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Effect of palm kernel cake inclusion on intake, digestibility, nitrogen balance, feeding behavior, and weight gain of feedlot heifers

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ABSTRACT - The objective of this study was to examine the effect of the increasing levels of inclusion of palm kernel cake (PKC) in the diet on the performance of feedlot heifers. Forty-eight Nelore heifers with an initial weight of 274 ± 4.58 kg, at 24 months of age, were confined for 98 days in a feedlot. The animals were allocated to the four treatments in a completely randomized design. Treatments consisted of PKC levels of 0 (control), 10, 20, and 30% in the total dry matter of the diet. The roughage:concentrate ratio in the diets was 30:70. Ether extract intake increased, whereas the intakes of non-fiber carbohydrates and total digestible nutrients decreased with the inclusion of PKC. The apparent digestibility of all nutrients decreased, as well as the amounts of nitrogen digested and retained. Microbial protein synthesis and its efficiency also declined. The inclusion of up to 20% PKC increased feeding time and reduced rumination time of heifers. Intake and rumination efficiencies decreased with the inclusion of PKC in the diet. Final weight and average daily gain did not change, but feed efficiency increased with the inclusion of PKC. The inclusion of up to 30% PKC in the diet of feedlot heifers is recommended.

Keywords: biodiesel byproducts, *Elaeis guineensis*, microbial protein synthesis, rumen undegradable protein

1. Introduction

Practices that intensify the production of animal protein, such as the cattle feedlotting, tend to increase the volume of meat produced as well as its quality (Smith et al., 2018). However, the use of grains that compete with the human diet and environmental pollution caused by animal excreta are major problems feedlots currently face (Greenwood, 2021). In this context, the utilization of agroindustrial wastes in cattle diets minimizes competition with human food and even resolves the issue of their disposal (Yang et al., 2021; Naderi et al., 2022).

Palm kernel cake (PKC) is an agroindustrial waste resulting from the mechanical extraction of palm oil. Its chemical composition includes (mean ± standard deviation, per kilogram) 911.3 ± 13.4 g/kg

dry matter (DM), 149.5 ± 14.8 g/kg crude protein (CP), 94.8 ± 52 .9 g/kg ether extract (EE), and 621.2 ± 105.6 g/kg neutral detergent-insoluble fiber (NDF) (Carvalho et al., 2009; Cruz et al., 2018; Lisboa et al., 2021a; Rodrigues et al., 2021; Silva et al., 2021). This richness in EE and NDF make it a strategic ingredient, especially in feedlot diets (Galyean and Hubbert, 2014). In high-grain diets, the addition of a byproduct rich in EE and NDF can improve rumen health (Lyu et al., 2022) without compromising the net energy of the diet (Weld and Armentano, 2017; Leal et al., 2022). Moreover, the type of protein in PKC, which is high in acid detergent-insoluble protein (Carrera et al., 2012), can reduce urinary nitrogen losses (Rehman et al., 2020) and consequently mitigate the pollutant potential of cattle urine. Lisboa et al. (2021a) found that the addition of up to 24% PKC impaired apparent nutrient digestibility, but did not compromise the weight gain or final weight of steers fed a high-grain diet. Conversely, Santos et al. (2019) reported that the addition of up to 16% PKC to a high-grain diet of feedlot cull cows increased their weight gain and improved their feed conversion. Due to differences in requirements for maintenance and gain (Chizzotti et al., 2008) and in the composition of gain (Paulino et al., 2009), it is important to test the effect of PKC in the diet of feedlot heifers, and no study has been found evaluating the use of PKC in the diet of this animal category.

The hypothesis of this study was that the concentrations of palm kernel cake inclusion up to 20% in the diet of confined crossbred heifers can improve the nitrogen balance and performance of these animals. Therefore, the objective of this study was to investigate the effect of increasing inclusion levels of PKC in the diet on the intake, digestibility, nitrogen balance, microbial protein synthesis, feeding behavior, and weight gain of feedlot heifers.

2. Material and Methods

All experimental procedures complied with the institutional Ethics Committee on Animal Use (approval no. 161/2017).

2.1. Location, animals, diets, and management

The experiment was carried out in Ribeirão do Largo, BA, Brazil (15°26'46" S, 40°44'24" W, 800 m above sea level).

Forty-eight Nelore heifers with an average initial weight of 274 ± 4.58 kg and an average age of 24 months were used. At the beginning of the experimental period, all animals were subjected to ecto- and endoparasite control (Ivermectin LA 3.5%). The animals were housed in a feedlot with an area of 400 m^2 that was divided into four pens (100 m^2 each). Half of each pen was lined with concrete floor and covered with fiber cement tile. Each pen was equipped with a feed bunk measuring 10 linear meters and an automatic 400-L water trough. The experimental period lasted 98 days, which were divided into six sub-periods. Of these 98 days, the first 14 were used for the animals to acclimate to the diets, and the remaining 84 (14 days per period) for data collection.

The treatments consisted of increasing inclusion levels (0, 10, 20, and 30% of the total diet DM) of PKC in the diet. The animals were allocated to the four treatments in a completely randomized design, with a total of 12 animals (replicates) per treatment.

All diets were formulated according to the NRC (2016) so as to meet the nutritional requirements of animals gaining 1 kg/day. The roughage:concentrate ratio in the diets was 30:70. The PKC was purchased from the Óleos de Palma AS Agroindustrial company, in the municipality of Taperoá, BA, Brazil. The roughage used in the experiment was a mixed silage composed of whole sorghum plant (hybrid BM 500) (50%) and *Brachiaria brizantha* cv. Marandu (50%) (Table 1).

The diet was provided to the animals in two periods: 60% of the total amount for the day at 07:00 h, and the remaining 40% at 16:00 h. Manure was removed from the pen every 15 days and the water reservoirs were washed every other day so as to keep the site clean at all times, in compliance with animal welfare principles.

Table 1 - Percentage and chemical composition of the experimental diets supplied to heifers

			PKC inclusion level (%)			
			0	10	20	30
Mixed silage[1]			30.0	30.0	30.0	30.0
Grain sorghum			63.5	54.6	45.8	37.1
Palm kernel cake (PKC)			0	10.0	20.0	30.0
Soybean meal			4.9	3.8	2.6	1.3
Sodium bicarbonate			1.0	1.0	1.0	1.0
Calcitic limestone			0.1	0.1	0.1	0.1
Mineral mixture[2]			0.5	0.5	0.5	0.5
	PKC	Mixed silage[1]	Total diet			
Dry matter (DM)	890.0	303.0	711.2	718.4	721.8	727.8
Organic matter	969.1	912.0	949.6	949.2	945.4	946.2
Crude protein	166.1	98.1	111.0	111.7	114.1	115.0
Ether extract	91.4	53.4	44.2	46.4	49.1	51.6
NDFap	638.2	553.3	323.3	392.5	403.2	414.2
ADF	477.1	343.2	190.3	219.2	234.1	246.4
NFC	73.1	208.2	461.1	405.6	364.2	368.2
Lignin	152.3	67.2	20.0	22.6	37.9	55.1
iNDF	237.1	367.4	210.9	244.0	260.7	265.9
TDN	487.2*	542.3*	715.9	711.4	669.0	666.9
ME (Mcal ME/kg DM)[3]	1.76	1.96	2.59	2.57	2.42	2.41

NDFap - neutral detergent-insoluble fiber corrected for ash and protein; ADF - acid detergent insoluble fiber; NFC - non-fiber carbohydrates; iNDF - indigestible neutral detergent-insoluble fiber; TDN - total digestible nutrients as determined by Weiss (1999).
[1] Mixed silage of whole sorghum plant (hybrid BM 500) and *Brachiaria brizantha* cv. Marandu.
[2] Composition of the mineral mixture: calcium, 235 g; phosphorus, 60 g; magnesium, 16 g; sulfur, 12 g; sodium, 107 g; cobalt, 150 mg; copper, 1600 mg; iodine, 190 mg; manganese, 1400 mg; iron, 1000 mg; selenium, 32 mg; zinc, 6000 mg; fluorine (maximum), 1600 mg.
[3] Metabolizable energy obtained by converting TDN (1 kg) into 4.409 Mcal of digestible energy. Conversion from digestible to metabolizable (*0.82).
* Calculated according to NRC (2001).

2.2. Sample collection and chemical analysis

The diets were supplied for *ad libitum* intake, allowing for 5% orts. Leftovers of each tested diet as well as samples of concentrate and silage were collected weekly, packed in plastic bags, and frozen at −10 °C to be pre-dried and ground later.

Stored samples were thawed, and a composite sample was made per period, which was then dried in a forced-air oven (60 °C) for 72 h and ground in a Wiley knife mill through 1- and 2-mm mesh sieves.

The contents of DM (method no. 967.03), CP (method no. 981.10), EE (method no. 942.05), and mineral matter (method no. 942.05) were determined as suggested by the AOAC (1997) methodology. Neutral and acid detergent fibers were determined using the method of Van Soest et al. (1991). Corrections for ash and protein in NDF were carried out through procedures proposed by Mertens (2002) and Licitra et al. (1996).

Non-fiber carbohydrates corrected for ash and protein (NFCap) were calculated according to the formula described by Detmann et al. (2021). The total digestible nutrients (TDN) content was calculated following Weiss (1999).

2.3. Evaluation of intake, digestibility, and growth performance

Chromic oxide (Cr_2O_3) was used as an external marker to estimate fecal DM production. The marker was supplied daily to each animal, at 07:00 h, inside a paper cartridge containing 10 g of the marker, for 12 days. The first seven days served to regulate the flow of the marker in the gastrointestinal tract of the animals and to adapt them to the handling procedures; the other five days consisted of the fecal

collection period (Smith and Reid, 1955). This stage took place between the 57th and 68th days of the experimental period.

Feces were collected once a day in the pen at five pre-established times, namely, 08:00, 10:00, 12:00, 14:00, and 16:00 h. Subsequently, they were stored in plastic bags and frozen at −10 °C. The five samples from each animal were pre-dried and ground separately and then pooled into a single composite sample for further analysis. The method by Detmann et al. (2021) was employed to obtain the acid extract removed from the feces to be quantified in the spectrophotometer. The chromic oxide levels in feces were analyzed by atomic absorption spectrophotometry, following the technique described by Williams et al. (1962).

Individual total dry matter intake (TDMIi, kg/day) was calculated as follows: TDMIi = (FOi * TDMIat) / FOat, in which FOi = individual fecal output (kg/day), obtained using chromic oxide; TDMIat = average total dry matter intake per treatment (kg/day); and FOat = average fecal output per treatment (kg/day) (Smith and Reid, 1955).

The apparent digestibility coefficients of DM (DC_{DM}, %) and nutrients were determined by the equation: DC_{DM} = [(DMI – DMO) × 100] / (DMI), in which DMI = dry matter intake and DMO = dry matter excreted in feces.

The heifers were weighed after a 12-h fast at the beginning and end of the experimental period and without fasting at the end of each sub-period (14 days) to monitor their growth curve. Growth performance was determined as the difference between initial (IBW) and final (FBW) body weight divided by the number of days in the experimental period, as follows: ADG = (FBW – IBW) / EP, in which ADG = average daily gain (kg/day) and EP = experimental period (days). Feed efficiency was calculated as the ratio between ADG and daily DM intake.

2.4. Nitrogen balance and microbial protein synthesis

Spot urine samples were collected from each animal from the 81st to the 84th day of the experimental period. Collections took place 4 h after the feed was provided in the morning (07:00 h), collected by stimulating the area below the vulva. The collected urine was homogenized and filtered through a gauze pad, and a 10-mL aliquot was immediately added to 40 mL of 0.036 N H_2SO_4, following the method described by Valadares et al. (1999), and then stored at −20 °C. Subsequently, the samples were evaluated for the concentrations of urea, total nitrogen, creatinine, allantoin, and urinary uric acid.

Creatinine, uric acid, and urea concentrations were determined using commercial kits (Bioclin®). Allantoin concentrations were determined by the colorimetric method, described by Chen and Gomes (1992).

On the 85th day of the experimental period, 4 h after the feed was supplied, individual blood samples were collected by jugular vein puncture, using a Vacutainer® tube. The samples were centrifuged at 3,000 rpm for 10 min to obtain the blood serum, which was immediately stored in Eppendorf® tubes that were kept at −20 °C until urea (plasma) analyses were carried out.

The total nitrogen in urine and feces was determined by using Kjeldahl method no. 981.10 (AOAC, 1997). Nitrogen balance (Retained N, g/day) was calculated by the following equation: Retained N = ingested N (g) – N in feces (g) – N in urine (g).

Creatinine excretion (CE; mg/kg of body weight), which was used to estimate the urinary volume, through spot samples, was calculated for each animal by the following equation (Chizzotti et al., 2006): CE = 32.27 – 0.01093 × BW, in which CE = daily creatinine excretion (mg/kg of body weight); and BW = body weight (kg).

The urinary volume was estimated as the ratio between CE (mg/kg BW/day) and the average concentration in urine samples (mg/dL).

The excretion of total purines (TP, mmol/day) was determined as the sum of the excretions of allantoin and uric acid; and the amount of microbial purines absorbed (AP, mmol/day) as the excretion of total purine derivatives (mmol/day), using the equation: AP (mmol/day) = TP – 0.385 × $LW^{0.75}$ / 0.85, in which 0.85 is the recovery of purines absorbed as purine derivatives and 0.385 $LW^{0.75}$ is the endogenous contribution to purine excretion (Chen and Gomes, 1992).

The intestinal flow of microbial nitrogen (g MN/day) was estimated from the amount of purines absorbed (mmol/day), using the following equation by Chen and Gomes (1992): MN (g/day) = 70 × AP / (0.83 × 0.116 × 1000), assuming the value of 70 for the nitrogen content in purines (mg/mmol), 0.83 for the intestinal digestibility of microbial purines, and 0.116 for the ratio of purine N:total bacterial N.

2.5. Evaluation of feeding behavior

The feeding behavior of the animals was evaluated over 144 h, which were subdivided into three stages of 48 h each, throughout the experimental period. Observations were made on the following days: 43rd and 44th, 71st and 72nd, and 92nd and 93rd.

Trained observers evaluated the heifers visually every 5 min (Silva et al., 2006), using data collection worksheets and digital stopwatches. At night, artificial lighting was provided by fluorescent lamps, throughout the experimental period. As defined by Silva et al. (2008), behavioral activities were considered mutually exclusionary, during which the times devoted to feeding, ruminating, and performing other activities were observed. The average duration of each of the discrete bouts was calculated by dividing the daily times expended on each of the activities by the number of discrete bouts (Silva et al., 2008).

The number of chews per cud and the time per ruminated cud were counted. To obtain chewing means and times, three cuds were observed in two periods of the day (06:00 and 15:00 h), following Bürger et al. (2000). Intake and rumination efficiencies were calculated in kilograms of DM and NDFap per hour.

2.6. Statistical analysis

All statistical assumptions were proven through normality tests of residuals and homogeneity of variances. For statistical analysis, the data were tested by analysis of variance (ANOVA), and linear and quadratic orthogonal polynomial contrast coefficients were applied to verify the adjustment of the variables concerning the inclusion of PKC. The following statistical model was employed:

$$Y_{ij} = \mu + T_i + \varepsilon_{ij},$$

in which Y_{ij} = value observed in the experimental unit that received treatment, μ = overall mean effect, T_i = effect of treatment i, and ε_{ij} = random error (residual). The procedure of mixed model (PROC MIXED) of SAS (Statistical Analysis System, OnDemand for Academics) was used. The 5% ($P<0.05$) probability was adopted for ANOVA and orthogonal polynomial contrast.

3. Results

The inclusion of PKC in the diet did not influence ($P>0.05$) the intakes of DM or CP by the heifers, but reduced ($P<0.05$) their NFC and TDN intakes (Table 2). The apparent digestibility of DM, OM, CP, and NFC from the diet decreased ($P<0.05$) linearly with the increasing levels of PKC added to the diet.

The addition of PKC to the diet reduced ($P<0.05$) the amounts of nitrogen ingested, digested, and retained by the heifers, but increased ($P<0.05$) fecal nitrogen losses (Table 3). Palm kernel cake inclusion in the diet did not influence ($P>0.05$) urea nitrogen concentrations in the plasma or urine of the heifers.

The excretion of total purine derivatives by the heifers decreased (P<0.05) (Table 4). Microbial protein synthesis and its efficiency also decreased (P<0.05) with the increasing inclusion levels of PKC in the diet. The inclusion of up to 20% PKC in the diet increased (P<0.05) the feeding time and reduced (P<0.05) the rumination time of feedlot heifers (Table 5). The number of cuds chewed per day and chewing speed per cud increased (P<0.05). The DM intake and rumination efficiencies decreased (P<0.05) linearly with the inclusion of PKC in the diet.

The inclusion of PKC in the diet did not influence (P>0.05) the final body weight or ADG of the heifers, but improved (P<0.05) their feed efficiency (Table 6).

Table 2 - Intake and apparent digestibility of nutrients of feedlot heifers fed diets with increasing levels of palm kernel cake (PKC)

	PKC inclusion level (%)				SEM	P-value	
	0	10	20	30		L	Q
Intake (kg/day)							
Dry matter	9.3	8.9	8.5	8.5	1.504	0.180	0.858
Crude protein	1.0	0.9	1.0	1.0	0.168	0.804	0.439
Ether extract	0.5	0.5	0.6	0.7	0.102	<0.001	0.974
NDFap	3.0	3.5	3.4	3.5	0.590	0.125	0.261
NFC	4.3	3.6	3.1	3.1	0.577	<0.001	0.037
TDN	6.6	6.3	5.6	5.5	0.528	<0.001	0.318
Digestibility (g/kg)							
Dry matter	715.9	691.7	644.2	609.2	66.591	<0.001	<0.001
Organic matter	726.1	704.9	655.7	628.7	50.913	<0.001	0.057
Crude protein	613.9	569.6	516.1	489.5	33.712	<0.001	0.488
Ether extract	647.6	659.1	626.4	617.6	42.724	<0.001	<0.001
NDFap	713.1	746.1	690.9	634.9	42.121	<0.001	<0.001
NFC	776.8	743.1	647.4	678.1	40.971	<0.001	0.009
TDN	715.9	711.4	669.0	666.9	62.744	0.024	0.999

NDFap - neutral detergent-insoluble fiber corrected for ash and protein; NFC - non-fiber carbohydrates; TDN - total digestible nutrients; SEM - standard error of the mean; L - linear effect; Q - quadratic effect.

Table 3 - Nitrogen balance and nitrogen concentrations in the plasma and urine of feedlot heifers fed diets with increasing levels of palm kernel cake (PKC)

	PKC inclusion level (%)				SEM	P-value	
	0	10	20	30		L	Q
Nitrogen (g/day)							
Ingested	161.1	150.9	152.4	153.1	0.941	<0.001	<0.001
Digested	101.3	88.3	80.7	67.4	13.254	0.002	0.998
Fecal	59.9	61.4	71.6	85.7	12.606	0.010	0.444
Urinary	3.95	3.15	2.87	3.61	0.662	0.229	0.551
Retained	97.3	82.4	77.9	63.8	13.980	0.004	0.999
Nitrogen ratios (%)							
Digested/ingested	62.9	58.5	52.9	44.0	8.622	0.006	0.805
Retained/ingested	60.4	54.6	51.1	41.7	9.143	0.010	0.863
Retained/digested	95.9	93.2	96.5	93.9	3.159	0.899	0.965
Urea nitrogen							
Plasma (mg/dL)	12.9	14.1	13.3	13.3	1.800	0.999	0.273
Urine (g/day)	6.9	7.4	7.6	6.2	1.601	0.971	0.331

SEM - standard error of the mean; L - linear effect; Q - quadratic effect.

Table 4 - Urinary purine excretion, microbial protein synthesis, and efficiency of microbial protein synthesis in feedlot heifers fed diets with increasing levels of palm kernel cake (PKC)

	PKC inclusion level (%)				SEM	P-value	
	0	10	20	30		L	Q
Purine derivatives (g/day)							
Uric acid	11.7	10.3	5.5	3.6	3.094	0.002	0.969
Allantoin	420.7	344.9	235.3	289.7	70.983	0.006	0.046
Total purine derivatives	432.4	355.2	240.8	293.3	73.354	0.005	0.052
Total absorbed purines	492.2	397.8	263.3	325.6	86.503	0.004	0.048
Microbial synthesis (g/day)							
Microbial nitrogen	309.6	250.4	165.7	205	54.469	0.004	0.048
Microbial protein	1935	1565	1036	1281	340.439	0.004	0.048
Microbial efficiency (g/kg TDN)							
Microbial nitrogen	47.2	39.5	30.1	35.7	8.220	0.033	0.083
Microbial protein	299.2	231.7	164.6	215.4	49.724	0.012	0.015

SEM - standard error of the mean; L - linear effect; Q - quadratic effect; TDN - total digestible nutrients.

Table 5 - Feeding behavior of feedlot heifers fed diets with increasing levels of palm kernel cake (PKC)

	PKC inclusion level (%)				SEM	P-value	
	0	10	20	30		L	Q
Time (min/day)							
Feeding	247.7	251.9	281.5	255.3	52.856	0.060	0.015
Rumination	381.9	378.9	370.0	428.2	68.985	<0.001	<0.001
Idleness	810.2	809.1	788.4	756.5	98.090	<0.001	0.182
Chewing (total)	629.6	630.9	651.6	683.5	97.983	<0.001	0.185
Number (N)							
Cuds ruminated per day	451.8	476.7	496.1	519.5	108.869	<0.001	0.999
Chews per cud	47.1	46.0	43.0	48.1	8.657	0.999	0.002
Rumination chews per day	18.204	17.669	16.000	20.558	5160.708	0.047	<0.001
Time (s)							
Duration of cud rumination	51.6	49.0	45.8	50.5	8.180	0.121	<0.001
Chewing speed per cud	0.91	0.93	0.94	0.96	0.079	0.001	0.999
Duration of cud chewing	1.10	1.08	1.07	1.07	0.087	0.001	0.974
Efficiency (kg/h)							
Intake (DM)	2.3	2.2	2.0	2.1	0.718	0.028	0.091
Intake (NDFap)	0.77	0.86	0.8	0.86	0.282	0.119	0.916
Rumination (DM)	1.5	1.5	1.4	1.2	0.365	<0.001	0.097
Rumination (NDFap)	0.50	0.58	0.57	0.49	0.138	0.898	<0.001

DM - dry matter; NDFap - neutral detergent-insoluble fiber corrected for ash and protein; SEM - standard error of the mean; L - linear effect; Q - quadratic effect.

Table 6 - Performance of feedlot heifers fed diets with increasing levels of palm kernel cake (PKC)

	PKC inclusion level (%)				SEM	P-value	
	0	10	20	30		L	Q
Initial body weight (kg)	272.2	277.3	274.4	276.2	32.722	0.983	0.999
Final body weight (kg)	353.3	361.2	364.2	363.3	40.275	0.738	0.933
Average daily gain (kg/day)	0.96	1.01	1.07	1.03	0.178	0.221	0.559
Feed efficiency (kg/kg)	0.10	0.11	0.13	0.12	0.032	0.043	0.404

SEM - standard error of the mean; L - linear effect; Q - quadratic effect.

4. Discussion

The inclusion of PKC increased the levels of EE, NDFap, and lignin and reduced the NFC and metabolizable energy contents of the experimental diets. It is possible that the addition of PKC did not influence DM intake because the mechanism regulating DM intake remained the same up to the maximum inclusion of the ingredient in the diet, with physiological regulation prevailing (see DM digestibility around 65%) (Forbes, 2007; Huuskonen et al., 2013). Crude protein intake was also similar between the treatments, possibly due to the similar CP contents of the diets and the similar DM intake of the heifers. Despite the similarity in CP intake, the inclusion of PKC influenced the intakes of digestible and metabolizable protein by the heifers (see N balance and microbial protein synthesis).

The intake of NDFap was similar between the treatment groups, possibly due to selectivity of the animals at the time of ingestion (note: increase in feeding time up to the PKC level of 20%). On the other hand, EE intake increased with the inclusion of PKC, going from 5% to almost 8% of DM intake, which was possibly a consequence of the increase in the EE content of the experimental diets. Cruz et al. (2018) also observed a significant increase in EE intake with the inclusion of PKC in the diet of feedlot steers.

The decrease in NFC intake observed in the current experiment was likely because the main source of NFC in the diet (sorghum grain) was reduced by about 41.5% with the inclusion of the test ingredient (from 0 to 30% PKC). Lisboa et al. (2021a) also reported a consistent decrease in NFC intake when sorghum was replaced with PKC in the diet of feedlot steers. This reduction in NFC possibly influenced the decline in TDN intake and in the digestibility of DM and OM from the diet.

Crude protein digestibility decreased by 20% with the inclusion of PKC in the heifers' diet (between the PKC levels of 0% and 30%). This effect was likely caused by the replacement of soybean meal with PKC as the main source of CP in the diet. The PKC used in the present study is rich in acid detergent-insoluble nitrogen (22% of total nitrogen), a fraction that negatively impacts the amount of true rumen-degradable protein (Carrera et al., 2012) and increases protein recovery in feces (see fecal nitrogen increase), resulting in a decrease in the apparent digestibility of dietary CP.

The reduced digestibility of carbohydrate fractions of the diet (NDF and NFC) can be attributed to the consistent addition of EE to the diet through the inclusion of PKC (Patra, 2013; Palmquist and Jenkins, 2017). This byproduct has a lipid fraction rich in medium-chain and saturated fatty acids that can cause ruminal dysbiosis (Faciola and Broderick, 2014; Fiorentini et al., 2015) and reduce NDF digestibility (Yanza et al., 2021). Additionally, the reduction in the apparent digestibility of NDF and NFC may also be associated with the decline in microbial protein synthesis, microbial protein synthesis efficiency, and nitrogen balance in the heifers (Wei et al., 2018).

The reduction in the amounts of nitrogen digested and retained can be attributed to the observed decrease in the apparent digestibility of CP (Lapierre and Lobley, 2001) following the inclusion of PKC. Both soybean meal (2.46% of total nitrogen) and sorghum grain (18.22% of total nitrogen) have lower levels of acid detergent-insoluble protein than PKC. Therefore, the inclusion of PKC increased the insoluble fraction of dietary protein (Carvalho et al., 2009), even augmenting fecal protein recovery (see fecal N). In addition, it is likely that the increase in NDFap heightened the abrasiveness of the digesta, thus contributing to greater endogenous fecal nitrogen production due to epithelial desquamation. Rodrigues et al. (2021) also reported a decrease in ingested and retained nitrogen in goats fed PKC.

Urinary urea nitrogen is highly correlated with plasma urea nitrogen, and both are related to nitrogen intake and urea synthesis in the liver of animals (Schuba et al., 2017). Because we did not observe an effect of PKC on urinary or plasma urea nitrogen, it is possible that even with a reduction in the amounts of nitrogen ingested and digested, hepatic synthesis of urea (and its level in urine and plasma) was maintained at the expense of nitrogen recycling in the body of heifers (Nichols et al., 2022).

The inclusion of PKC in the diet increased levels of acid detergent-insoluble nitrogen and probably reduced the rumen-degradable protein fraction of the diets (Chrenková et al., 2014). Therefore, the decreases seen in total purine excretion and microbial protein synthesis can be attributed to the reduced presence of the fermentable protein fraction in the rumen of the heifers (Tedeschi et al., 2015; Putri et al., 2021). Saeed et al. (2018) also reported higher excretions of allantoin and xanthine in the urine of sheep when their diet contained higher levels of PKC. In addition, the decrease in fermentable carbohydrate fraction (see decrease in NFC intake and digestibility) also contributed to reducing microbial protein synthesis and, most importantly, its efficiency (Batista et al., 2017) in the rumen of heifers fed PKC.

As regards feeding behavior, the observed increase in feeding time (up to the PKC level of 20%) can be attributed to greater selection of the feed by the heifers—note that NDF intake did not increase, even with an increase in the diet NDFap. In addition to increasing the time expended at the trough, the inclusion of up to 20% PKC reduced rumination time and the number of chews per cud per day. Lisboa et al. (2021b) reported a reduction in the number of cuds ruminated per day following the inclusion of PKC in the diet of steers.

It is noteworthy that the inclusion of 30% PKC led to a reversal of the trend observed up to 20% PKC, possibly due to the increase in the NDFap content of the diet that was accompanied by a decrease in DM digestibility (below 65%). We speculate that this change in feeding behavior at the PKC level of 30% (reduced intake and increased rumination) marks the moment of a change in the regulatory mechanism of DMI in heifers and signals the opportunity to utilize PKC as a physically effective source of fiber in feedlot diets. In this respect, Goulart et al. (2020) reported that agroindustrial byproducts can be used as a source of physically effective fiber in high-concentrate diets for feedlot cattle.

Dry matter intake and rumination efficiencies decreased with the inclusion of PKC probably due to the increased selection at the trough and higher lignin content of the NDFap that was consumed (Llonch et al., 2020), respectively. Santos et al. (2022) also attributed decreases in intake and rumination efficiencies of steers fed diets with palm oil to increased selection by the animals at the trough.

Despite consistent decreases in microbial protein synthesis and retained nitrogen, we did not observe an effect of PKC inclusion on the final weight or ADG of the feedlot heifers. It is possible that the animals were already close to sexual maturity (360 kg) (Ferraz Junior et al., 2017), with a gain composition that was favorable to greater fat deposition and less protein deposition in the carcass (Silva et al., 2021). Therefore, the smaller amount of amino acids that reached the small intestine of the animals that received PKC was sufficient to meet their requirements (Mariz et al., 2018) without causing a noticeable decrease in performance. Similarly, Lisboa et al. (2021a) reported no effect on the final weight or ADG of steers fed diets containing up to 24% PKC.

The maintenance of weight performance (1.0 kg/day) in the heifers can be attributed to the similar net energy input provided by the diets (Zinn et al., 2008). Even with the removal of 41.5% of the main starch source from the diet, energy intake was maintained, in part, due to the high EE content of PKC (91.4 g/kg). Because lipids are not fermented in the rumen, they contribute to greater energy uptake in the small intestine of ruminants (Plascencia et al., 2003). This is especially true for sources of short- and medium-chain fatty acids, which are easier to metabolize (Schönfeld and Wojtczak, 2016), as those in PKC. In this context, the feed efficiency of heifers improved possibly due to the numerical reduction in DM intake (9.3 to 8.5 kg) and the numerical increase in weight gain (0.96 to 1.07 kg/day). According to Weld and Armentano (2017), the use of lipids increases energy utilization efficiency in ruminants. Thus, the inclusion of PKC (and the ingested lipid content) may have increased the net energy available for the heifers, improving their feed efficiency.

5. Conclusions

The inclusion of 30% palm kernel cake in the diet of feedlot heifers is recommended, as it improves their feed efficiency and does not compromise weight gain.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

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