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REGULAR ARTICLES

Intake, digestibility and performance of lambs fed diets containing peach palm meal

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Abstract The aim of this study was to evaluate the intake and apparent digestibility of nutrients, performance, and plasma glucose concentration of ram lambs fed diets containing peach palm meal substituting maize (0, 10, 40, 60, and 85 % dry matter (DM)). Thirty Santa Inês rams with an average initial body weight of 21.6 ± 0.87 kg were distributed in a completely randomized design with five diets and six replicates. The substitution of the maize for the peach palm meal affected ($P < 0.05$) the intakes of DM, organic matter (OM), crude protein (CP), neutral detergent fiber corrected for ash and protein (NDFap), total carbohydrates (TC), total digestible nutrients (TDN), and metabolizable energy (ME), which decreased linearly ($P < 0.05$); the intake of ether extract (EE), however, fit an increasing linear equation ($P < 0.05$). The apparent digestibility coefficients of DM, OM, NDFap, and TC decreased linearly ($P < 0.05$) as the level of peach palm meal in the concentrate was increased. The total weight gain and the average daily gain decreased by 0.09 and 0.001 kg with each level of substitution of the maize for peach palm meal, respectively. It is recommended to substitute 40 % of the maize for peach palm meal.

Keywords Alternative feed · *Bactris gasipaes* Kunth · Maize · Santa Inês

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Introduction

Maize is the most commonly used energy concentrate in animal supplementation around the world. However, in the last decades, researchers of ruminant nutrition have endeavored to find feedstuffs that can replace it, on the basis of the following facts: high cost and high fluctuation of prices over the year; its use in poultry, pig, and human feeding; and more recently, its use in a larger proportion in alcohol production in the USA, which may affect the price of the grain worldwide (Santos et al. 2010). In this scenario, the use of wastes and by-products from the agro-industry is a feasible option for producers aiming to maintain good productivity rates. In Brazil, this proposal is even more interesting because of its regional pecularities.

In the northeast region of Brazil, especially in the state of Bahia, a territory with a south coast identity, the production of peach palm fruit waste has grown outstandingly in the south of this state, because of the valuation of the palm kernel and consequent value adding of the seeds extracted from the fruit. This process generates a large amount of fruit pulp, which still does not have a proper destination (Ribeiro 2014). Thus, its use in the feeding of feedlot lambs may be an alternative, in addition to adding value to this product and also preventing environmental impacts caused by the disorderly discard of this material. Therefore, the present study aimed to evaluate the effects of substituting maize for peach palm meal (0, 10, 40, 60, and 85 % of the dry matter) on the intake, digestibility, and performance of feedlot lambs.

Material and methods

The experiment was conducted at the Sheep Farming Section on the Juvino Oliveira Campus of the State University of Southwest Bahia, UESB, located in Itapetinga-BA, Brazil. Thirty Santa Inês ram lambs with an approximate age of 120 days and an average initial body weight of 21.6 ± 0.87 kg.

The animals were distributed in a completely randomized design with five experimental diets (0, 10, 40, 60, and 85 % of substitution of maize for peach palm meal) and six replicates. The experimental period was 87 days, with 15 days of acclimatization, and three 24-day periods.

The pulp of the pitted fruit was supplied by the Industry of Foods in the Palm Kernel Market (*Indústria de Alimentos no Mercado de Palmitos*—INACERES), located in Uruçuca-BA, Brazil. The peach palm meal was produced in a flour mill of Instituto Federal Baiano—IF BAIANO, Uruçuca-BA Campus. The diets, balanced by estimating the requirements according to National Research Council (2007) equations, were composed of maize, soybean meal, peach palm peal, a mineral supplement, and Tifton 85 hay, with a roughage:concentrate ratio of 30:70 (Table 1). Diets were supplied daily at 0700 and 1600 hours, ad libitum, in a way that 10 to 20 % of the total supplied would be left over.

In the samples of feces (leftovers and supplied) and feces, the contents of dry matter (DM), mineral matter (MM), crude protein (CP), and ether extract were determined according to AOAC (1995).

For the analyses of neutral detergent fiber (NDF), the samples were treated with thermostable alpha-amylase, without using sodium sulfite, and corrected for the residual ash (Mertens 2002). The correction of NDF for the nitrogen compounds and the estimate of the concentration of neutral (NDIN) and acid (ADIN) detergent insoluble compounds were performed according to Licitra et al. (1996).

The concentration of non-fiber carbohydrates (NFC) was calculated by adapting the method proposed by Hall (2003), utilizing NDFap. The total digestible nutrients (TDN) were calculated according to Weiss (1999), but using NDF and NFC corrected for ash and protein.

The lipid fraction of the experimental diets was analyzed at the Center for Chromatographic Analyses (*Centro de Análises Cromatográficas*, CEACROM) of UESB, by Bligh and Dyer's (1959) method (Table 2).

The animals' individual intake was evaluated over 72 days of supply of the experimental diets, by subtracting the leftovers from the amount of feed offered to each animal. Feces were collected at 0600 and 1800 hours, from the 17th to the 19th day, in each experimental sub-period. After being collected, the feces from each animal were weighed, and aliquots of approximately 1 % of the total excreted were inserted in plastic bags and stored in a freezer at −20 °C for later analyses.

Table 1 Centesimal composition of the ingredients and chemical composition (% DM) of the experimental diets

Ingredient (%DM)	Level of substitution (% DM)				
	0	10	40	60	85
Tifton 85 hay	30.0	30.0	30.0	30.0	30.0
Ground maize	50.7	45.6	29.7	20.3	7.6
Soybean meal	17.8	17.8	17.8	17.8	17.8
Peach palm meal	0.0	5.1	21.0	30.4	43.1
Mineral supplement[a]	1.5	1.5	1.5	1.5	1.5
Total	100	100	100	100	100
Chemical composition					
Dry matter	92.9	92.5	92.8	92.2	92.7
Organic matter[b]	93.5	93.1	93.5	93.2	93.5
Crude protein[b]	15.0	15.2	15.1	14.2	14.5
Neutral detergent insoluble protein[c]	31.6	32.5	29.5	31.3	26.8
Acid detergent insoluble protein[c]	20.6	20.0	21.2	20.9	17.9
Ether extract[b]	3.7	3.8	5.4	5.6	6.8
Non-fiber carbohydrates[b]	28.8	31.7	32.7	36.8	36.6
NDF corrected for ash and protein[b]	46.4	43.0	40.7	37.2	35.9
Acid detergent fiber[b]	22.4	22.4	21.4	23.3	23.1
Hemicellulose[b]	27.1	23.6	21.9	16.9	15.6
Cellulose[b]	19.2	19.0	18.0	19.9	19.0
Lignin[b]	3.3	3.3	3.4	3.3	4.1
Total digestible nutrients[b,d]	71.4	71.8	74.2	75.4	75.7
Metabolizable energy (Mcal/kg)	2.7	2.7	2.9	2.9	2.9

Analyses conducted at the Laboratory of Forage Crops and Pastures of UESB

[a] Amount/kg of product: calcium (max.)—170 g; phosphorus—85 g; sodium—113 g; sulfur—19 g; magnesium—13 g; copper—600 mg; cobalt—45 mg; chromium—20 mg; iron—1850 mg; iodine—80 mg; manganese—1350 mg; selenium—16 mg; zinc—4000 mg; fluorine (max.)—850 mg

[b] In % of DM

[c] In % of CP

[d] Estimated according to National Research Council (2001)

Table 2 Lipid fraction (g/100 g DM) of the experimental diets

Lipid fraction (g/100 DM)	Level of substitution (% DM)				
	0	10	40	60	85
Total lipids	3.25	3.52	4.37	4.87	5.54
Total saturated	0.92	0.94	1.00	1.03	1.08
Total unsaturated	2.34	2.59	3.37	3.83	4.46
Monounsaturated	0.03	0.11	0.34	0.48	0.67
Polyunsaturated	2.30	2.48	3.03	3.36	3.80

The digestibility coefficients of the nutrients were calculated as the ratio between the total consumed and the excreted amount, multiplied by 100.

For the evaluation of performance, the animals were weighed at the beginning and end of each period, after a 12-h period of deprivation of solids, on the first and last days of the experiment only. Feed conversion was calculated as the ratio between the intake and the average daily gain.

Blood was collected from the jugular vein on the 24th day of the third experimental period only, after the last time the animals were weighed, approximately 4, 8, 12, and 24 (time 0) h after the supply of the morning meal. Next, the blood samples were centrifuged at 3.500 rpm for 10 min, and then the glucose was analyzed with commercial kits (Bioclin Reagents, Belo Horizonte, MG, Brazil).

The statistical analysis of the data was achieved by the MIXED procedure of the SAS statistical computer program (SAS 2006), considering a mixed model. Polynomial contrasts were performed for the comparison between the means of the diet that contained only maize (0 % peach palm meal) and the diets in which the maize was substituted for the peach palm meal (10, 40, 60, and 85 %). The following statistical model was adopted:

$$Y_{ijk} = \left(\beta_0 + \beta_1 \mathrm{Tr} + \beta_2 \mathrm{Tr}^2\right) + \varepsilon_{ijk}; \mathrm{NID}\left(0; \sigma^2\right),$$

where Y = the estimated value according to the diets; β_0 = intercept; β_1 and β_2 defined the variation of Y according to the level of substitution; and Tr = level of substitution (0, 10, 40, 60, and 85 % of peach palm meal).

For the regression of the plasma concentration of glucose, the effects of diets and times were decomposed into third-degree linear polynomial regressions. The multiple linear regression statistical model with two independent variables (i.e., levels of substitution and the data collection time) was:

$$Y_{ijk} = \beta_0 + \beta_1 \mathrm{Tr} + \beta_2 \mathrm{Tr}^2 + \beta_3 \mathrm{T} + \beta_4 \mathrm{T}^2 + \beta 5 \mathrm{Tr} \times T + \varepsilon_{ijk};\ \mathrm{NID}\left(0; \sigma^2\right),$$

where Y = the estimated value according to the diets; β_0 = intercept; β_1 and β_2 defined the variation of Y according to the level of substitution; Tr = level of substitution (0, 10, 40, 60, and 85 % of peach palm meal); and T = postprandial collection time (0, 4, 8, and 12). For all statistical procedures, the critical level of probability for type-I error was fixed at 0.05.

Results

The substitution of maize for the peach palm meal at the levels of 0, 10, 40, 60, and 85 % DM affected the intakes of dry matter (DM), organic matter (OM), crude protein (CP), neutral detergent fiber corrected for ash and protein (NDFap), total carbohydrates (TC), total digestible nutrients (TDN), and metabolizable energy (ME), which decreased linearly ($P < 0.05$). An increase was observed ($P < 0.05$) in EE intake according to the experimental diets, in which this variable rose by 0.004 g/kg BW with every level of substitution of maize for the peach palm meal, as compared with the control diet (Table 3).

The intakes of CP and NDFap decreased linearly ($P < 0.05$), with an estimated reduction of 0.02 and 0.08 g DM/kg BW, respectively, for each level of peach palm meal, as compared with the average intake of the lambs fed the control diet (maize). In addition, the contrasts ($P < 0.05$) were significant when the control diet was compared with the diets containing peach palm meal (Table 3).

The TDN intake in gram per kilogram BW and gram per kilogram $BW^{0.75}$ decreased ($P < 0.05$) with the increase in the levels of peach palm meal added to the diets. The diet containing only maize resulted in a TDN intake of 26.2 g/kg BW and 64.1 g/kg $BW^{0.75}$, whereas the group of animals fed peach palm meal consumed on average 22.5 g/kg BW and 52.6 g/kg $BW^{0.75}$ (Table 3). These results were reinforced by the regression equations, which showed a decreasing linear response ($P < 0.05$), with an estimated reduction of 0.08 g/kg BW and 0.23 g/kg $BW^{0.75}$ with each level of peach palm meal as compared with the average intake of TDN by the lambs fed the control diet (maize) (Table 3).

The apparent digestibility coefficients of DM, OM, NDFap, and TC decreased linearly ($P < 0.05$), with estimated reductions of 0.05, 0.04, 0.18, and 0.05, respectively, with every level of peach palm meal, as compared with the control diet (maize). The apparent digestibility of CP and TDN, in turn, were not influenced by the levels of substitution of maize for peach palm meal, averaging 73.6 and 79.9 %, respectively (Table 4).

The substitution of maize for the peach palm meal increased the digestibility coefficient of EE, with an estimated increase of 0.06 for each level of substitution, as compared with the control diet (maize) (Table 4). The total and average daily weight gains decreased linearly ($P < 0.05$); for every level of substitution, a reduction of 0.09 and 0.001 kg, respectively, was observed, as compared with the control diet (maize). Furthermore, the contrast between the control diet and the diets containing peach palm meal was significant ($P < 0.05$), and the animals fed treatment 0 % (control) obtained TWG and ADG of 17.2 and 24.9 %, respectively, which are higher values than those obtained with the group of animals fed diets containing the peach palm meal (Table 5).

There was an interaction effect between level of substitution and time ($P < 0.05$) on the plasma glucose concentration; however, analyzing the effect of level of substitution within each time, a decreasing linear response was found ($P < 0.05$)

Table 3 Intake of nutrients according to the levels of substitution of maize for peach palm meal in feedlot lambs

Item	Level of substitution (% DM)					SEM	P value		
	0	10	40	60	85		*M* vs *P*	*L*	*Q*
Intake (g/kg BW)									
DM	35.6	34.4	29.6	28.5	25.6	0.9	0.0004	<0.0001[a]	0.9788
OM	33.2	31.8	27.8	26.8	24.1	0.8	0.0003	<0.0001[b]	0.9201
CP	5.4	5.2	4.6	4.0	3.7	0.1	<0.0001	<0.0001[c]	0.8839
EE	1.4	1.3	1.6	1.5	1.7	0.1	0.0391	0.0005[d]	0.7269
NDFap	15.8	14.6	12.2	10.8	9.4	0.5	<0.0001	<0.0001[e]	0.7248
TC	26.5	25.5	21.8	21.3	18.7	0.7	<0.0001	<0.0001[f]	0.9633
NFCap[g]	10.7	10.9	9.5	10.5	9.3	0.2	0.2815	0.1564	0.6302
TDN	26.2	26.0	22.7	21.8	19.6	0.7	0.0079	<0.0001[h]	0.6893
Intake (g/kgBW$^{0.75}$)									
DM	86.5	81.2	69.9	65.6	58.4	2.2	<0.0001	<0.0001[i]	0.7507
TDN	64.1	61.7	53.8	50.2	44.6	1.7	0.0003	<0.0001[j]	0.8177
Metabolizable energy intake									
Mcal/day	3.6	3.2	2.7	2.4	2.1	0.1	0.0003	<0.0001[l]	0.7540
Kcal/BW	10.1	10.1	8.8	8.4	7.6	0.3	0.0117	<0.0001[m]	0.6516
Kcal/BW$^{0.75}$	24.6	23.8	20.8	19.4	17.2	0.7	0.0005	<0.0001[n]	0.7705

M vs P contrasts between the diet containing only maize and the diet with levels of substitution of maize for the peach palm meal, *L* linear, *Q* quadratic, *BW* body weight

*$P < 0.0001$; **$P < 0.001$; ***$P < 0.01$; ****$P < 0.05$

[a] $\hat{Y} = 35.4682{*} - 0.1189X{*}$

[b] $\hat{Y} = 33.0332 - 0.1075X{*}$

[c] $\hat{Y} = 5.3833{*} - 0.02121X{*}$

[d] $\hat{Y} = 1.3473{*} + 0.004237X{*}$

[e] $\hat{Y} = 15.6950{*} - 0.07894X{*}$

[f] $\hat{Y} = 26.4207{*} - 0.09042X{*}$

[g] $\hat{Y} = 10.6627{*}$

[h] $\hat{Y} = 26.2398{*} - 0.07723X{*}$

[i] $\hat{Y} = 85.7357{*} - 0.3324X{*}$

[j] $\hat{Y} = 63.9309{*} - 0.2299X{*}$

[l] $\hat{Y} = 3.4368{*} - 0.01645X{*}$

[m] $\hat{Y} = 10.0959{*} - 0.02924X{*}$

[n] $\hat{Y} = 24.6253{*} - 0.08787X{*}$

as the levels of substitution of maize for peach palm meal were increased (Table 6).

The peaks of plasma glucose occurred between the times 4 and 8 h after the morning feeding, which represents 4 h after the supply of the morning and afternoon meals, as the animals were fed twice daily (Fig. 1).

Discussion

Several factors influence feed intake in ruminants, among which are rejection, heat, distension of the rumen, increased level of short-chain fatty acids, and imbalance of nutrients absorbed by microorganisms (Silva 2011). Of these, rejection was one of the characteristics observed during the present experiment; as the level of substitution of maize for peach palm meal was elevated, the animals rejected the concentrate. It is possible that the increase in the EE contents with the substitution of maize for the peach palm meal affected the palatability, due to a possible rancidification that occurred as the peach palm meal replaced the maize. According to Quaranta et al. (2006), the palatability can be influenced by smell, texture, nutrients, and toxins. Thus, it is considered that, in this experiment, the increase in the level of peach palm meal in the concentrate possibly compromised the palate, so it could be one of the possible factors of reduction in DM intake (Table 3).

The ether extract intake increased with the substitution of maize for the peach palm meal, demonstrating that these responses were as a result of the concentration of this analytical

Table 4 Apparent digestibility coefficients of nutrients (%) according to the levels of substitution of maize for peach palm meal in feedlot lambs

Item	Level of substitution (%DM)					SEM	*P* value		
	0	10	40	60	85		*M* vs *P*	*L*	*Q*
DM	74.2	76.0	73.8	73.3	70.9	0.7	0.5575	0.0119[a]	0.1136
OM	75.3	77.0	75.2	74.6	72.7	0.6	0.7095	0.0295[b]	0.1443
CP[c]	72.2	75.7	73.8	72.9	72.3	0.6	0.2761	0.4871	0.1198
EE	81.7	82.3	84.7	84.4	87.4	0.6	0.0198	0.0006[d]	0.5859
NDFap	64.6	64.9	59.4	53.9	49.4	1.5	0.0004	<0.0001[e]	0.1496
TC	75.7	77.2	74.8	74.4	71.6	0.7	0.3275	0.0042[f]	0.1215
NFCap	92.1	93.5	94.8	95.3	94.1	0.5	0.0085	0.0213	0.0330[g]
TDN[h]	74.1	76.1	76.4	75.9	75.8	0.4	0.0775	0.2829	0.1718

M vs P contrasts between the diet containing only maize and the diet with levels of substitution of maize for the peach palm meal, *L* linear, *Q* quadratic

**P* < 0.0001; ***P* < 0.001; ****P* < 0.01; *****P* < 0.05

[a] $\hat{Y} = 75.5809^{*} - 0.04608X^{***}$

[b] $\hat{Y} = 76.6283^{*} - 0.03859X^{****}$

[c] $\hat{Y} = 73.5995^{*}$

[d] $\hat{Y} = 81.6572^{*} + 0.06039X^{**}$

[e] $\hat{Y} = 66.0972^{*} - 0.1872X^{*}$

[f] $\hat{Y} = 77.0547^{*} - 0.05529X^{***}$

[g] $\hat{Y} = 92.2805^{*} + 0.1104X^{***} - 0.00102X^{2\ ***}$

[h] $\hat{Y} = 75.8984^{*}$

fraction in the diet, in which the substitution level of 85 % was 1.84 times higher than the control diet. For Silva et al. (2007), the responses of ruminants to the presence of fat in the diet are closely related to the form of inclusion, the degree of unsaturation, and the chain length. Therefore, feedstuffs with higher amounts of saturated fatty acids are less problematic than more unsaturated sources, and thus the responses observed with the inclusion of fat may be closely related to the fatty acid profile of the feedstuff or diet supplied. However, it is noteworthy that, in this experiment, the concentrations of

Table 5 Performance according to the levels of substitution of maize for the peach palm meal in feedlot lambs

Item	Level of substitution (%DM)					SEM	*P* value		
	0	10	40	60	85		*M* vs *P*	*L*	*Q*
iBCS[a]	2.7	2.4	2.5	2.4	2.3	–	–	–	–
iBW (kg)[b]	24.3	22.7	21.0	19.9	22.2	–	–	–	–
fBW (kg)	40.8	37.1	35.4	32.4	30.2	1.3	0.0259	0.0050[c]	0.8648
TWG (kg)	16.5	14.5	14.4	12.5	8.0	0.7	0.0033	0.0001[d]	0.1117
ADG (kg/day)	0.229	0.201	0.201	0.175	0.111	0.01	0.0033	0.0001[e]	0.1120
FC	5.5	5.6	4.7	4.7	6.6	0.05	0.8172	0.3501	0.0092[f]
DF	72	72	72	72	72	–	–	–	–

M vs P contrasts between the diet containing only maize and the diet with levels of substitution of maize for the peach palm meal, *L* linear, *Q* quadratic, *iBCS* initial body condition score, *iBW* initial body weight, *fBW* final body weight, *tWG* total weight gain, *ADG* average daily gain, *FC* feed conversion (kgDMI/kgBW), *DF* days in feedlot

**P* < 0.0001; ***P* < 0.001); ****P* < 0.01; *****P* < 0.05

[a] $\hat{Y} = 2.3927^{*}$

[b] $\hat{Y} = 21.6413^{*}$

[c] $\hat{Y} = 39.8473^{*} – 0.1155X^{***}$

[d] $\hat{Y} = 16.5066^{*} - 0.09291X^{*}$

[e] $\hat{Y} = 0.2295^{*} - 0.00129X^{*}$

[f] $\hat{Y} = 5.6156^{*} - 0.05561X^{***} + 0.000709X^{2\ ***}$

Table 6 Deployment of the interaction between the level of substitution and the time for plasma glucose concentration

		Plasma glucose (mg/dL)				Level (time)		
		Time after meal (h)						
Level of substitution		0	4	8	12	*L*	*Q*	*C*
0		84.2	100.3	97.6	106.3	<0.0001	0.2508	0.0399
10		77.1	96.5	104.7	91.4	0.0019	<0.0001	0.5078
40		83.2	95.1	94.9	82.0	0.8029	0.0003	0.9696
60		73.0	91.5	88.8	73.6	0.9421	<0.0001	0.5499
85		71.0	88.4	76.3	68.8	0.2025	0.0003	0.0211
Level (time)	*L*	0.0063	0.0095	<0.0001	<0.0001			
	Q	0.6345	0.9511	0.0068	0.1057			

L linear, *Q* quadratic, *C* cubic

unsaturated fatty acids increased as the maize was substituted for the peach palm meal (Table 2). It is thus considered that these factors possibly partially compromised the intake of most nutrients (Table 3).

The reduction in NDFap intake with each level of peach palm meal added to the concentrate is explained by the composition of the diet, in which the NDFap content was 22.6 % lower in the diet with 85 % of substitution as compared with treatment 0 %. Besides, the hemicellulose was 29.2 % lower with 85 % substitution as compared with 0 %, whereas for lignin, the treatment with 85 % of substitution had 24.2 % higher values of this component than the control diet (Table 4). These results demonstrate that the animals that consumed peach palm meal ingested fiber in lower quantity and quality, which indicates that these are the main factors that compromised the intake and digestibility of DM and NDFap (Tables 3 and 4).

The apparent digestibility coefficients of DM, OM, NDFap, and TC decreased as maize was substituted for peach palm meal (Table 4). It is likely that the reduction in the intake of these nutrients and the ingestion of low-fiber quality contributed to these results.

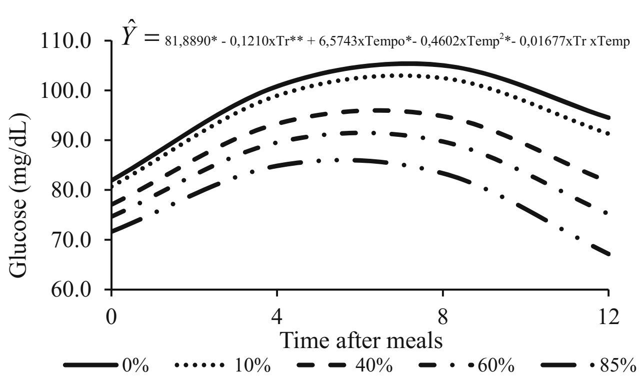

Fig. 1 Plasma glucose concentration as a function of time and of the levels of substitution of maize for peach palm meal in feedlot lambs. Significant *$P < 0.0001$; **$P < 0.001$); ***$P < 0.01$; ****$P < 0.05$

The fiber quality and the reduction in the NDFap/EE ratio with the increase in the amount of peach palm meal (Table 1) affected the DM intake and consequently the intake of metabolizable energy (Table 3) and the lambs' performance (Table 5). Nevertheless, it was found that the feed conversion had a quadratic response, with minima of 4.5 (kgDMI/kgBW) at the level of 39.3 % of substitution of maize for peach palm meal (Table 5). This fact possibly resulted from the increased energy density of the diet with the use of peach palm meal.

Mathematically, a reduction was observed in the intake of concentrate with the levels of substitution of the maize for the peach palm meal; the control diet resulted in an average concentrate intake of 27.2 g/kg, whereas the animals fed the diet with 85 % of substitution consumed 17.6 g/kg concentrate (Table 3). However, it is believed that these factors contributed to the reduction of TDN and ME intake.

The elevation in the apparent digestibility of EE as the substitution of maize for the peach palm meal was increased is directly related to the amount and type of the fatty acid ingested (Table 4). However, the amount of polyunsaturated fatty acids in the diet containing 85 % of peach palm meal was 1.65 times higher than that in the control diet (Table 2); this difference may explain the elevation in the digestibility of EE with the increase in the amount of peach palm meal, as unsaturated fatty acids are more digestible than the saturated ones (Palmquist and Mattos 2011). We can also state that the increase in the amount of polyunsaturated fatty acids in the diet provided a reduction in the digestibility of NDFap (Table 4), due to a possible toxic effect of these fatty acids on the ruminal microorganisms.

The reduction of the energy availability with the increase in the amount of peach palm meal in the concentrate can be verified, indirectly, by the response obtained for plasma glucose, in which, when the effect of diets within each time was evaluated, a decreasing linear response was found as maize was substituted for peach palm meal (Table 6). This fact may indicate a lower production of propionate in the rumen, because this fatty acid is extensively metabolized in the liver (around 60 %), where it is the main gluconeogenic substrate for ruminants (National Research Council 2007).

It was observed that the plasma glucose peaks occurred between the times 4 and 8 h after the morning feeding, which represents 4 h after the supply of the morning and afternoon meals, since the animals were fed twice daily (Fig. 1). This result was similar to that obtained by Macedo Junior et al. (2012), who evaluated the concentration of glucose in sheep every 3 h, after feeding, and found an increase in plasma glucose after this time. Peach palm meal has the potential to substitute maize in sheep diets; however, the level of 40 % of substitution of maize for peach palm meal is recommended.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no competing interests.

References

AOAC. 1995. Official methods of analysis. 16th ed. Association of Official Analytical Chemists, Arlington, Virginia.

Bligh, E.G., Dyer, W.J. 1959. A rapid method of total lipid extraction and purification. Journal Biochemistry and Physiology. 37, 911–917.

Hall, M.B. 2003. Challenges with non-fiber carbohydrate methods. Journal of Animal Science. 81, n.12, p.3226-3232.

Licitra, G., Hernandez, T.M., Van Soest, P.J. 1996. Standardization of procedures for nitrogen fracionation of ruminant feed. Animal Feed Science Technological. Amsterdam, 57, p.347-358.

Macedo Junior, G.L., Perez, J.R.O., Paula, O.J., Almeida, T.R.V., Assis, R.M., França, P.M. 2012. Intake, digestibility and glycemic index of sheep in late gestation receiving different forage: concentrate. Ciência Animal Brasileira, 13, 180–188.

Mertens, D.R. 2002. Gravimetric determination of amylase-treated neutral detergent fiber in feeds with refluxing in beakers or crucibles: collaborative study. Journal of AOAC International. 85, 1217–1240.

National Research Council. 2001. Nutrient requirements of dairy cattle. 7th ed. Washington: National Academy Press, 450p.

National Research Council. 2007. Nutrient Requirements of Small Ruminants: Sheep, Goats, Cervids and New World Camelids. Washington: National Academies Press.

Palmquist, D.L., Mattos, W.R.S. 2011. Metabolismo de lipídeos na alimentação de ruminantes. In: Nutrição de ruminantes. Editores: Berchielli, T.T., Pires, A.V., Oliveira, S.G. Jaboticabal: Funep. 2. ed. 299–322.

Quaranta, A., D'Alessandro, A.G., Frate, A., Colella, G.E., Martemucci, G., Casamassina, D. 2006. Behavioural response towards twelve feedstuffs in lambs. Small Ruminant Research. 64, 60–66.

Ribeiro, L.S.O. Peach palm meal in feeding confined goats, 125 f. thesis (Doctorate in Animal Science) - Southwest Bahia State University, Itapetinga, 2014.

Santos, J.W., Cabral, L.S., Zervoudakis, J.T., Abreu, J.G., Souza, A.L., Pereira, G.A.C.; Reverdito, R. 2010. Rice meal in diets for sheep. Revista Brasileira de Saúde e Produção Animal. 11, 193–201.

Sas Institute. 2006. Statistical Analysis System. User's guide. Cary: SAS Institute.

Silva, J.F.C. 2011. Mecanismos reguladores de consumo. In: Nutrição de ruminantes. Editores: Berchielli, T.T., Pires, A.V., Oliveira, S.G. Jaboticabal: FUNEP. 2. ed. 61–114.

Silva, M. M. C., Rodrigues, M. T., Rodrigues, C.A.F., Branco, R.H., Leão, M.I., Magalhães, A.C.M., MATOS, R.S. 2007. Lipid supplementation's effect on digestibility and rumen fermentation parameters in dairy goats. Revista Brasileira de Zootecnia, 36, 246–256.

Weiss, W. 1999. Energy prediction equations for ruminant. 1999. In: Cornell Nutrition Conference for Feed Manufacturers, 61. Ithaca. Proceedings Cornell University. Ithaca. pp. 176–185.