Night		
Feeding (min per day)	69.6b	105.5a	43.1c	25.0d	3.93	<0.001
Ruminating (min per day)	117.7a	34.3c	63.8b	130.4a	5.50	<0.001
Idling (min per day)	172.7c	220.2b	253.1a	204.6b	6.93	<0.001

[1]Means followed by equal letters, on the lines, do not differ by Tukey's test, at 5% probability. SEM, standard error of the mean.

time in the afternoon corresponds to the period of the second diet offer, since the diet was offered in fractions, part in the morning and part in the afternoon. These observations confirm the stimulation of food distribution to feeding activity proposed by Fischer et al. (1998).

The behavior of the goats regarding the time spent on leisure activity was more intense at night. As the experiment took place in the Brazilian semiarid hinterland region, only at night the animals generally achieve a thermal comfort index, based on temperature, relative humidity, winds, and humidity (Oliveira et al., 2024). Thus, goats have possibly adaptive mechanisms to adapt to daily temperatures and carry out resting activities during the night, leaving the daytime period to feeding and rumination activities. Similarly, Ribeiro et al. (2006), working with Moxotó and Canindé goats confined in the Brazilian Semiarid region, found that this activity was more intense between 16:00 and 20:00, period when temperatures were milder during the experiment.

Conclusions

1. The use of licuri cake, residual soybean oil, and inert fat, as lipid sources in goat diets, do not influence nutrient intake.
2. The use of licuri cake, as lipid source in goat diets, reduces the digestibility of crude protein and total digestible nutrients and increases the rumination time of the animals, providing less idle time.

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