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FULL LENGTH ARTICLE

Digestibility, rumen protozoa, and ruminal fermentation in goats receiving dietary palm oil by-products

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Abstract Sixteen goats fitted with a rumen cannula were used in completely randomized block design to test the effects of dietary crude palm oil (PO), palm kernel cake (PKC) and decanter cake (DC) on rumen total protozoa counts, rumen fermentation, and digestibility. Goats received once daily (1.5% of BW) one of four concentrate diets: reference diet (RD), DC diet (DCD), PKC diet (PKCD) and RD plus 5% PO diet (CPOD). The RD was based on corn grain and soybean meal and was fed to all goats for 28 days before the start of a 30-day experiment. Organic matter (OM) digestibility was reduced ($P < 0.05$) by feeding DCD, whereas digestibility of acid detergent fiber (ADF) was higher ($P < 0.0001$) in the goats fed PKCD. The digestibility of neutral detergent fiber (NDF) was higher ($P < 0001$) in goats fed PKCD followed by those fed DCD, CPOD and CD. Ammonia–N concentration was lower ($P < 0.001$) for treatments DCD, PKCD and CPOD than for treatment RD. Volatile fatty acid (VFA) concentrations were lower ($P < 0.05$) for treatments PKCD and CPOD than for treatments RD and DCD. Total protozoa counts were higher ($P < 0.001$) for treatment CD than for other treatments. It was concluded that the dietary DC, and PKC could be included in the diet of goats up to 80% without any adverse effects on dry matter intake; however, rumen fermentation parameters and total protozoa counts were changed.

1. Introduction

Rumen bacteria, especially cellulolytic species, are essential for the rumen function and wellbeing of the host ruminant (Hungate, 1966), whereas the role of ciliate protozoa is controversial (Santra et al., 2007) and their presence in the rumen may not be essential (Williams and Withers, 1993; Jouany, 1994; Santra et al., 2003). Rumen ciliate protozoa ingest rumen bacteria resulted in increased recycling of microbial N in the rumen (Jouany, 1996) and decreased amino acid supply to the intestine by 20–28% (Ivan et al., 1991). Many published studies reported that under certain conditions the elimination of protozoa results

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in the improvement of growth, wool and mohair yields, and feed conversion efficiency (Bird and Leng, 1985; Demeyer, 1992; Ivan et al., 1992; Santra and Karim, 2000, 2002). Many techniques such as dietary chemical agents, rumen wash, rumen emptying, rearing animals in isolation, and most recently, immunological approach have been used experimentally to reduce or eradicate the protozoal population in the rumen. However, these techniques seem not to be practical for its use in the ruminant production industry (Hegarty, 1999). Several studies showed that dietary lipids reduce protozoal concentrations in the rumen (Firkins et al., 2007), but can also reduce the rumen population of cellulolytic bacteria (Jenkins and Palmquist, 1984). Crude palm oil (PO) production generates a large amount of process residues annually; this includes oil palm frond, palm kernel cake (PKC), decanter cake (DC), empty fruit bunch, oil palm trunk and palm oil mill effluent. PKC is a by-product after the removal of the oil from the palm kernel, while DC is a by-product obtained after dehydration of palm oil mill effluent and characterized by considerable variability in chemical composition. Currently most of DC is used as fertilizer and soil cover materials in the oil palm plantation areas or as material for biogas production (Chavalparit et al., 2006; Paepatung et al., 2009). Both, DC and PO originate from the mesocarp, while PKC originates from the kernel of the palm oil plant. The chemical composition of PKC can also vary significantly depending on the method of extraction, however, the CP and EE contents range from 15% to 20% and 7.8% to 12.5%, respectively (Hindle et al., 1995; O'Mara et al., 1999; Moss and Givens, 1994). Research documenting the effect of high levels of PKC and DC on the rumen function in goats is limited, and therefore, the objective of the present experiment was to describe their effects on rumen fermentation characteristics, total protozoa counts and nutrients digestibility.

2. Material and methods

2.1. Experimental animals and diets

Sixteen Boer × Catcang crossbred male goats, each fitted with a rumen cannula and trained for housing in metabolism crates, were used in the present 30-day experiment. The BW of goats (mean ± SE) at the start was 28 ± 4 kg. The digestibility measurements were performed during the last 5 days of the experiment. The goats were housed in individual pens with wooden slotted flooring in an open wooden sheep barn raised above the ground, except for the last 7 days of the experiment when the animals were transferred to metabolism cages for total fecal collection. The care of the experimental goats was in accordance with the country standards and the experimental protocol was reviewed by the Institutional Animal Care and Use Committee. The goats were randomly assigned to each of the four dietary treatments as follows: reference diet (RD), DC diet (DCD), PKC diet (PKCD) and RD plus 5% PO diet (CPOD), where PO replaced an equal amount of corn grain (Table 1). The chemical composition of DC, PKC and PO is shown in Table 2. In addition to the concentrate diets, rice straw was available *ad libitum* to all goats during the entire experiment. All groups were fed the RD during the 28 days before the start of the experiment, and then followed by the respective dietary treatments (CD, DCD, PKCD or CPOD) during the 30-day experiment. The concentrate diets were fed in limited amounts (1.5% of BW) once daily at 08:00 h to minimize refusals and differences in intake among the dietary treatments. The refusals of straw were collected daily. Fresh water and mineral blocks were available *ad libitum* throughout the experiment.

2.2. Sampling procedures

Rumen content samples (50 ml) were collected on two consecutive days before the introduction of the experimental diets and pooled to give one sample per goat at time 0, and on days 4, 6, 8, 12, 18, 24 and 30 following the start of feeding the experimental diets. All samples were collected 2 h after the morning feeding and used for measuring pH, enumeration of total protozoa, and for an analysis of volatile fatty acids (VFA) and ammonia–N.

During the last 7 days of the study, goats were placed individually in metabolism crates to collect feces. The goats were given 2 days as an additional adaptation to crates, followed by 5 days for sample collection. The 2 day adaptation was considered to be enough as the goats were already previously adapted to the crates and dietary treatments. Daily fecal output of each goat was collected, weighed and mixed thoroughly. Daily samples (10% of the output) were accumulated in a plastic bag for each goat and stored frozen at −20 °C. The samples were later thawed, mixed and a subsample of 300 g was taken and frozen until required for an analysis of dry matter (DM), organic matter (OM), crude protein (CP), ether extract (EE), acid detergent fiber (ADF) and neutral detergent fiber (NDF). The amount of concentrate diets, rice straw offered and refused was recorded and sampled daily during the last week of the experiment and analyzed for DM, OM, EE, ADF and NDF.

2.3. Chemical analysis

A small proportion of each rumen content sample was squeezed through one layer of cheesecloth and the ruminal fluid was used for a measurement of pH and for protozoa counts. The reminder of each rumen content sample was squeezed through four layers of cheesecloth and the ruminal fluid was used for the analysis of volatile fatty acids (VFA) and ammonia–N. A 5 ml portion of the ruminal fluid was squeezed through four layers of cheesecloth, mixed with 1 ml of 25% (w/v) meta-phosphoric acid and kept frozen (−20 °C) for the analysis of VFA. The frozen samples were thawed at 4 °C and centrifuged at 3000*g* for 10 min. The supernatant (0.5 ml) was mixed with the same volume of 20 mM 4-methyl N-valeric acid as an internal standard. Ruminal VFA profile was assessed by gas chromatography (Agilent 6890, Mississauga, ON, Canada) as described by Erwin et al. (1961).

A 30 ml portion of the ruminal fluid that was squeezed through four layers of cheesecloth was mixed with 0.3 ml 6.0 M HCl and kept frozen at −20 °C. The samples were used for the determination of ammonia–N by steam distillation (Bremner and Keeney, 1965). Total protozoa cell numbers in the rumen fluid were determined as described by Dehority (1984). Samples were analyzed in duplicate.

Triplicates of feeds, feed residues and fecal samples were analyzed for DM, OM, EE and CP according to procedures of AOAC (1990). Acid detergent fiber and NDF were determined using the method of Van Soest et al. (1991); NDF anal-

Table 1 Ingredient and chemical composition of experimental concentrate diets and rice straw.

Item	Diet[a]				
	CD	DCD	PKCD	CPOD	Rice straw
Ingredients (% DM)					
Corn grain	78	4	12	73	
Soybean meal	21	5	7	21	
Palm kernel cake	0	0	80	0	
Decanter cake	0	90	0	0	
Palm oil	0	0	0	5	
Sodium sulfate	0.5	0.5	0.5	0.5	
Vitamin–mineral premix[b]	0.5	0.5	0.5	0.5	
Chemical composition (% DM)					
Dry matter	94.9	96.2	96.2	95.7	91.2
Organic matter	86.7	86.7	87.7	87.1	83.4
Crude protein	16.6	16.5	16.8	16.0	2.7
Ether extract	1.5	6.8	7.6	7.7	1.1
Acid detergent fiber	4.2	17.1	30.0	4.2	54.3
Neutral detergent fiber	21.1	54.1	60.6	20.5	73.2
Fatty acid (g/100 g total fatty acid)					
C-12:0	0	0.02	53.41	0.01	
C-14:0	0	0.50	16.21	0.81	
C-16:0	9.87	40.35	4.26	45.53	
C-18:0	5.82	5.80	11.21	4.45	
C-18:1, *n*−9	29.43	38.76	7.80	40.64	
C-18:2, *n*−6	54.43	12.12	4.57	8.94	
C-18:3, *n*−3	0.51	2.34	2.44	0.22	
C-20:0	0.34	0.11	0.10	0.21	

[a] CD (control diet), DCD (decanter cake diet), PKCD (palm kernel cake diet), and CPOD (control + 5% palm oil diet).
[b] Contained (g/kg) $FeSO_4 \cdot 7H_2O$, 170; $CuSO_4 \cdot 5H_2O$, 70; $MnSO_4 \cdot 5H_2O$, 290; $ZnSO_4 \cdot 7H_2O$, 240; (mg/kg) $CoCl_2 \cdot 6H_2O$ 510; KI, 220; NaSeO, 130; vitamin K_3, 150; vitamin B_1, 450; vitamin B_{12}, 0.9; vitamin B_5, 1,050; pantothenic acid, 750; folic acid, 15; (IU) vitamin A, 620,000; vitamin D_3, 324,000.

Table 2 Chemical and fatty acid composition (dry matter basis) of decanter cake (DC), palm kernel cake (PKC) and palm oil (PO).

Item	PKC	DC	PO
Dry matter	94.7	72.4	
Organic matter	93.0	93.7	
Crude protein	15.9	12.7	
Ether extract	9.1	10.9	
Ash	6.1	6.3	
Neutral detergent fiber	72.3	45.6	
Acid detergent fiber	47,6	17.2	
Fatty acids composition (g/100 g total fatty acid)			
C-12:0	52.13	0.47	1.69
C-14:0	15.38	0.88	0.58
C-16:0	8.65	38.98	49.64
C-18:0	4.63	4.65	3.76
C-18:1, *n*−9	15.64	43.77	35.4
C-18:2, *n*−6	1.39	9.44	7.34
C-18:3, *n*−3	1.77	1.38	1.08
C-20:0	0.41	0.43	0.51

ysis was performed without sodium sulfate or alpha amylase and is expressed with residual ash. The ADF concentration was also expressed with residual ash. Fatty acid composition of feed samples was assessed by the method described by Folch et al. (1957) and modified by Rajion et al. (1985) using chloroform/methanol 2:1 (v/v).

2.4. Statistical analysis

The digestibility parameters were subjected to one-way ANOVA using the general linear model procedure of SAS (SAS, 2003). Mean treatment differences were determined by Duncan multiple range test (Steel and Torrie, 1980.) at $P < 0.05$. The mixed procedure from SAS (SAS, 2003) was used to analyze the pH, VFA, ammonia–N and protozoa data as repeated measurements in time. The model used was

$$Y_{ijk} = \mu + D_i + A_j + T_k + (DT)_{ik} + e_{ijk},$$

where Y_{ijk} = values of observation; μ = general mean; D_i = effect of day of sampling; A_j = effect of animal; T_k = effect of dietary treatment; and e_{ijk} = residual error. Tukey's Adjustment was used to further compare means at $P < 0.05$.

3. Results and discussion

3.1. Feed intake and nutrient digestibility

The total daily DM intake (Table 3) ranged between 616 and 730 g and there were differences among dietary treatments in the intake of rice straw ($P < 0.01$), concentrate diet ($P < 0.001$) and the total DM intake ($P < 0.001$). The intake

Table 3 Dry matter intake and effects of dietary treatments on dry matter intake apparent digestibility.

Item	Diet					
	CD	DCD	PKCD	CPOD	SE	*P* Value
Dry matter intake (g day^{-1})						
Rice straw	218[b]	308[a]	257[b]	246[b]	10.9	**
Concentrate diet	398[d]	423[c]	443[a]	432[b]	2.2	***
Total	616[d]	731[a]	700[b]	678[c]	3.4	***
Apparent digestibility (%)						
Dry matter	74.5	75.8	74.1	73.7	1.39	NS‡‡
Organic matter	73.8[a]	65.8[b]	72.9[a]	72.6[a]	1.36	*
Crude protein	71.6	69.5	70.4	70.9	1.07	NS
Ether extract	58.4[c]	73.5[a]	66.4[b]	76.9[a]	2.13	***
Acid detergent fiber	47.6[b]	44.0[b]	53.9[a]	43.1[b]	1.46	***
Neutral detergent fiber	54.7[c]	61.2[b]	66.7[a]	55.4[c]	1.22	***

CD (control diet), DCD (decanter cake diet), PKCD (palm kernel cake diet), and CPOD (control + 5% palm oil diet).
SE standard error ($N = 4$).
*$P < 0.05$.
**$P < 0.01$.
***$P < 0.001$.
[a–d] Means in the same row with different superscripts are statistically different ($P < 0.05$).
‡‡ Not significant statistically ($P > 0.05$).

of rice straw was higher ($P < 0.05$) for diet DCD than for other diets which had a similar ($P > 0.05$) intake. The intake of the concentrate diet was different ($P < 0.05$) for each diet (PKCD > CPOD > DCD > RD). The total DM intake was also different ($P < 0.05$) for each diet (DCD > PKCD > CPOD > RD). All diets containing PO by-products were accepted well by goats, as evidenced by the higher feed intake in goats fed DCD, PKCD and CPOD compared to those fed RD. The results showed that goats can tolerate DC and PKC dietary inclusions up to the levels used in the present experiment and support earlier studies (Hutagulung and Mahyuddin, 1985; Jalaludin et al., 1991) in which the dietary PKC-generally resulted in a satisfactory animal performance and no negative effects on health in finishing beef cattle and buffaloes. Recently, it was reported that PKC up to 55% in a hay-based diet did not affect DM intake in Thai native goats (Chanjula et al., 2010).

The apparent digestibility of DM and CP was not different ($P > 0.05$) among the treatments, while there were differences among the treatments in the apparent digestibility of OM ($P < 0.05$) and in those of EE, ADF and NDF ($P < 0.001$). The OM digestibility was lower ($P < 0.05$) for the treatment DCD than for other treatments which had a similar ($P > 0.05$) OM digestibility. The digestibility of EE was higher ($P < 0.05$) for the treatments DCD and CPOD than for treatments RD and PKCD. Also, the digestibility was higher ($P < 0.05$) for the treatment PKCD than for the treatment RD, while the differences between the treatments DCD and CPOD were not significant. The digestibility of ADF and NDF were higher ($P < 0.05$) for the treatment PKCD than for other treatments. The digestibility of ADF was not different ($P > 0.05$) among the treatments CD, DCD and CPOD, while the digestibility of NDF was higher ($P < 0.05$) for the treatment DCD than for the treatments RD and CPOD which were similar ($P > 0.05$).

The apparent digestibility of DM and CP was similar for dietary treatments. However, the digestibility of OM was lower and the total DM intake was higher in goats fed DCD than in those fed the other diets; nutrient digestibility may decrease with increased DM intake (Nigdi et al., 1990; Hadad and Younis, 2004; Weiss and Wyatt, 2004). In their review, Devendra and Lewis (1974) reported that fat could depress cell wall degradation by four mechanisms: physical coating of fiber by lipids, shortage of cations (e.g. Ca) due to the formation of insoluble soaps, inhibition of the rumen microbial activity, and the modification of microbial population. The results of the present experiment clearly show that dietary treatments affect the fiber digestion in goats. Higher levels of lipids in PKCD and DCD probably promoted changes in the composition of rumen microorganisms, both protozoa and bacteria. The decline in the population of protozoa in the rumen due to dietary lipids would promote an increase in fiber digestion due to increased bacterial, especially cellulolytic, biomass and due to decreased protozoal engulfment of bacteria. Costa et al. (2010) also showed that 30% of dietary PKC improved the apparent digestibility of ADF in sheep.

An increase in the EE digestibility due to dietary fat was previously reported in lambs (Manso et al., 2006) and in dairy cattle (Weiss and Wyatt, 2004). It was suggested that the EE digestibility increases because the added fat has greater digestibility than the fatty acids within feed particles, and because the endogenous fat losses are diluted by the increment in the dietary fat. In the present experiment the higher digestibility of EE in goats fed the DCD, PKCD, and CPOD compared to the RD would indicate that the added fat was more digestible than that contained in the ingredients of the RD. This is in agreement with Grummer (1988) and Naik et al. (2009).

3.2. Rumen fermentation characteristics

The mean pH in the rumen fluid (Table 4) ranged from 6.1 (DCD) to 6.4 (PKCD) and was affected by both the diet ($P < 0.05$) and the day of sampling ($P < 0.001$). It was also affected by the diet × day of sampling interaction ($P < 0.05$), which showed variable effects of the dietary treatments at different sampling days (Fig. 1). However, the pH values in all

Table 4 Effects of dietary treatments on rumen fermentation characteristics of goats.

Item	Diet‡					Effect		
	CD	DCD	PKCD	CPOD	SE	Diet	Day	Diet × day
pH	6.35	6.07	6.42	6.25	0.103	*	***	**
NH_3-N (mg/L)	49.9[a]	35.0[b]	34.4[b]	33.9[b]	1.00	***	***	**
Total VFA (mmol)	98.5[a]	98.1[a]	94.8[b]	94.4[b]	0.90	*	**	NS‡‡
VFA¶ (mol/100 mol)								
Acetate	62.6	63.4	62.6	63.5	0.30	NS	***	NS
Propionate	20.2	20.6	21.4	20.5	0.30	NS	NS	NS
Isobutyrate	1.24	1.26	1.22	1.37	0.069	NS	NS	NS
Butyrate	12.2	10.8	11.0	10.8	0.30	NS	***	**
Isovalerate	1.31	1.38	1.40	1.43	0.082	NS	NS	NS
Valerate	2.43	2.51	2.50	2.43	0.041	NS	NS	NS
Acetate/propionate	3.13	3.15	2.95	3.13	0.060	NS	NS	NS
Total protozoa (×105)	6.2	2.1	2.1	2.1	0.3		***	***

*$P < 0.05$.
**$P < 0.01$.
***$P < 0.001$.
SE standard error ($N = 4$).
¶ Volatile fatty acids,
‡ CD (control diet), DCD (decanter cake diet), PKCD (palm kernel cake diet) and CPOD (control + 5% palm oil diet).
‡‡ Not significant statistically ($P > 0.05$).
[a,b] Means in the same row with different superscripts are statistically different ($P < 0.05$).

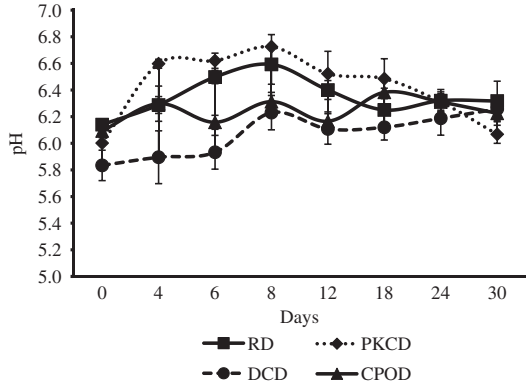

Figure 1 Mean pH in the rumen fluid of goats at different days after start of feeding experimental diets. Vertical bars are standard errors ($N = 4$). CD, control diet; DCD, decanter cake diet; PKCD, palm kernel cake diet; CPOD, CD plus 5% PO diet.

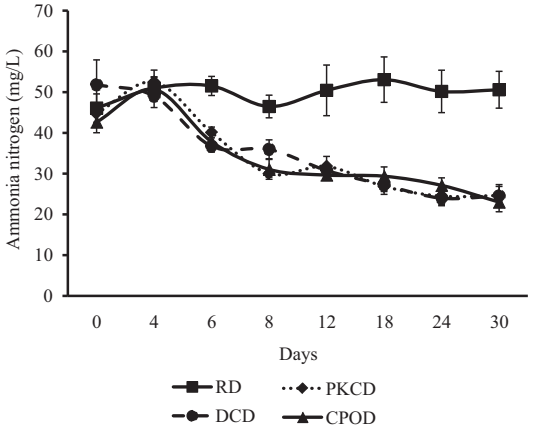

Figure 2 Mean concentrations of ammonia–N in the rumen fluid of goats at different days after start of feeding experimental diets. Vertical bars are standards errors ($N = 4$). CD, control diet; DCD, decanter cake diet; PKCD, palm kernel cake diet; CPOD, CD plus 5% PO diet.

dietary treatments were within the range of 5.8–7 below which the rumen function might be negatively affected (de Veth and Kolver, 2001). The mean concentration (mg/L) of ammonia–N in the rumen fluid (Table 4) was also affected by the diet ($P < 0.001$), day of sampling ($P < 0.001$) and interaction ($P < 0.01$). The interaction was due to high ammonia–N concentrations for the treatment RD (Fig. 2) during the duration of the experiment, whereas the ammonia–N concentration decreased rapidly after day 4 and was somewhat variable for treatments DCD, PKCD and CPOD. Such a decrease is probably one of the most consistent effects observed in defaunated ruminants (Veira et al., 1983) or in ruminants with reduced fauna (e.g. Ivan et al., 2009). The lower rumen ammonia–N concentration in defaunated compared to faunated animals results from reduced recycling of bacterial protein due to lower protozoal predation, higher bacterial population to utilize ammonia, lower deaminase activity and the rate of deamination associated with protozoa (Wallace et al., 1987), and the absence of lyses of protozoa and degradation of protozoal protein by bacteria (Koenig et al., 2000). Moreover, a slow rumen degradation of protein fraction in PKC (Hindle et al., 1995) might have contributed to the reduced rumen ammonia–N in goats receiving PKCD.

The mean total VFA concentration (mmol) in the rumen fluid (Table 4) was higher ($P < 0.05$) for the treatment DCD than for the treatments PKCD and CPOD. The concentration was affected by the diet ($P < 0.05$), and the day of sampling ($P < 0.01$), but not ($P > 0.05$) by the diet × day of sampling

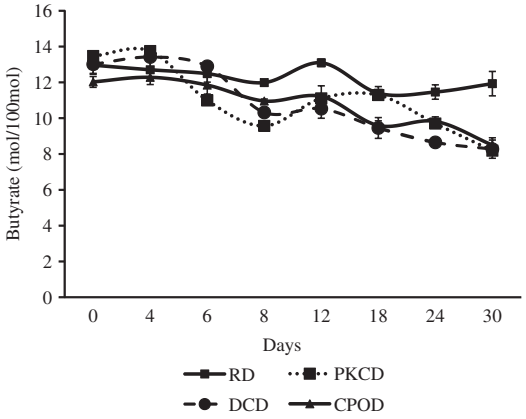

Figure 3 Mean molar proportions of butyrate in the rumen fluid of goats at different days after start of feeding experimental diets. Vertical bars are standard errors ($N = 4$). CD, control diet; DCD, decanter cake diet; PKCD, palm kernel cake diet; CPOD, CD plus 5% PO diet.

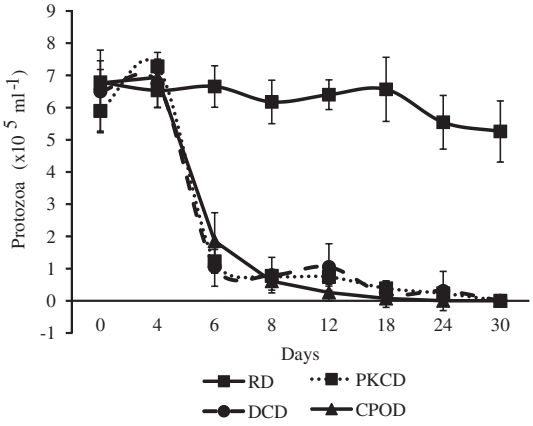

Figure 4 Mean numbers of ciliate protozoa in the rumen fluid of goats at different days after start of feeding experimental diets. Vertical bars are standard errors ($N = 4$). CD, control diet; DCD, decanter cake diet; PKCD, palm kernel cake diet; CPOD, CD plus 5% PO diet.

interaction. One hypothesis could explain the reduction of total VFA, that the addition of high levels of PKC to the diet of goats probably reduced the digestibility of energy from PKC. The VFA molar proportions (%) were not affected ($P > 0.05$) by diets. The concentration of acetate was affected by the day of sampling ($P < 0.001$) and that of butyrate was affected by the day of sampling ($P < 0.001$) and the interaction ($P < 0.01$). The molar proportion of butyrate (Fig. 3) changed differently between the sampling days for individual treatments. For example, the molar proportion fluctuated in a wider range for the treatment PKCD than for the treatments RD and CPOD. This probably might be due to the shift in microbial population, namely ciliate protozoa, caused by these diets. Ruminal protozoa produce butyric acid as an end product of carbohydrate fermentation (Williams and Coleman, 1997) and defaunation often associated with a decreased rumen butyrate concentration (Williams and Coleman, 1992).

3.3. Rumen protozoa

The mean number of protozoa in the ruminal fluid (Table 4) was higher ($P < 0.05$) in the treatment RD than the other treatments. The concentrations were affected ($P < 0.001$) by the diet, day of sampling and by the diet × day of sampling interaction. Although the protozoa numbers were almost constant between day 0 and day 30 for the treatment RD (Fig. 4), the numbers decreased rapidly between days 4 and 6 for the other treatments and remained low thereafter.

It has been reported that oils (Machmuller and Kreuzer, 1999) and unsaturated C_{18} fatty acids (Newbold and Chamberlain, 1988) are toxic to rumen ciliate protozoa. Williams (1989) postulated that the toxicity of high dietary lipid concentrations to rumen protozoa is due to their limited ability to absorb and transform lipids, resulting in swelling and consequent rupture of the protozoa cells (Girard and Hawke, 1978). In the present study protozoa numbers in the rumen decreased rapidly to a very low concentration after day 4 of feeding diets containing PO, DC and PKC, and totally disappeared from the rumen of goats fed the CPOD on day 24 and of goats fed both the DCD and PKCD on day 30. This is in agreement with Abdullah and Hutagalung (1988) reporting the eradication of protozoa from the rumen of cattle fed PKC. Additionally, decreased protozoa numbers due to different sources of dietary fat have been reported in other studies (Sutton et al., 1983; Yanez Ruiz et al., 2004; Wanapat and Khampa, 2006). However the concentration of the dietary lipids must be sufficient to affect notably the rumen protozoa population. In the present experiment, regardless of fatty acid composition, EE for the diet RD was 4.5 to 5.1-fold lower than in the other diets (DCD, PKCD and CPOD) indicating that the concentration of lipids in the RD diet was not enough to affect the rumen concentration of protozoa.

In conclusion, the results of the present experiment showed clearly that the DC, PKC could be included in goat diets up to 80% without any harmful effect on DM intake and nutrient digestibility with improved fiber digestion, however, rumen protozoa were reduced and eventually eradicated from the rumen of goats as similar as 5% PO. More research will be desirable to determine whether other rumen microbes especially cellulolytic bacteria could be affected by high levels of dietary PKC and DC.

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