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Effect of Feeding Rubber Seed Kernel and Palm Kernel Cake in Combination on Nutrient Utilization, Rumen Fermentation Characteristics, and Microbial Populations in Goats Fed on *Briachiaria humidicola* Hay-based Diets

P. Chanjula*, Y. Siriwathananukul and A. Lawpetchara
Department of Animal Science, Faculty of Natural Resources, Prince of Songkla University, 90110, Thailand

ABSTRACT : Six male crossbred (Thai Native×Anglo Nubian) goats, with an average initial weight of 22±2 kg, were randomly assigned according to a 3×2 factorial arrangement in a 6×6 Latin square design with a 21-d period to evaluate the effect of feeding rubber seed kernel (RSK) and palm kernel cake (PKC) in combination on nutrient utilization, rumen fermentation characteristics, and nitrogen utilization. The dietary treatments were as follows: i) concentrate containing 0% RSK and 20% PKC (T_1), ii) 0% RSK and 30% PKC (T_2), iii) 20% RSK and 20% PKC (T_3), iv) 20% RSK and 30% PKC (T_4), v) 30% RSK and 20% PKC (T_5), and vi) 30% RSK and 30% PKC (T_6). During the experiment, signal hay was given on an *ad libitum* basis as the roughage. It was found that RSK levels and PKC levels had no interaction effects on feed intake, apparent digestibility, NH_3-N, blood metabolites, VFA concentrations, and nitrogen utilization, but there were interactions between RSK levels and PKC levels with respect to total DMI (kg/d) and total VFA concentrations, and goats receiving 30% RSK had lower values ($p<0.05$) than those receiving 0 and 20% RSK, respectively. Feeding different PKC levels did not affect ($p>0.05$) feed intake, digestibility, rumen fermentation patterns, blood metabolites, and nitrogen utilization. However, increasing RSK levels (>20%) resulted in a slightly lower daily DMI (% BW and g/kg $BW^{0.75}$), apparent digestibility (NDF and ADF), total N intake, and N excretion than in goats fed on 0 and 20% RSK. BUN, blood glucose, and propionate were variable among treatment and were highest in 0% RSK with the 20% PKC fed group having values which were higher than those in other groups. However, there were no differences ($p>0.05$) among treatments with respect to N retention, PD output, and microbial N supply. Based on this study, RSK levels up to 20% and PKC at 20-30% in concentrate could be efficiently utilized for goats fed on signal hay. (**Key Words :** Rubber Seed Kernel, Palm Kernel Cake, Feed Intake, Rumen Fermentation, Goat)

INTRODUCTION

Persistent shortages of the conventional feedstuffs for livestock feeding in Thailand and the developing countries are caused largely by inadequate production of farm crops to meet the needs both of humans and of their domestic animals. Additionally, the high cost of feed is a sequel to the competition between man and livestock for these feed ingredients. This has forced animal nutritionists to intensify research into the feeding values of potentially useful, attractive, cheaper and readily available protein and energy sources from unconventional crop products. One of these is rubber seed meal obtained from rubber tree seed (*Hevea brasiliensis*). These seeds are very rich in oil and are produced in quantities of approximately 5 kg/tree annually (Bressani et al., 1983). If the oil, which is very rich in linolenic and linoleic acids (Babatunde and Pond, 1987b), can be extracted and used commercially for food and industrial markets, the cake may be used for livestock feeding. In Kerala, India, feeding of meal at a level of 20 percent has been found suitable for calves and lactating cows (Anonymous, 1976), and Rajan et al. (1990) used rubber seed cake at the 20 percent level (for 200 days) for fattening goats for meat production without adverse effect.

Palm kernel cake (PKC), also known as palm kernel meal (PKM), is obtained after extraction of oil as a by-product from the oil palm industry, and is readily available in tropical countries at competitive prices. It has been widely used in ruminant diets because of its fibrous nature (Abdullah et al., 1995). These by-products have moderate digestible energy and CP contents and high fiber content

* Corresponding Author : Pin Chanjula. Tel: +66-74-558805, Fax: +66-74-558805, E-mail: pin.c@psu.ac.th
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(O'Mara et al., 1999; Carvalho et al., 2005). Earlier studies showed that cattle and buffaloes fed on PKC as supplements or basal diets generally show improved growth performance (Hutagalung and Mahyuddin, 1985; Jelan et al., 1991). Rubber seed kernel (RSK) and palm kernel cake (PKC) are very abundant in the southern region of Thailand where they are produced for domestic purposes and for export. Although the cake or rubber seed meal and palm kernel cake can be used as animal feed (Stosic and Kaykay, 1991; Abdullah et al., 1995), the information available on the use of feeding combinations of rubber seed kernel and palm kernel cake in diets for goats is very scarce. Additionally, a negative effect was not observed in a subsequent study when RSK and PKC were fed using signal hay (SH) as the roughage source. Therefore, the purpose of this study was to examine interaction between levels of RSK- and PKC-based diets on nutrient utilization, rumen fermentation characteristics and microbial populations in goats fed on SH.

MATERIALS AND METHODS

All procedures involving animals were approved by the Ethical Principles for the Use of Animals for Scientific Purposes of the National Research Council of Thailand (NRCT) for the metabolism and finishing studies.

Animals and experimental diets

Six male crossbred (Thai Native x Anglo Nubian) goats, about 18 months old and 22±1.6 kg body weight, were randomly allocated in a 6×6 Latin square experiment with a 3×2 factorial arrangement of treatments to evaluate the effects of 3 levels of rubber seed kernel (RSK: 0, 20 and 30% of DM) and 2 levels of palm kernel cake (PKC: 20 and 30% of DM) on feed intake, digestibility, ruminal fermentation, blood metabolites, microbial populations and nitrogen balance. The dietary treatments were as follows: i) concentrate containing 0% RSK and 20% PKC (T_1), ii) 0% RSK and 30% PKC (T_2), iii) 20% RSK and 20% PKC (T_3), iv) 20% RSK and 30% PKC (T_4), v) 30% RSK and 20% PKC (T_5), and vi) 30% RSK and 30% PKC (T_6). Ingredients and composition of each diet are shown in Table 1. The concentrate mixed diets were formulated to be isonitrogenous at 16% CP (2.56% N).

All goats were drenched for internal worms (Ivermectin, IDECTIN®, The British Dispensary, Co., Ltd.) and injected

Table 1. Composition of the experimental diets, signal hay (SH), rubber seed kernel (RSK), palm kernel cake (PKC) (% DM basis)

Attributes	Dietary treatments [1]						SH	RSK	PKC
	T_1	T_2	T_3	T_4	T_5	T_6			
Physical composition									
Ground corn, GC	59.71	53.19	48.86	41.14	41.75	31.75	-	-	-
Soybean meal, SBM (44% CP)	15.13	12.81	3.14	1.00	-	-	-	-	-
Rubber seed kernel, RSK	-	-	20.00	20.00	30.00	30.00	-	-	-
Palm kernel cake, PKC	20.00	30.00	20.00	30.00	20.00	30.00	-	-	-
Molasses	3.16	2.00	5.00	4.86	5.00	5.00	-	-	-
Salt	1.00	1.00	1.00	1.00	1.00	1.00	-	-	-
Mineral and vitamin mix[2]	1.00	1.00	1.00	1.00	1.00	1.00	-	-	-
Urea	-	-	1.00	1.00	1.25	1.25	-	-	-
Chemical composition							-	-	-
DM[3]	90.33	90.78	91.08	90.71	91.25	91.35	94.30	94.30	92.88
Ash	4.63	4.83	4.58	4.75	4.43	4.88	3.28	3.50	4.52
OM	95.37	95.17	95.42	95.25	95.57	95.12	96.72	96.65	95.48
CP	16.57	16.50	16.60	16.60	16.15	16.52	3.01	23.64	18.72
EE	5.93	8.05	14.07	16.78	17.98	16.55	0.80	40.77	8.02
NSC[4]	36.79	28.88	29.51	21.91	24.31	22.02	11.70	20.21	2.54
NDF	36.08[c]	41.74	35.24	39.96	37.13	40.03	81.21	11.88	67.20
ADF	14.08	15.28	16.08	17.81	17.86	20.03	54.01	6.35	44.63
ADL	4.58	5.25	5.60	6.17	5.29	6.42	12.80	5.20	13.52
Hemicellulose[5]	29.58	32.20	29.12	31.97	30.48	30.20	27.20	5.53	44.63
Cellulose[6]	1.92	4.29	0.52	1.82	1.36	3.41	41.21	1.15	13.52
GE MJ/kg DM	-	-	-	-	-	-	15.64	26.47	19.56

[1] T_1 = Concentrate containing 0% RSK and 20% PKC, T_2 = 0% RSK and 30% PKC, T_3 = 20% RSK and 20% PKC, T_4 = 20% RSK and 30% PKC, T_5 = 30% RSK and 20% PKC, T_6 = 30% RSK and 30% PKC.

[2] Minerals and vitamins (each kg contains): Vitamin A: 10,000,000 IU; Vitamin E: 70,000 IU; Vitamin D: 1,600,000 IU; Fe: 50 g; Zn: 40 g; Mn: 40 g; Co: 0.1 g; Cu: 10 g; Se: 0.1 g; I: 0.5 g.

[3] DM = Dry matter; OM = Organic matter; CP = Crude protein; EE = Ether extract; NSC = Non-structural carbohydrate; NDF = Neutral detergent fiber; ADF = Acid detergent fiber; ADL = Acid detergent lignin.

[4] Estimated: NSC = 100-(CP+NDF+EE+Ash). [5] Estimated: Hemicellulose = NDF-ADF. [6] Estimated: Cellulose = ADF-ADL.

with vitamins A, D_3 and E prior to commencing the experiment. Each goat was kept individually in a ventilated metabolism crate in well-ventilated sheds where water and mineral salt were available at all times. During each period, all animals received a concentrate diet at 2% BW (DM basis) and were allowed to consume signal hay (SH, *Briachiaria humidicola*) *ad libitum*, allowing for 10% refusals. Feeds were provided twice daily in two equal portions at 0800 and 1600 h. Each morning before feeding, feed refusals were weighed and recorded daily at 0700 h. Fresh orts samples were bulked by pen and dried at 60°C, and subsamples were used for dry matter determinations. This information was used to calculate signal hay (SH) intake. Feed samples obtained each time were oven dried at 60°C for 72 h and ground to pass through a 1-mm sieve, and composited by period on an equal weight basis for further analysis. Goats were individually weighed before the morning feeding at the beginning and end of each experimental period.

Data collection and sampling procedures

Each experimental period lasted for 21 days; the first 15 days were a period for treatment adaptation and for feed intake measurements while the last 6 days were used to measure digestibility using the total collection method. This comprised 5 days of total collection of feces and urine, followed by 1 day of rumen fluid and blood collection. At the end of each period, rumen fluid was collected from all goats using a stomach tube at 0 and 4 h-post feeding during the digestibility trial. It was strained through 4 layers of cheese cloth and pH measured immediately using a pH meter (HANNA instruments HI 98153 microcomputer pH meter, Singapore) fitted with a combined electrode. The rumen fluid was then acidified with H_2SO_4 (1 M) solution and stored at -20°C for analyses of NH_3-N and volatile fatty acids (VFA). Blood samples (about 10 ml) were collected via the jugular vein into heparinized tubes at the same time as rumen fluid sampling (0 and 4 h-post feeding). Blood samples were centrifuged at 4°C at 3,300×*g* for 15 min and plasma was separated and frozen at -20°C until analysis.

Laboratory analyses

Feed, feed refusals, and feces were analyzed in duplicate for DM, ash, CF, ether extract and Kjeldahl N using AOAC (1990) procedures. Neutral detergent fiber (NDF), acid detergent fiber (ADF) and acid detergent lignin (ADL) fractions were determined with the procedure of Goering and Van Soest (1970). Digestion coefficients were calculated using the formula given by Schneider and Flatt (1975). Blood urea nitrogen (BUN) was determined according to the method of Crocker (1967), ruminal NH_3-N using the micro kjeldahl method (AOAC, 1990) and VFA analyses by HPLC (Waters model 600E controller and model 484 UV detector; column novapak C_{18}; column size 4 mm×150 mm; mobile phase 10 mM H_2SO_4 (pH 2.5), ETL Testing Laboratory, Inc., Cortland, New York, 13045, USA) according to Samuel et al. (1997). Plasma glucose and packed cell volume (PCV) were measured by commercial kits (No. 640, Sigma Chemical Co., St. Louis, USA).

Urine samples were analyzed for Kjeldahl N (AOAC, 1990) and purine derivatives (i.e., allantoin, uric acid, hypoxanthine and xanthine) according to Chen and Gomez (1992) by HPLC (Waters model 600E controller and model 484 UV detector; column novapak C_{18}; column size 4 mm× 150 mm; mobile phase 10 mM H_2PO_4 (pH 2.5), ETL Testing Laboratory, Inc., Cortland, New York, 13045, USA). The amount of microbial purines absorbed (x mmol/d) corresponding to the purine derivatives excreted (Y mmol/d) was calculated according to Chen et al. (1990) as follows:

$$Y = 0.84x+(0.15BW^{0.75}e^{-0.25}x)$$

where Y is the excretion of purine derivatives (mmol/d); x is the microbial purines absorbed (mmol/d); BW is the body weight. Microbial N supplied to the small intestine was calculated from microbial purine absorbed (x) according to the equation of Chen and Gomez (1992):

$$\text{Microbial N (g/d)} = \frac{70x}{0.83\times 0.116\times 1{,}000}$$

Statistical analyses

Statistical analyses were conducted using the GLM procedure of SAS (SAS Inst. Inc., Carry, NC). The model used was: $Y_{ijk} = \mu+A_i+P_j+R_k+K_l+RK_{kl}+E_{ijkl}$, where Y_{ijkl} = nutrient intake or rumen fermentation values; μ = overall mean; A_i = effect of animal; P_j = effect of period; R_k = effect of level of RSK; K_l = effect of level of PKC; RK_{kl} = effect of interaction of level of RSK and PKC; E_{ijkl} = error term. Treatment means were statistically compared using Duncan's Multiple Range Test (DMRT) (Steel and Torrie, 1980) to identify differences between means. Significant differences were declared if $p<0.05$.

RESULTS AND DISCUSSION

Chemical composition of feeds

The chemical composition of roughages and experimental diets is summarized in Table 1. Experimental diets contained similar concentrations of DM, OM, CP, NDF, ADF, and ADL, but varying amounts of EE and NSC. Diets were formulated to be 16% CP (DM basis). Slightly greater concentrations of CP in DM offered may have occurred because of greater than expected CP levels in some ingredients or inconsistencies in diet mixing or sampling (Table 1). Diets containing RSK had a slightly lower non-structural carbohydrate (NSC) content as the level of RSK and PKC increased in the diets, ranging from 21.91 to 36.79%, whereas EE content was slightly higher as the level of RSK and PKC increased in the diets, ranging from 5.93-17.98%. The differences among concentrate mixed diets in NSC and EE concentrations could be related to differences in the ingredients used in diet formulation (Table 1), especially a high content of EE in RSK (40.77%) which would depend on the oil content and method of processing RSK (Stosic and Kaykay, 1991). In this study, the RSK was not an expeller or defatted rubber seed meal.

Signal hay (SH) contained 3.01% CP, 81.21% NDF, 54.01% ADF, and 12.80% ADL. The PKC contained 18.72% CP and high OM (95.48%), NDF (67.20%), ADF (44.63), and ADL (13.52%) contents. The CP and EE contents in PKC in this study were similar to those reported by Agunbiade et al. (1999), O'Mara et al. (1999), and Carvalho et al. (2005) who found that PKC contained 16.42-21.00% CP and 7.83-9.40% EE. The sample had a GE content of 19.56 MJ/kg DM. Similar values for PKC have been previously reported by Jalaludin et al. (1991), and O'Mara et al. (1999). In the current study, the RSK contained 23.64% CP, 40.77% EE, 11.88% NDF, 6.35% ADF, 5.20% ADL, and 19.56 MJ/kg DM which agreed with the report of Giok et al. (1967); George et al. (2000) reported that the dried kernel from rubber seed contained 32 to 45% fat and 27 to 30% protein. However, the chemical composition of RSK and PKC is variable due to different processing methods and the degree of impurities, such as shell content (Jalaludin et al., 1991; Stosic and Kaykay, 1991). In general, the expeller samples had lower contents of CP, NDF and, ADF than the extracted samples. These differences can be mainly attributed to the dilution effect of the oil in the expeller samples (O'Mara et al., 1999).

Feed intake and apparent digestibility of nutrients

As shown in Table 2, there were no RSK×PKC interactions ($p>0.05$) with respect to feed intake and apparent digestibility, but there were interactions ($p = 0.05$) with respect to total DMI (kg/d). The greatest total DMI was observed in goats fed on T_3, and the least total DMI occurred on T_6. Feeding PKC levels did not affect ($p>0.05$) feed intake and digestibility whereas overall means for daily DMI (% BW and g/kg $BW^{0.75}$) and apparent digestibility (NDF and ADF) were significantly affected ($p<0.05$) by levels of RSK; goats receiving 30% RSK had lower daily DMI (% BW and g/kg$BW^{0.75}$) and apparent digestibility (NDF and ADF) than those fed on 0 and 20% RSK. DM, OM and CP digestibility were similar ($p>0.05$), but DM and OM tended to be slightly lower for goats fed on 30% RSK as compared with other treatments. Similar to our results, Njwe et al. (1988) also reported that DMI, nutrient digestibility of DM and OM, and weight gain were not affected when sheep were fed concentrate containing 20% RSK, but a linear decrease in DMI, nutrient digestibility, and weight gain was observed when RSK increased from 30 to 50%, whereas CP digestibility was not affected ($p>0.05$), ranging from 74.96 to 79.99%. Likewise, Rajan et al. (1990) used rubber seed cake at a 20% level (for 200 days) for fattening goats for meat without adverse effect on growth performance. This result suggested that goats can utilize up to 20% RSK with no effect on voluntary feed intake and nutrient digestibility, whereas PKC levels did not have an effect on both voluntary feed intake and nutrient

Table 2. Effect of feeding combinations of rubber seed kernel (RSK) and palm kernel cake (PKC) based diets on feed intake (kg/d) and apparent digestibility in goats fed on signal hay as roughage

Item	Dietary treatments [1]						SEM	p-value		
	T_1	T_2	T_3	T_4	T_5	T_6		RSK	PCK	RSK×PCK
DMI (kg/d)										
Signal hay (kg/d)	0.256	0.265	0.335	0.280	0.280	0.264	0.03	0.14	0.29	0.40
Concentrate (kg/d)	0.460^{ab}	0.497^{a}	0.435^{abc}	0.378^{bc}	0.382^{bc}	0.316^{c}	0.03	0.02	0.57	0.22
Total DMI (kg/d)	0.716^{ab}	0.763^{a}	0.771^{a}	0.659^{b}	0.663^{b}	0.630^{b}	0.03	0.01	0.19	0.05
DMI (% BW)	2.28^{ab}	2.41^{a}	2.39^{a}	2.08^{b}	2.10^{b}	2.01^{b}	0.08	0.01	0.21	0.08
DMI (g/kg $W^{0.75}$)	54.02^{ab}	57.06^{a}	57.01^{a}	49.45^{b}	49.81^{b}	47.75^{b}	2.16	0.01	0.22	0.07
Total-tract apparent digestibility (%)										
DM	73.36	73.48	70.56	70.94	70.24	70.99	1.26	0.06	0.68	0.96
OM	74.43	74.44	71.67	72.05	71.50	72.31	1.25	0.08	0.70	0.95
CP	70.93	73.97	74.17	73.87	73.97	72.42	1.54	0.60	0.75	0.32
NDF	64.06^{ab}	66.61^{a}	63.63^{ab}	63.58^{ab}	60.05^{b}	59.87^{b}	1.91	0.03	0.62	0.72
ADF	60.05^{ab}	61.99^{a}	59.78^{ab}	59.70^{ab}	52.99^{b}	52.99^{b}	2.70	0.02	0.78	0.91
EE	82.52^{b}	84.46^{b}	90.00^{a}	94.92^{a}	92.87^{a}	91.53^{a}	1.75	0.01	0.42	0.45

[1] T_1 = Concentrate containing 0% RSK and 20% PKC, T_2 = 0% RSK and 30% PKC, T_3 = 20% RSK and 20% PKC, T_4 = 20% RSK and 30% PKC, T_5 = 30% RSK and 20% PKC, T_6 = 30% RSK and 30% PKC.

[a-c] Within rows values not sharing a common superscript are significantly different ($p<0.05$).

SEM = Standard error of the mean (n = 6).

Table 3. Effect of feeding combinations of rubber seed kernel (RSK) and palm kernel cake (PKC) based diets on rumen fermentation characteristics and blood metabolites in goats fed on signal hay as roughage

Item	Dietary treatments [1]						SEM	p-value		
	T_1	T_2	T_3	T_4	T_5	T_6		RSK	PCK	RSK×PCK
NH_3-N (mg/dl)	16.31	17.74	16.19	16.55	14.30	14.29	1.42	0.13	0.56	0.90
BUN (mg/dl)	16.62[a]	14.72[ab]	12.91[b]	13.33[ab]	14.02[ab]	16.31[a]	1.02	0.05	0.74	0.15
Glucose (mg/dl)	65.87[a]	61.85[ab]	58.22[b]	58.97[b]	59.84[b]	57.65[b]	1.58	0.01	0.17	0.33
PCV (%)	31.83	32.25	33.16	31.91	33.00	31.83	0.59	0.41	0.82	0.85

[1] T_1 = Concentrate containing 0% RSK and 20% PKC, T_2 = 0% RSK and 30% PKC, T_3 = 20% RSK and 20% PKC, T_4 = 20% RSK and 30% PKC, T_5 = 30% RSK and 20% PKC, T_6 = 30% RSK and 30% PKC.

[a-c] Within rows values not sharing a common superscript are significantly different (p<0.05).

SEM = Standard error of the mean (n = 6).

digestibility. Goats receiving concentrate containing more than 20% RSK had lower voluntary feed intake than those on 0 and 20% RSK. This result may be due to comparatively low palatability and rancidity of concentrate containing >20% RSK, which resulted in lower intake. Additionally, this trend may be related to the high fibrous fraction (ADF and ADL) and EE content (Table 1). The EE content of >20% RSK inclusion was high enough to reduce digestibility, especially fiber digestion and rumen microbial fermentation (Palmquist and Jenkins, 1980; NRC, 2001). Similarly, Palmquist and Jenkins (1980), Doreau et al. (1997), and NRC (2001) indicated that feeding large amounts of dietary fat to ruminants (above 6-7%) can negatively affect digestibility, bacterial growth and rumen fermentation, resulting in decreased overall DMI. Furthermore, it is possible that low digestibility could have been attributed to a high fibrous fraction (ADF and ADL) (Van Soest, 1994). Digestibility appears to be negatively related to a fibrous content (Van Soest, 1994; O'Mara et al., 1999), especially the large proportion of lignified cell walls with low fermentation rate and digestibility, leading to a low rate of disappearance through digestion or passage and limited feed intake. Additionally, the slightly lower CP digestibility at combinations of RSK and PKC of >20% may have been contributed by lower intake of concentrate that contained slightly lower true protein (soybean meal, SBM) in the diet (Table 1). Saxena et al. (1971) indicated that supplementation of true protein was more effective than NPN. Similarly, McAllan (1991), Huntington and Archibeque (1999) reported that protein digestion in animals supplemented with true protein was greater than in those supplemented with urea or NPN. In our trial, apparent digestibility of EE when feeding 20 and 30% RSK was greater (p = 0.01) than with 0% RSK in the diets, probably as a result of higher EE intake which was expected.

Rumen fermentation patterns and blood metabolites

Ruminal NH_3-N concentration in this study was not changed by levels of RSK and PKC, ranging from 14.29-17.74 mg/dl which agreed with results of Wanapat and Pimpa (1999) (13.6-17.6 mg/dl). Concentration of ruminal NH_3-N was higher than 5 mg %, which is the optimal level of NH_3-N for microbial protein synthesis in mixed culture in a closed system (Satter and Slyter, 1974). Moreover, the rumen ammonia concentrations in all animals were closer to optimal ruminal NH_3-N (15-30 mg %, Perdok and Leng, 1990) for improving microbial protein synthesis, digestibility and feed intake. Likewise, BUN concentration in this study was similar regardless of levels of RSK and PKC; however, BUN was significantly affected (p = 0.05) by levels of RSK. Goats receiving 20% RSK had lower BUN than other treatments, ranging from 15.58 to 17.58 mg/dl, and the values were similar to the appropriate BUN of 15 mg % reported by Baker et al. (1995). These levels were close to the optimal level in normal goats, which has been reported in the range of 11.2 to 27.7 mg/dl (Lloyd, 1982).

Blood glucose concentration was higher (p<0.01) in goats receiving 0% RSK than 20 and 30% RSK, but feeding levels of PKC did not affect (p>0.05) blood glucose concentration, ranging from 57.65-65.87 mg/dl. All treatment means were within the normal range of 50 to 75 mg/dl (2.78 to 4.16 mmol/L) (Kaneko, 1980). Observed blood glucose concentrations were similar to those reported by Gelaye et al. (1990) and Turner et al. (2005). Packed cell volume (PCV) was similar (p>0.05) regardless of levels of RSK and PKC, ranging from 31.83-33.16% but within the normal range of 22-38 mg/dl (Jain, 1993).

Volatile fatty acid profiles

Table 4 illustrates data on volatile fatty acid (VFA) profiles. There was interaction (p<0.05) between levels of RSK and PKC with respect to ruminal total VFA and propionate concentrations, but feeding levels of RSK and PKC did not have an effect. The highest total VFA was observed in goats fed T_3, and the lowest total VFA occurred when goats were fed T_5 compared with other treatment groups, while propionate concentration was lower in T_6. Acetate concentrations in the rumen were similar among treatments and were found at normal concentrations of

Table 4. Effect of feeding combinations of rubber seed kernel (RSK) and palm kernel cake (PKC) based diets on volatile fatty acid profiles in goats fed on signal hay as roughage

Item	Dietary treatments [1]						SEM	p-value		
	T_1	T_2	T_3	T_4	T_5	T_6		RSK	PCK	RSK×PCK
Total VFA (mmol/L)	55.84[ab]	60.60[ab]	62.05[a]	55.35[ab]	52.46[b]	54.78[ab]	2.59	0.37	0.43	0.02
Molar proportion of VFA mol/100 mol										
Acetate (C_2)	59.10	59.82	61.37	59.69	58.91	63.67	1.61	0.25	0.11	0.43
Propionate (C_3)	28.67[a]	24.80[ab]	25.80[ab]	26.47[ab]	28.16[a]	20.20[b]	2.06	0.54	0.26	0.03
Butyrate (C_4)	7.39[b]	10.04[ab]	7.76[b]	7.96[b]	6.62[b]	10.92[a]	0.71	0.01	0.85	0.56
C2:C3 ratio	2.38	2.61	2.61	2.43	2.41	3.29	0.35	0.27	0.30	0.62
Isobutyrate	1.21	1.41	1.21	1.52	1.67	1.27	0.88	0.58	0.91	0.13
Isovalerate	2.11	2.07	2.31	2.43	2.64	2.25	0.18	0.95	0.32	0.11
Valerate	1.54	1.86	1.56	1.96	2.03	1.78	0.34	0.61	0.74	0.30

[1] T_1 = Concentrate containing 0% RSK and 20% PKC, T_2 = 0% RSK and 30% PKC, T_3 = 20% RSK and 20% PKC, T_4 = 20% RSK and 30% PKC, T_5 = 30% RSK and 20% PKC, T_6 = 30% RSK and 30% PKC.
[a-c] Within rows values not sharing a common superscript are significantly different (p<0.05).
SEM = Standard error of the mean (n = 6).

58.91-63.67 mol/100 mol total VFA (Hungate, 1966). No interactions (p>0.05) between effects of levels of RSK and PKC were observed with respect to ruminal butyrate concentrations, but goats fed diets with 20% RSK had lower butyrate concentrations than those fed on 0 and 30% RSK, while levels of PKC did not have any effect (p>0.05). Concentrations of branched-chain VFA (isobutyrate and isovalerate) and valerate of goats in all treatments were similar regardless of levels of RSK and PKC; also, no interactions (p>0.05) between main effects were observed for branched-chain VFA (Table 4). Branched-chain VFA are products of degradation of branched AA, but they are also, together with valerate, growth factors primarily metabolized in the rumen by fiber-digesting bacteria (Andries et al., 1987; Wallace, 1994). Thus, ruminal concentrations of branched-chain VFA may indicate levels of protein degradation or fiber digestion in the rumen. Additionally, the increase in isovaleric acid could be an advantage to the animal as earlier reports showed that the use of isoacids in the diet improved microbial protein synthesis and cellulose digestion (Russell and Sniffen, 1984; Gorosito et al., 1985). Ruminal acetate:propionate ratio was similar among treatments. It was also noted that propionate production was remarkably high and resulted in a suitable ratio of acetate to propionate ratio (2.38-3.29). Bach et al. (1999) found that the proportion of acetate increased when fiber intake increased, while Zebeli et al. (2008) found that elevating non-structural carbohydrate intake decreased ruminal acetate proportion. However, proportions of acetate, propionate and butyrate in this study were in accordance with Hungate (1966).

Efficiency of nitrogen utilization

Whole body N data are summarized in Table 5. There were no interactions (p>0.05) between levels of RSK and PKC with respect to total N intake, N excretion, and microbial N supply while RSK levels had an effect on total N intake and N excretion. Total N intake and N-concentrate were higher in goats receiving 0-20% RSK. Likewise, total N excretion (fecal and urinary N) was higher in goats receiving 0-20% RSK. This trend may be related to the higher DMI of goats fed diets containing 0-20% RSK, compared with other treatments. This pattern of fecal and urinary excretion is indicative of the extremely high N intake for goats fed diets containing RSK. This could be explained by the fact that excess ruminal NH_3-N is absorbed and excreted in the urine in the form of urea (Nolan, 1993). Additionally, Cronje (1992) found that inadequate energy reduced the percentage of N retention in goats fed adequate levels of protein and that N recycling increased as the supply of energy increased. It is now well established that nitrogen retention depends on the intake of nitrogen, and amount of fermentable carbohydrate of the diet (Sarwar et al., 2003). In this regard, however, the amounts of N absorption and retention were similar among treatments, except for treatment T_4 which tended to have slightly lower (p = 0.11) N absorption for goats fed a diet containing 20% RSK. However, the positive N balance observed in this study indicates the positive combinations of RSC and PKC in the diets with SH based feeding of goats. The excretion of PD output (mmol/d) in the urine was similar (p>0.05) among treatments. Likewise, the microbial N supply to the small intestine, as calculated from excretion of purine derivatives using the equation of Chen and Gomes (1992), was unaffected by levels of RSK and PKC, and ranged from 4.66 to 5.32 g N/d. Similarly, the efficiency of rumen microbial protein synthesis was not influenced by dietary treatment and the values ranged from 15.26 to 17.52 g N/kg of OMDR. Non-treatment variability in EMNS may be due to various factors like concentration

Table 5. Effect of feeding combinations of rubber seed kernel (RSK) and palm kernel cake (PKC) based diets on nitrogen utilization and purine derivatives in goats fed on signal hay as roughage

Item	Dietary treatments [1]						SEM	p-value		
	T_1	T_2	T_3	T_4	T_5	T_6		RSK	PCK	RSK×PCK
N balance (g/d)										
Total N intake	13.42^{ab}	14.04^{a}	13.08^{ab}	11.34^{b}	11.78^{b}	11.48^{b}	0.65	0.01	0.39	0.21
N-concentrate	12.18^{ab}	12.76^{a}	11.46^{ab}	9.99^{b}	10.43^{b}	10.21^{b}	0.66	0.01	0.50	0.32
N-roughage	1.24	1.27	1.61	1.34	1.34	1.27	0.11	0.15	0.30	0.42
N excretion (g/d)										
Fecal N	3.87^{a}	3.65^{ab}	3.23^{ab}	2.93^{b}	2.92^{b}	2.91^{b}	0.24	<0.01	0.37	0.83
Urinary N	1.88^{a}	1.43^{ab}	1.43^{ab}	0.92^{b}	1.14^{b}	1.41^{ab}	0.22	0.09	0.21	0.16
Total N excretion	5.76^{a}	5.08^{ab}	4.67^{ab}	3.85^{b}	4.07^{b}	4.50^{b}	0.39	0.01	0.28	0.24
Absorbed N	9.54^{ab}	10.39^{a}	9.84^{ab}	8.41^{b}	8.85^{ab}	8.57^{ab}	0.57	0.11	0.54	0.17
Retained N	7.66	8.95	8.40	7.48	7.71	7.15	0.59	0.35	0.90	0.15
N output (% of N intake)										
Absorbed	70.94	73.96	74.16	73.86	73.99	73.74	1.54	0.54	0.51	0.47
Retained	57.07^{b}	63.83^{ab}	62.96^{ab}	65.59^{a}	63.51^{ab}	61.58^{ab}	2.42	0.30	0.22	0.22
PD output (mmol/d)	6.11	6.21	5.90	5.94	5.40	5.45	0.53	0.39	0.89	0.99
Microbial N supply										
g N/d[2]	5.29	5.32	5.05	5.08	4.62	4.66	0.46	0.36	0.92	0.99
EMNS, g N/kg of OMDR[3]	15.64	15.26	15.33	17.52	16.80	16.60	1.61	0.72	0.69	0.67

[1] T_1 = Concentrate containing 0% RSK and 20% PKC, T_2 = 0% RSK and 30% PKC, T_3 = 20% RSK and 20% PKC, T_4 = 20% RSK and 30% PKC, T_5 = 30% RSK and 20% PKC, T_6 = 30% RSK and 30% PKC.

[a-c] Within rows values not sharing a common superscript are significantly different ($p<0.05$).

SEM = Standard error of the mean (n = 6).

[2] Microbial N (g N/d) = (X×70)/(0.116×0.83×1,000) = 0.727X (where, X = total absorption of purine derivatives) (Chen and Gomez, 1992).

[3] EMNS = Efficiency of microbial nitrogen supply (g N/kg OMDR), organic matter digestible in the rumen (OMRD, kg) = 65% of organic matter digestible in total tract (ARC, 1990).

and sources of nitrogen and carbohydrates. Moreover, Singh et al. (2007) reported that the excretion of urinary purine derivatives was positively correlated with the level of feed intake.

CONCLUSIONS

Based on the results of this experiment, RSK and PKC levels had no interaction effects on feed intake, apparent digestibility, NH_3-N, blood metabolites, VFA concentrations, and nitrogen utilization. Feeding increased PKC levels did not affect feed intake, digestibility, rumen fermentation patterns, blood metabolites, and nitrogen utilization, whereas increasing RSK levels (>20%) resulted in a slightly lower daily DMI (% BW and g/kgBW$^{0.75}$), apparent digestibility (NDF and ADF), total N intake and N excretion than in those goats fed on 0 and 20% RSK. There were no differences among treatments with respect to N retention, PD output, and microbial N supply. Under this study, the optimal levels of RSK up to 20% and PKC levels of 20-30% in concentrate should be efficiently utilized by goats fed with signal hay, and indicates a good approach in exploiting the use of local feed resources for goat production.

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