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Effect of Replacing Rolled Corn with Potato Pulp Silage in Grass Silage-based Diets on Nitrogen Utilization by Steers

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ABSTRACT : Three Holstein steers fitted with ruminal and duodenal cannulae were fed grass silage-based diets supplemented with potato pulp silage as a substitute for rolled corn at levels of 0%, 50% and 100% on a DM basis in a 3×3 Latin square design to investigate the effect of potato pulp silage on nitrogen (N) utilization in ruminants. Organic matter (OM) intake, and rumen and total tract digestibilities did not differ among treatment diets. Rumen and post-rumen starch digestibilities were similar among treatments, although starch intake decreased ($p<0.01$) with potato pulp supplementation. There were no significant differences ($p>0.05$) in ruminal N utilization and non-ammonia N supply to the duodenum of steers fed grass silage supplemented with potato pulp silage as a substitute for rolled corn. There were no treatment differences ($p>0.05$) in rumen pH, volatile fatty acid (VFA) concentration or the molar percentages of acetate and propionate. The ammonia-N concentration in rumen fluid tended to decrease ($p<0.1$) when rolled corn was substituted with potato pulp silage. Ether extract intake and post-ruminal digestibility significantly ($p<0.01$) decreased in steers fed diets containing potato pulp silage. Concentrations of total cholesterol and phospholipids in serum markedly decreased ($p<0.01$) with potato pulp silage supplementation without adversely affecting liver function. These data suggested that potato pulp silage has a similar value as rolled corn as an energy source for rumen microorganisms. (**Key Words :** Nitrogen Utilization, Potato Pulp Silage, Rumen, Rolled Corn, Steers)

INTRODUCTION

The use of potato by-products in livestock diets had been examined for lactating dairy cows (Dickey et al., 1971; Mori et al., 1986), beef cattle (Duncan et al., 1991; Nelson et al., 2000) and sheep (Okine et al., 2005). General observations arising from these studies are that large quantities of potato by-products can be consumed by ruminants and degraded in the rumen. Okamoto et al. (2004), in a study with Holstein steers, reported that the voluntary dry matter intake of potato pulp silage exceeded 6.0 kg per day, which corresponded to 1.6 kg of dry matter per 100 kg live weight of steers. Since a huge amount of potato pulp is produced yearly in Hokkaido, the northern island of Japan and this by-product has become an important feedstuff for growing and lactating dairy cattle. Generally potato pulp is ensiled since it can be preserved well without any silage additives or bacterial inoculants (Hanada et al., 2004; Okine et al., 2005; Okine et al., 2006).

Aibibula et al. (2004) and Okine et al. (2005) reported that the high energy digestibility of potato pulp silage was closely associated with high contents of starch, which can be more slowly degraded by rumen microorganisms than wheat starch (Monteils et al., 2002). The composition of degradable dry matter (DM) and organic matter (OM) fractions in potato by-products are quite high and are estimated to be 886 g/kg and 605 g/kg, respectively (Cone et al., 2002). Hanada et al. (2004) found that the daily weight gain of growing steers was satisfactory when corn grain was substituted with potato pulp silage. In contrast, some clinical studies on lactating dairy cows suggested that feeding potato pulp silage significantly decreased the concentrations of urinary nitrogen (N), total cholesterol and phospholipids in the serum when the diet was partially substituted with corn grains (Mori et al., 1986; Hanada et al., 2005). Therefore, there is a need to clarify how the feeding of potato pulp silage affects the physiological and nutritional conditions of the animals and how it can be used as a feedstuff for improving animal performance. If it is possible to substitute grains in ruminant feed with potato

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Table 1. Chemical composition of potato pulp silage, grass silage, rolled corn and soybean meal (Values are given in g/kg DM, unless otherwise stated)

	Potato pulp silage	Grass silage	Rolled corn	Soybean meal
Dry matter (g/kg)	233	292	842	856
Organic matter	983	913	943	929
Crude protein	37	157	94	520
Ether extract	5	43	42	24
Starch	430	49	706	56
Acid detergent fiber	243	337	31	-
Gross energy (MJ/kg DM)	17.5	19.9	19.2	20.2

pulp silage, feed costs and risk of environmental pollution would decrease because most of the potato pulp produced in northern island of Japan has been discarded.

The aim of the present study was to examine the effect of the substitution ratio of potato pulp silage in a concentrate mixture on N utilization in the rumen and N flow to the duodenum of steers fed on grass silage-based diets.

MATERIALS AND METHODS

Experimental design and feeding trial

Three Holstein steers (257±22 kg) cannulated at the rumen and duodenum were fed grass silage-based diets supplemented with either rolled corn (RC), or potato pulp silage (PPS), or a mixture of rolled corn and potato pulp (CPS) in a 3×3 Latin square design. Diets were formulated to meet the nutrient requirement for steers growing at 1.2 kg per day (Japanese feeding standard for beef cattle, 2000). Orchardgrass (*Dactylis glomerata* L.) dominant pasture containing 12% legume was harvested at the second growth stage, ensiled with an additive of formic acid (2.0 kg/t) and preserved for 60 days. Fresh potato pulp was obtained from a local starch-processing factory and preserved in a bunker silo for 40 days. The chemical compositions and components of the experimental diets are shown in Table 1 and 2.

The steers were fed twice daily at 08.00 and 17.00 h. Chromic dioxide (Cr_2O_3), 1 g/kg DM, was administered into the rumen via a cannula at each feeding time throughout the experimental period and was used to estimate duodenal digesta flow and fecal output of steers. Steers were allowed *ad libitum* access to water and mineral block (Nihonzenyaku Ltd. Tokyo, Japan).

Sample collection

Each experimental period lasted 21 days with 13 days of adaptation and 8 days for sampling. Feeds were sampled and orts recorded daily during the first 4 days of the sampling period and fecal samples were collected from the rectum at 8:00, 12:00, 16:00, 20:00 and 24:00 h on those days. Fecal samples of each steer were mixed on a fresh weight basis. The combined samples of feed, orts and feces were dried at 60°C for 48 h in an air-forced oven, ground to pass a 1-mm screen and stored for subsequent analyses. Duodenal digesta were collected every 4 h on the 5th and 6th days of the sampling period and were mixed on a fresh weight basis. The composite digesta sample was divided into two portions; one half was lyophilized and milled through a 1-mm screen for subsequent general analyses, while the other was acidified with 50% H_2SO_4 and frozen at -20°C until the measurement of ammonium N concentration. On the 7th day of the sampling period, rumen fluid was extracted at 08:00, 11:00, 14:00, 17:00 and 20:00 h and its pH measured immediately. The fluid was strained through four layers of gauze and acidified with 50% H_2SO_4 and frozen at -20°C until analyzed. Ruminal fluid was collected at 11.00 h, 3 h after the morning feeding on the last day in each sampling period to obtain a rumen bacterial fraction. The bacterial fraction was isolated using the method of Smith and McAllan (1974) and freeze-dried for chemical analysis. Blood samples were taken from the jugular vein at 11.00 h on the last day of each sampling period and processed in an automated system for serum chemical analysis.

Table 2. Ingredients and chemical composition of diets*

	RC	CPS	PPS
Ingredients (g/kg DM)			
Grass silage	450	425	400
Steam-rolled corn	500	250	0
Potato pulp silage	0	250	500
Soybean meal	50	75	100
Chemical composition (g/kg DM)			
Organic matter	929	939	950
Crude protein	143	138	133
Ether extract	42	32	22
Starch	378	309	240
Gross energy (MJ/kg DM)	19.6	19.2	18.8

* RC: grass silage with rolled corn; CPS: grass silage with rolled corn and potato pulp silage; PPS: grass silage with potato pulp silage.

Chemical analyses

Samples of feeds, duodenal digesta and feces were analyzed for ash, N and ether extracts (EE) (AOAC, 1990). Starch was determined according to Abe (1988), as described by Okine et al. (2005), while gross energy (GE) was by an adiabatic bomb calorimeter (Shimadzu GC4P A, Kyoto, Japan). Chromium concentration of duodenal digesta and feces was measured by a colorimetric method (Yoshida et al., 1967). Purine content in the ruminal bacterial fraction, duodenum digesta and feces was determined according to the method of Zinn and Owens (1986).

Ammonium N in rumen fluid and duodenal digesta was determined by a colorimetric method as described by Okuda

Table 3. Organic matter and gross energy digestion in dairy steers fed grass silage supplemented with corn grain or potato pulp silage

	Diets*			SEM	p value
	RC	CPS	PPS		
Organic matter					
Intake (kg/d)	6.10	6.14	6.16	0.12	0.97
Duodenal flows (kg/d)	2.95	2.95	2.78	0.11	0.81
Excretion in to feces (kg/d)	1.95	1.85	1.89	0.04	0.67
Digestibility					
Ruminal (apparent)	0.52	0.52	0.55	0.02	0.76
Ruminal (true)	0.64	0.64	0.67	0.02	0.64
Post-ruminal	0.16	0.18	0.14	0.01	0.72
Total tract	0.68	0.70	0.69	0.01	0.76
Gross energy (MJ)					
Intake	128.5	125.4	121.7	2.7	0.27
Fecal output	43.4	41.6	42.2	0.9	0.41
Digestible energy					
MJ/day	84.8	83.8	79.5	2.7	0.49
MJ/Gross energy intake (MJ)	0.66	0.67	0.65	0.01	0.63

* RC: grass silage with rolled corn; CPS: grass silage with rolled corn and potato pulp silage; PPS: grass silage with potato pulp silage.

Table 4. Starch and ether extract digestion in dairy steers fed grass silage supplemented with corn grain or potato pulp silage

	Diets*			SEM	p value
	RC	CPS	PPS		
Starch					
Intake (kg/d)	2.48[a]	2.02[b]	1.54[c]	0.14	<0.01
Duodenal flows (kg/d)	0.63[a]	0.48[ab]	0.38[b]	0.04	0.02
Excretion in to feces (kg/d)	0.34[a]	0.25[ab]	0.19[b]	0.03	0.03
Disappearance (kg/d)					
Ruminal	1.85[a]	1.54[a]	1.15[b]	0.12	0.01
Post-ruminal	0.30	0.23	0.19	0.02	0.19
Digestibility					
Rumenal	0.74	0.76	0.75	0.01	0.91
Post-ruminal	0.12	0.11	0.13	0.01	0.78
Total tract	0.86	0.87	0.88	0.01	0.94
Ether extract					
Intake (g/d)	273.5[a]	210.1[b]	145.1[c]	19.1	<0.01
Duodenal flows (g/d)	250.6[a]	197.6[b]	130.7[c]	18.7	<0.01
Excretion in to feces (g/d)	78.8[a]	66.0[b]	57.0[b]	3.8	0.03
Digestibility					
Ruminal	0.08	0.06	0.10	0.02	0.66
Post-ruminal	0.63[a]	0.63[a]	0.51[b]	0.03	0.01
Total tract	0.71[a]	0.69[a]	0.61[b]	0.02	0.05

RC: grass silage with rolled corn; CPS: grass silage with rolled corn and potato pulp silage; PPS: grass silage with potato pulp silage.
[a, b, c] Means in a row with different letters differ significantly ($p<0.05$).

(1965), and the volatile fatty acid (VFA) composition of rumen fluid was by gas chromatography (Shimadzu 2010, Kyoto, Japan) equipped with a FID detector and capillary column (ULBON HR-52, 0.53 mm×30 m).

Serum samples were analyzed for 28 constituents (electrolytes, metabolites, enzymes) and four derived indices (A:G, Na:K, % saturation, anion gap) at Tokachi Diagnostic Laboratory, Hokkaido, Japan, using a Hitachi 917 multi-channel auto analyzer (Roche Diagnostics Corp., Indianapolis, USA).

Calculations and statistical analysis

The microbial OM and N flows to the duodenum were calculated by dividing the amount of purine flow to the duodenum by the ratio of purine to OM or N in the microbial fraction. The OM truly digested in the rumen (OMTDR) and the rumen degradable nitrogen (RDN) was calculated as follows:

OMTDR = OM intake
-(duodenum OM-duodenum microbial OM)

RDN = N intake
-(duodenum N-duodenum ammonium N
-duodenum microbial N)

Data were analyzed as a 3×3 Latin square design using

Excelstats 2004 for Windows (Social Survey Research Information Co., Ltd.) and mean differences compared for all variables, with p- values less than 0.05 considered statistically significant. Tendency to differences was declared at p≤0.1.

RESULTS

The PPS used in the present study had lower contents of starch, crude protein, ether extracts and gross energy than the RC (Table 1). As a consequence, the diet of grass silage with 100% PPS was lowest in these feed components but highest in the diet of grass silage with 100% RC. The diet of grass silage with 50% corn and 50% CPS was intermediate between the two (Table 2).

Organic matter and energy consumption of the growing dairy steers did not differ among the three dietary treatments (Table 3). The apparent and true OM digestibility of the rumen and post-rumen as well as OM digestibility of whole digestive tract, did not differ among treatments. The same tendency of the three diets was also observed with consumption of digestible energy.

The starch digestibility in the rumen, post-rumen and whole digestive tract did not differ among treatments (Table 4). In contrast a greater decrease of starch intake was observed in accordance with increasing compositional percentages of potato pulp supplementation ($p<0.01$) with a consequent decrease ($p<0.01$) in the starch flow to the duodenum. Starch excretion into feces was also lower with relatively higher percentages of potato pulp

Table 5. Effect of corn grain or potato pulp silage supplementation on nitrogen (N) utilization in dairy steers fed grass silage

	Diets*			SEM	p value
	RC	CPS	PPS		
N intake (g/d)					
Total	150.5	145.7	140.1	3.3	0.32
Rumen degradable N	82.1	71.7	78.8	4.4	0.78
Duodenal N flow					
Total (g/d)	144.7	154.4	142.1	6.5	0.73
Microbial N (g/d)	76.3	80.4	80.8	5.4	0.94
Rumen undegradable N	65.5	71.3	59.5	4.2	0.57
N excretion in to feces					
Total (g/d)	63.1	64.5	62.3	1.5	0.86
Purine-N (g/d)	35.8	39.6	39.9	1.0	0.13
N disappearance (g/d)					
Rumen	5.8	-8.7	-2.0	4.1	0.35
Post-rumen	81.6	89.9	79.8	6.5	0.83
Apparent N digestibility (g/g of N intake)					
Rumen	4.1	-6.1	-1.5	4.1	0.55
Post-rumen	0.54	0.61	0.57	0.04	0.70
Total tract	0.58	0.55	0.55	0.01	0.32
Efficiency of microbial N synthesis					
(g/g RDN[i])	0.94	1.18	1.03	0.09	0.53
(g/kg OMTDR[ii])	19.5	20.8	19.6	1.4	0.84

* RC: grass silage with rolled corn; CPS: grass silage with rolled corn and potato pulp silage; PPS: grass silage with potato pulp silage.
[i] Rumen degradable nitrogen.
[ii] Organic matter truly digested in the rumen.

Table 6. Ruminal fermentation characterstics of dairy steers fed grass silage supplemented with corn grain or potato pulp silage

	Diets*			SEM	p value
	RC	CPS	PPS		
pH	6.15	6.04	6.08	0.09	0.91
Total VFA (mmol/L)	82.0	85.9	82.2	2.61	0.90
Molar proportion of VFA's (mmol/mol)					
Acetic acid (A)	548.0	556.1	571.9	8.33	0.55
Propionic acid (P)	252.5	253.6	278.7	6.11	0.13
A/P	2.2	2.2	2.1	0.06	0.69
Butyric acid	154.6	141.6	116.2	6.61	<0.01
Valeric acid	44.8	48.7	33.3	3.43	0.16
Ruminal NH_3-N (mg/L)	117.6	110.2	78.8	0.79	<0.01

* RC: grass silage with rolled corn; CPS: grass silage with rolled corn and potato pulp silage; PPS: grass silage with potato pulp silage.
** Although means were were seperated using a level of 0.05 and p values were 0.09 and 0.07, respectively, differences between treatments were significantly different.

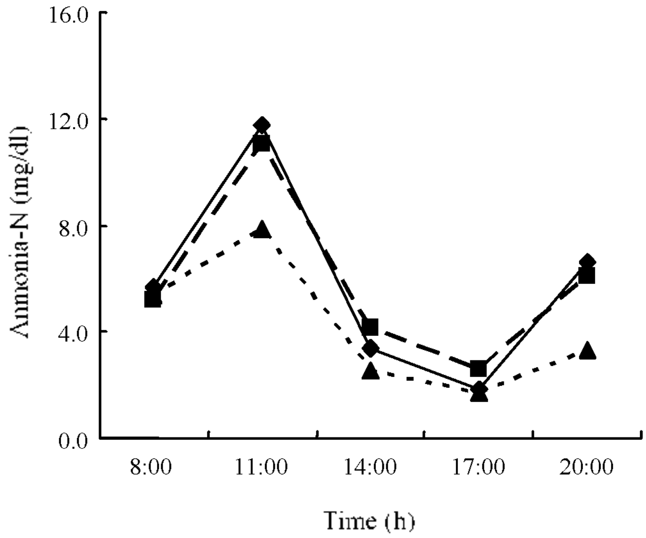

Figure 1. Time course change of ruminal ammonia-N content of steers fed grass silage supplemented with corn grain or potato pulp silage. (♦) RC, grass silage with rolled corn; (■) CPS, grass silage with rolled corn and potato pulp silage; (▲) PPS, grass silage with potato pulp silage.

supplementation in the diet ($p<0.05$).

Intake of ether extracts and flow to the duodenum were lower ($p<0.05$) in accordance with increasing compositional percentages of potato pulp supplementation (Table 4). The digestibility of ether extracts in the post-rumen and whole digestive tract was also lower ($p<0.05$) for PPS than RC.

Intake and digestion characteristics of N in the diets, including N disappearance and digestibility both in the rumen and post-rumen, did not differ among treatments (Table 5). Microbial synthesis in the rumen and lower digestive tract, as shown in the concentrations of microbial N in the duodenum and N excretion into feces, did not differ among treatments. Purine N, however, tended to increase in PPS relative to RC. The efficiency of microbial N was similar among dietary treatments, when it was estimated as ratios of OMTDR and RDN.

A lower but insignificant ruminal pH was observed in PPS compared with RC (Table 6). Concentration of total VFA in the rumen did not differ among treatments whereas the molar percentage of butyric acid tended to be lower in PPS.

Maximal concentration of ammonia N in the rumen was observed 3 h after feeding in all dietary treatments (Figure 1). When potato pulp silage replaced RC, the maximum concentration of ammonia N in the ruminal fluid tended to decrease (Table 6) and did not exceed 8.0 mg/dl (Figure 1).

Concentrations of glutamic oxalacetic transaminase (GOT), non-esterified fatty acid, calcium, inorganic phosphate and glucose in the blood of steers did not differ among treatments, whereas those of total cholesterol, HDL-cholesterol (free cholesterol) and phospholipids markedly decreased ($p<0.01$) with diets supplemented with PPS (Table 7). In all treatments, blood urea N numerically decreased with PPS supplementation but was below 8.0 mg/dl in all treatment diets.

DISCUSSION

To meet the nutritional requirement for a 1.2 kg daily gain of a Holstein steer, the percentage of soybean meal in the diets used in the present study was adjusted to provide an adequate supply of energy and crude protein to the animals. A small change in the compositional percentage of soybean meal was sufficient for this purpose, since the DM digestibility and digestible energy content of PPS are quite high and in the range of 720-760 g/kg DM and 12-13 MJ/kg DM, respectively (Aibibula et al., 2004; Okine et al., 2005), and comparable to corn grain in these respects.

Since the moisture content of potato pulp is quite high, the moisture contents of RC, CPS and PPS diets differed markedly: 40.5%, 54.3% and 68.1%, respectively. However, no decrease of DM consumption of PPS was observed compared with RC, although the higher moisture content generally decreases feed consumption of animals, especially for immature and young ones. In contrast, lower contents of starch and ether extracts in the PPS were not completely

Table 7. Blood chemical findings of dairy steers fed grass silage supplemented with corn grain or potato pulp silage

	Diets*			SEM	p value
	RC	CPS	PPS		
Glutamic oxalacetic transaminase (IU/L)	52.3	49.7	58.7	5.1	0.76
Total cholesterol (mg/dl)	101.7[a]	75.0[b]	45.0[c]	8.4	<0.01
HDL-cholesterol (mg/dl)	88.3[a]	69.7[b]	43.0[c]	6.7	<0.01
LDL-cholesterol (mg/dl)	18.3[a]	16.7[a]	12.3[b]	1.5	0.03
Phospholipid (mg/dl)	121.0[a]	90.0[b]	62.0[c]	8.8	<0.01
Non esterified fatty acid (mEq/L)	0.27	0.28	0.27	0.0	0.85
Calcium (mg/dl)	10.6	10.3	10.8	0.1	0.13
Inorganic phosphate (mg/dl)	6.8	6.5	5.6	0.3	0.12
Urea nitrogen (mg/dl)	7.7	6.7	6.8	0.5	0.61
Glucose (mg/dl)	82.3	81.7	83.0	1.5	0.91

* RC: grass silage with rolled corn; CPS: grass silage with rolled corn and potato pulp silage; PPS: grass silage with potato pulp silage.
[a, b, c] Means in a row with different letters differ significantly ($p<0.05$).

recovered by increasing the compositional percentage of soybean meal in the diet with 100% PPS supplementation.

Starch and OM quality were almost the same among the three diets, as evaluated by their disappearances in the rumen and post-rumen. This is consistent with the similarity in efficiency of microbial protein synthesis in the rumen and large intestine, as shown in the microbial N flow to the duodenum, and purine-N excretion in the feces. The similar ratios of microbial protein synthesis to the OMTDR in the three diets indicate a phenomenon different from that reported by Cone et al. (2002), who recorded much higher values. Since potato starch is more resistant to breakdown in the small intestine than corn starch (Daniel et al., 2003), differences reported in the literature can be due to the wide range of starch contents in potato pulp (between 180 and 440 g/kg DM) resulting from different processing methods of starch factories (Okamoto et al., 2004; Okine et al., 2005). Further research is thus needed to clarify the extent and rate of microbial degradation of potato starch in the rumen.

Generally, the decline of ammonia N concentration in rumen fluid occurs due to lack of sufficient N intake or excessive fermentable carbohydrate intake. Although N intake of steers slightly decreased with increasing PPS replacement with RC in the present study, this met the N requirement of dairy steers growing at the rate of 1.2 kg/day. The daily average ammonium N concentration of ruminal fluid tended to decline with substitution of PPS for RC in the diet (Table 6). Furthermore, the maximum concentration of ammonia N in the ruminal fluid did not exceed 8.0 mg/dl in PPS compared with RC and CPS treatments (Figure 1). This is in agreement with the report of (Hanada et al., 2003) that some N might apparently be absorbed from the rumen when the proportion of RDN to OMTDR is above 22 g/kg or the ammonium N concentration in rumen fluid is above 9 mg/dl (Aibibula et al., 2002). In the present study, the negligible N losses from the rumen and the low ammonium N concentration in rumen fluid in steers supplemented with PPS might be related to the increase in OMTDR and decrease in N intake.

Although non-ammonia N flow to duodenum did not differ among the treatments, N digestion in the whole digestive tract decreased numerically with PPS supplementation probably due to an increase of microbial N synthesis in the large intestine. Daniel et al. (2003) reported that potato starch resists breakdown in the small intestine compared with corn starch and that feeding of raw potato starch-based diets increases the purine base and short chain fatty acids concentration in the proximal colonic digesta in comparison with feeding corn starch. The purine base N excretion in feces of steers fed PPS tended to increase in steers fed RC in the present trial, suggesting that starch digestion occurred in the large intestine largely as a result of the microbial activity.

The fermentable carbohydrate contents of the diets used in the present study were reflected in the total VFA concentrations in the rumen. Feeding of PPS would seem to enhance acetate and propionate production in the rumen more than butyrate and valerate production.

Supplementation with 100% PPS employed in the present study may not be a recommendable level in designing feed supplementation with PPS since this level of PPS supplementation may severely reduce supply of fat sources, as shown by the lower digestibility of ether extracts in the present study. This reduction is due to the fact that the enzymatic activity of GOT, one of the enzymes associated with cholesterol metabolism and physiology in the liver, was similar among dietary treatments. In general the decline of total cholesterol and cholesterol ester (LDL-cholesterol) would be attributable to hepatopathy resulting from malfunction of enzymes such as the GOT, guanosine triphosphate (GTP) and γ-GTP. On the contrary, this could be a consequence of the low ether extract intake and digestion of PPS in this trial. Further, it is assumed that the fibrous materials escaping digestion in the rumen of the steers may have been adsorbed by bile acid in the large intestine, inducing its excretion in the feces which, consequently, decreased concentration of serum cholesterol in the steers supplemented with PPS, irrespective of the rate of inclusion. However, there was no decrease of total serum cholesterol when intake from PPS was about 20% of the total digestible nutrients requirement of the dairy cow (Hanada et al., 2005). More studies are warranted in this direction.

CONCLUSION

Growing steers fed grass silage and supplemented with PPS as replacement for RC increased intake of fermentable OM in the rumen and decreased concentration of ruminal ammonium N and blood urea N levels. These data suggest that PPS has a similar value as RC as an energy source for rumen microorganisms. Although PPS supplementation did not enhance animal performance compared with RC, it may be an economical alternative to traditional grain-based supplements for ruminants.

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