Effects of spent mushroom *Cordyceps militaris* supplementation on apparent digestibility, rumen fermentation, and blood metabolite parameters of goats

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ABSTRACT: The objective of this experiment was to study the effects of dried spent mushroom *Cordyceps militaris* (SMCM) supplementation on digestibility, rumen fermentation, and blood metabolite parameters in goats. When the mushroom production and harvesting was complete, SMCM was collected fresh from a mushroom farm. Four 18-mo-old male crossbred (Thai Native × Anglo Nubian) goats with initial BW of 26.0 ± 1.40 kg were randomly assigned according to a 4×4 Latin square design to receive four different levels of SMCM at 0, 100, 200, and 300 g/d. There were quadratic effects ($P < 0.06$) on apparent digestibility of DM, OM, CP, NDF, and ADF among treatment groups, and greater values for the goats fed SMCM at 100 g/d were observed. A quadratic effect in energy intake (ME, Mcal/kg DM) ($P = 0.02$), with greater values for the goats fed SMCM at 100 g/d, was also observed. Rumen temperature was similar among groups ($P = 0.23$), whereas feeding of SMCM linearly

decreased ($P = 0.001$) ruminal pH with increasing SMCM supplementation. Supplementing SMCM linearly decreased plasma concentration of cholesterol ($P = 0.01$), and there was also a tendency of reduction in plasma concentration of triglyceride ($P = 0.10$), with greater values for the goats fed SMCM at 100 g/d. There were quadratic effects on plasma of total protein, HgB, and MCHC among treatment groups. However, there were quadratic effects on fecal N ($P = 0.04$) and nitrogen retention ($P = 0.07$) based on g/d/animal or percentage of nitrogen retained ($P = 0.01$) among treatment groups, and greater values for the goats fed SMCM at 100 g/d were observed. Based on this experiment, it could be concluded that supplementing goat diets with SMCM at 100 to 200 g/d results in improved apparent digestibility of nutrients and blood metabolites, suggesting that SMCM has positive functions as a feed additive to improve energy substance metabolism and contribute to glyconeogenesis.

Key words: apparent digestibility, blood metabolite parameters, goats, rumen fermentation, spent mushroom *Cordyceps militaris*

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INTRODUCTION

The *Cordyceps* species, the fungi of the genus *Cordyceps* belonging to the family *Clavicipitaceae* of the order *Hypocreales*, are valuable medical mushrooms well known for their pharmacological

actions in traditional Chinese medicine and have long been used in general tonics and aphrodisiacs (Li et al., 2017). *Cordyceps militaris* is another species of *Cordyceps* spp., which is the most valued species in traditional medicine (Das et al., 2010). Many important secondary metabolites have been found in *C. militaris* mycelia including cordycepin, 3'-deoxyadenosine and adenosine, mannitol, polysaccharides, and ergosterol, and they exhibit pharmacological functions (Das et al., 2010).

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The cordycepin and polysaccharides are used as prebiotics in animal nutrition and could improve the immune system, promote weight gain in broiler chicks and can be used as a substitute for antibiotic growth promoters (Koh et al., 2003). Furthermore, *C. militaris* mycelia could alter in vivo rumen microbial fermentation, causing increased production of gas and VFA, as well as cellulose digestion (Yeo et al., 2011) and inhibited in vitro methane production (Kim et al., 2014).

As reported in a previous study, *C. militaris* has significant pharmacological functions, but its cost greatly limits its application and development for livestock production due to the difficulty of its supply (Koh et al., 2003; Li et al., 2017). Therefore, feeding spent mushroom *C. militaris* (SMCM), after harvesting is completed, could meet livestock production demands and reduce feed cost. SMCM is a type of new feed additive, and there have been functional components similar to those of *C. militaris*. The objective of this experiment was to study the effects of SMCM supplementation on digestibility, rumen fermentation, and blood metabolite parameters in goats.

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 Guide of Thailand, and all of the animal experimental procedures were approved by the Prince of Songkla University Animal Care and Use Committee.

Preparing of Dried SMCM

The SMCM used in this study was provided by the Department of Pest Management, Faculty of Natural Resources. When the mushroom production and harvesting was complete, then SMCM was collected fresh from a mushroom farm. The SMCM was dried at 60 °C for 72 h, ground to pass through a 0.2 mm mesh screen using a Cyclotech Mill (Tecator, Höganäs, Sweden) and stored at room temperature until being offered to the animals. The SMCM was made by mixing 15 g/L dextrose, 5 g/L sucrose, and 0.5 g/L $\text{MgSO}_4 \cdot 7\text{H}_2\text{O}$ in silkworm pupae juice 50 g/L and was incubated with *C. militaris* mycelia. The concentrations of cordycepin and adenosine in the SMCM were determined using HPLC (Chang et al., 2005).

Animals, Treatments, and Experimental Design

Four of 18 mo old male crossbred (Thai Native × Anglo Nubian) goats with initial BW of

26.0 ± 1.4 kg were randomly assigned according to a 4×4 Latin square design to receive four different levels of SMCM.

The dietary treatments were as follows: daily supplementation with SMCM at 0, 100, 200, and 300 g/goat per d. The animals were allowed ad libitum access to diets (50 g/kg refusals) twice daily (0700 and 1800). Ingredients and chemical compositions of TMR (total mixed ration) and SMCM are shown in Table 1. Before the morning feeding, SMCM was individually hand-mixed with 200 g of the TMR feed to ensure that all supplements were ingested by the animals and more TMR was fed to individual animals subsequently.

All animals were kept individually in pens (0.115×0.95 m) under well-ventilated sheds where water and mineral salt block were available at all time. The experiment was conducted for four periods, each periods lasted 21 d. During the first 14 d, all animals were fed respective diets for ad libitum intake, whereas during the last 7 d, the animals were moved to metabolism crates for total collection

Table 1. Ingredients and chemical compositions of diet, oil palm frond (OPF), and SMCM used in the experiment

Item	Basal diet	OPF	SMCM
Ingredients, g/kg DM			
OPF	300.0		
Ground corn	450.0		
Soybean meal	73.0		
Fish meal	4.0		
Leucaena leave meal	70.0		
Palm kernel cake	70.0		
Molasses	21.0		
Dicalcium phosphate	4.0		
Salt	2.0		
Mineral and vitamin mix ^a	7.0		
Chemical composition, % of DM			
DM, %	95.29	41.83	93.14
CP, %	15.12	5.45	11.62
Ash, %	5.30	7.37	0.97
OM, %	94.70	92.63	99.03
Ether extract, %	1.95	1.85	0.96
NDF, %	46.33	74.21	49.60
ADF, %	25.34	63.41	10.41
ME, Mcal/kg DM ^b	2.75	-	-
TDN, % ^b	76.06	35.8	-
GE, Mcal/kg DM	4.35	4.69	4.08
Cordycepin, g/kg	-	-	3.32
Adenosine, g/kg	-	-	0.095

^aMinerals 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.

^bCalculated values.

during which time they were restricted to 90% of the individual previous voluntary feed intake of TMR and supplemented with different levels of SMCM to ensure total feed intake.

Data Collection and Sampling Procedures

Feed and fecal sampling procedures. Feed offered, SMCM and refusal samples were recorded daily during the experimental period. At the last 7 d of each period, feeds, refusals, and fecal samples were collected by using total collection method from each individual goat. Collected samples were dried at 60 °C and ground (1 mm screen using a Cyclotech Mill, Tecator, Sweden) and analyzed for DM, ash, ether extract (EE), CP, and ADF according to the methods of the Association of Official Analytical Chemists (AOAC, 2000). NDF in samples was estimated according to Van Soest et al. (1991) with addition of α -amylase but without sodium sulphite and results are expressed inclusive of residual ash. The SMCM contained 11.62% CP, 0.96% EE, 49.60% NDF, 10.41% ADF, 0.97% crude ash of DM, 3.32 g cordycepin per kg of DM, and 0.095 g adenosine per kg of DM (Table 1).

Urine sampling procedures. Total urine samples were collected on the same days as feces by using a plastic container fixed with sulfuric acid (10%) to keep the final pH below 3 and protect nitrogen (N) loss. The urinary samples were collected about 100 mL of the total volume urine, kept in a refrigerator, and then pooled at the end of each period for total N analysis according to AOAC (2000) for determining N utilization.

Rumen fluid sampling procedures. Rumen fluid samples were collected at 0 and 4 h post-feeding on the last day of the data collection period. Approximately, 50 mL of rumen fluid was taken from the middle part of the rumen by a stomach tube connected to a vacuum pump each time. Rumen fluid was immediately measured for pH and temperature using a portable pH and temperature meter (HANNA instruminals HI 98153 microcomputer pH meter, Singapore). Rumen fluid samples were then filtered through four layers of cheesecloth. About 30 mL of rumen fluid sample was collected and kept in a plastic bottle to which 5 mL of H_2SO_4 solution (1 M) was added to stop fermentation process of microbial activity. The mixture was centrifuged at $16,000 \times g$ for 15 min (Table Top Centrifuge PLC-02, United States). The supernatant of 20 mL was collected and analyzed for ammonia nitrogen ($\text{NH}_3\text{-N}$) by Kjeltach Auto 1030 Analyzer (AOAC 2000) and VFA using HPLC

(Instruments by controller water model 600E; water model 484 UV detector; column novapak C18; column size 4 mm $\times$ 150 mm; mobile phase 10 mM H_2PO_4) (pH 2.5) according to the method of Mathew et al. (1997).

Blood sampling procedures. Blood sample (about 10 mL) was collected at 0 and 4 h post-feeding on the last day of the data collection period from the jugular vein into tubes containing of 12 mg of EDTA, and the plasma was separated by centrifugation at $1,500 \times g$ for 10 min (Table Top Centrifuge PLC-02, United States). The obtained plasma was stored at -20°C until analysis for total protein (TP), albumin (ALB), globulin (GLB), blood urea nitrogen (BUN), cholesterol (CHOL), triglyceride (TG), high-density lipoprotein (HDL), blood glucose (GLU), NEFA, and beta-hydroxybutyric acid (BHBA) concentrations. These analyses were performed on a fully automatic biochemical analyzer using standard commercial kits supplied from Stanbio Laboratory (Boerne, TX); NEFA and BHBA were analyzed using kits from Randox (Crumlin, United Kingdom).

The plasma concentrations of urea nitrogen and plasma glucose were measured by using commercial kits (No. 640, Sigma Chemical Co., St. Louis, MO). Packed cell volume (PCV) was determined using a microhematocrit method.

Statistical Analysis

All the data obtained from the experiment were subjected to ANOVA for a 4×4 Latin square design using the GLM procedures (SAS Institute Inc., Cary, NC). Data were analyzed by using the model $Y_{ijk} = \mu + M_i + A_j + P_k + \varepsilon_{ijk}$, where Y_{ijk} is the observation from animal j , receiving diet i , in period k ; μ is the overall mean; M_i is the effect of the different levels of FTOPF ($i = 1, 2, 3, 4$); A_j is the effect of animal ($j = 1, 2, 3, 4$); P_k is the effect of period ($k = 1, 2, 3, 4$); and ε_{ijk} is the residual effect. Orthogonal polynomial contrasts (linear and quadratic) were used to examine treatment effects on response variables. The level of significance was defined as $P < 0.05$ and trends ($0.05 < P < 0.10$). Standard errors of the mean are reported.

RESULTS

Effects of SMCM on Nutrient Intake and Apparent Digestibility of Nutrients in Goats

Feed intake and apparent digestibility are presented in Table 2. Total DMI (kg/d, %BW, and g/

Table 2. Effects of supplement levels (g/d) of SMCM on feed intake, nutrient intake, and apparent digestibility of nutrients in goats

Item	Supplement levels (g/d) of SMCM ^a					Contrast <i>P</i> -value ^c	
	0	100	200	300	SEM ^b	Linear	Quadratic
DMI, kg/d							
Total DMI, kg/d	0.735	0.755	0.737	0.667	0.07	0.50	0.54
DMI, %BW	2.70	2.69	2.61	2.42	0.19	0.32	0.64
DMI, g/kg BW ^{0.75}	61.95	62.37	60.34	56.31	4.86	0.41	0.66
OMI, kg/d	0.69	0.71	0.70	0.63	0.06	0.56	0.49
CPI, kg/d	0.10	0.11	0.11	0.10	0.01	0.91	0.33
EEL, kg/d	0.02	0.02	0.01	0.01	0.003	0.21	0.67
NDFI, kg/d	0.29	0.32	0.32	0.31	0.03	0.76	0.60
ADFI, kg/d	0.17	0.15	0.15	0.13	0.01	0.18	0.80
Apparent digestibility, %							
DM	62.75	69.91	67.99	60.45	2.79	0.50	0.03
OM	63.89	71.04	69.20	61.79	2.54	0.50	0.02
CP	56.38	65.22	64.13	52.95	3.12	0.15	0.06
Ether extract	65.36	70.93	67.64	58.54	3.21	0.15	0.06
NDF	41.14	55.46	55.98	52.32	3.68	0.08	0.05
ADF	18.56	35.23	31.51	20.36	4.95	0.94	0.03
Estimated energy intake ^d							
ME, Mcal/d	1.66	1.92	1.85	1.48	0.22	0.56	0.21
ME, Mcal/kg DM	2.27	2.55	2.49	2.23	0.08	0.64	0.02

^a0, 100, 200, 300 g/goat per d of SMCM.^bSEM = standard error of the mean.^cSignificant at $P < 0.05$ and were considered trends when $P < 0.10$.^d1 kg digestible organic matter = 3.8 Mcal ME/kg (Kearl, 1982).

kg BW^{0.75}) and nutrient intake (OMI, CPI, EEI, NDFI, and ADFI) were not affected ($P = 0.18$) by SMCM supplementation. There were quadratic effects on apparent digestibility of DM ($P = 0.03$), OM ($P = 0.02$), CP ($P = 0.06$), NDF ($P = 0.05$), and ADF ($P = 0.03$) among treatment groups, and greater values for the goats fed SMCM at 100 g/d were observed. A quadratic effect in energy intake (ME, Mcal/kg DM) ($P = 0.02$), with greater values for the goats fed SMCM at 100 g/d were also observed.

Effects of SMCM on Ruminal Fermentation and Blood Metabolites in Goats

Ruminal temperature, pH, NH₃-N, and BUN concentrations from the rumen fermentation study are presented in Table 3. The results showed that rumen temperature was not different among groups ($P = 0.23$). However, feeding of SMCM linearly decreased ruminal pH ($P = 0.01$) with increasing SMCM supplementation. Likewise, the concentration of NH₃-N and BUN also linearly decreased ($P = 0.01$ and $P = 0.001$, respectively) by the addition of SMCM to the diet. Plasma GLU ($P = 0.01$) linearly improved with increasing SMCM supplementation but plasma concentration of BHBA

($P = 0.01$) and NEFA ($P = 0.001$) linearly decreased. However, PCV was not affected ($P = 0.52$) by the addition of SMCM to the diet.

Effects of SMCM on Plasma Biochemistry in Goats

The effects on plasma parameters are presented in Table 4. Supplementing SMCM linearly decreased the plasma concentration of CHOL ($P = 0.01$), and there was also a tendency of reduction in the plasma concentration of TG ($P = 0.10$). Greater values for the goats fed SMCM at 100 g/d were also observed. There were quadratic effects on plasma concentration of TP ($P = 0.04$), HgB ($P = 0.02$), and MCHC ($P = 0.02$) among treatment groups, but other indicators were not affected.

Effects of SMCM on N Metabolism and Utilization

Table 5 presents the N intake, N excretion, and N utilization in goats fed different levels of SMCM. There were no differences ($P > 0.20$) among treatments for total N intake and absorbed N. However, there were quadratic effects on fecal N ($P = 0.04$) and nitrogen retention ($P = 0.07$) based on g/d/

Table 3. Effects of supplement levels (g/d) of SMCM on rumen fermentation and blood metabolites in goats

Item	Supplement levels (g/d) of SMCM ^a					Contrast <i>P</i> -value ^c	
	0	100	200	300	SEM ^b	Linear	Quadratic
Temperature, °C	39.35	39.10	39.25	39.10	0.16	0.83	0.23
Ruminal pH	6.40	6.41	6.26	6.16	0.03	0.001	0.16
NH ₃ -N, mg/dL	16.61	13.92	11.43	12.32	1.01	0.01	0.12
BUN, mg/dL	14.03	12.31	9.25	5.98	1.11	0.001	0.50
GLU, mg/dL	63.75	63.62	67.25	67.75	1.01	0.01	0.76
NEFA, µmol/L	231.12	212.64	209.54	75.85	25.70	0.001	0.06
BHBA, µmol/L	0.43	0.42	0.41	0.37	0.025	0.01	0.13
PCV, %	28.63	28.88	29.00	29.25	0.66	0.52	1.00

^a0, 100, 200, 300 g/goat per d of SMCM.^bSEM = standard error of the mean.^cSignificant at *P* < 0.05 and were considered trends when *P* < 0.10.**Table 4.** Effects of supplement levels (g/d) of SMCM on plasma parameters in goats

Item	Supplement levels (g/d) of SMCM ^a					Contrast <i>P</i> -value ^c	
	0	100	200	300	SEM ^b	Linear	Quadratic
TG, mg/dL	39.50	25.75	24.75	24.12	5.61	0.10	0.28
CHOL, mg/dL	76.25	74.75	72.75	55.37	4.29	0.01	0.11
HDL, mmol/L	1.47	1.42	1.40	1.67	0.098	0.17	0.13
TP, g/L	5.64	6.12	5.93	5.91	0.09	0.22	0.04
ALB, g/L	3.65	3.99	3.76	3.77	0.10	0.79	0.18
GLB, g/L	1.99	2.14	2.17	2.13	0.07	0.20	0.24
A/G ratio	1.83	1.86	1.73	1.77	0.09	0.70	0.91
RBC, count × 10 ⁶ /µL	3.26	3.97	3.58	3.57	0.17	0.50	0.08
HgB, g/dL	10.06	10.96	10.58	10.01	0.25	0.66	0.02
MCV, fL	86.42	74.93	79.38	79.92	3.51	0.37	0.13
MCH, pg	31.02	27.71	29.65	28.03	1.04	0.18	0.44
MCHC, %	35.98	37.04	37.40	35.10	0.57	0.40	0.02
WBC, count × 10 ³ /µL	9.99	10.99	11.41	11.27	0.53	0.12	0.32
As a % of WBC							
Neutrophils	62.4	64.2	62.1	56.5	3.48	0.24	0.22
Lymphocyte	35.4	33.6	35.7	40.6	3.62	0.29	0.30

^a0, 100, 200, 300 g/goat per d of SMCM.^bSEM = standard error of the mean.^cSignificant at *P* < 0.05 and were considered trends when *P* < 0.10.

A/G ratio = albumin to globulin ratio; HgB = hemoglobin; MCV = mean corpuscular volume; MCH = mean corpuscular hemoglobin; MCHC = mean corpuscular hemoglobin concentration.

animal or percentage of nitrogen retained (*P* = 0.01) among treatment groups, and greater values for the goats fed SMCM at 100 g/d were observed.

DISCUSSION

SMCM is a type of new feed additive, with functional components similar to those of *C. militaris*, and it could be used to meet livestock production demands. However, its pharmacological and biochemical actions have not been clearly elucidated, particularly application of *Cordyceps* to ruminants. The current study evaluated the effects

of SMCM supplementation on apparent digestibility, rumen fermentation, and blood metabolite parameters. Although treatments did not affect DMI and nutrient intake, they increased apparent DM, OM, NDF, and ADF digestibility and tended to increase CP and EE digestibility; maximum responses were seen with 100 g/d supplementation of SMCM in goats. Similar results were observed by Li et al. (2017), who supplemented *Acremonium terricola* culture (ATC) containing cordycepin to dairy cows and did not find effects on DM intake, but they reported improved DM and CP digestibility without altering NDF and ADF digestibility.

Table 5. Effects of supplement levels (g/d) of SMCM on N balance in goats

Item	Supplement levels (g/d) of SMCM ^a					Contrast <i>P</i> -value ^c	
	0	100	200	300	SEM ^b	Linear	Quadratic
N balance g/d							
Total N intake	16.53	17.63	17.85	16.33	1.66	0.96	0.46
N excretion g/d							
Fecal N	6.83	6.16	6.54	7.73	0.36	0.11	0.04
Urinary N	1.50	0.71	0.72	1.55	0.57	0.95	0.20
Total N excretion	8.34	6.87	7.26	9.28	0.79	0.38	0.06
Absorbed N	9.69	11.46	11.31	8.60	1.58	0.64	0.20
Retained N	8.18	10.75	10.59	7.05	1.38	0.58	0.07
N output (% of N intake)							
Absorbed	59.28	65.23	62.53	52.95	3.66	0.23	0.07
Retained	50.12	61.16	58.96	44.58	3.89	0.32	0.01

^a0, 100, 200, 300 g/goat per d of SMCM.^bSEM = standard error of the mean.^cSignificant at *P* < 0.05 and were considered trends when *P* < 0.10.

Indeed, these effects may be related to alterations in rumen microbial fermentation. Some research has shown that the addition of *C. militaris* mycelia to rumen fluid inoculum caused a marked increase in gas production, cellulose FP degradation, and VFA production (Yeo et al., 2009), and improved cellulose digestion and cellulolytic enzyme activities. In particular, there was an increase of cellulolytic bacteria with 0.25 g/L supplementation (Yeo et al., 2011). These data indicate that SMCM has positive effects on apparent digestibility of nutrients in goats. On the other hand, the response of apparent digestibility to the supplementation of SMCM showed a linear decrease; the lowest response was seen with 300 g/d supplementation of SMCM. These results were similar to previous work by Yeo et al. (2009), who reported that supplementation of *C. militaris* mycelia (0.30 g/L) decreased the gas production, cellulose FP degradation, and VFA production, as well as decrease the number of total and cellulolytic bacteria compared with the control (Yeo et al., 2011). Similarly, Patra and Yu (2014) reported that increasing the dose of feed additives (vanillin) from plants can decrease the degradability of DM and NDF, pH, and ammonia concentration in the cultures, a result similar to the current research. However, in the current study, the reasons for the slightly decreased nutrient digestibility were found when increasing concentration of SMCM above the level of 200 g/d is not known, since there is no report on the effect of cordycepin on rumen microbes. The application of *Cordyceps* to ruminants is not simple for monogastric animals because of the digestion of rumen microorganisms and the antibacterial and antifungal effects of cordycepin (Yeo et al., 2009). Recently, however, it has

been reported that the addition of ATC caused a marked increase in DM disappearance of corn silage and CP disappearance from roughages, suggesting that major changes in the microbial population had occurred in response to the addition of ATC (Li et al., 2017).

Measured rumen variables included temperature, pH, and NH₃-N; BUN was also determined to investigate the relationship with rumen NH₃-N and protein utilization. Rumen pH, temperature, NH₃-N, and BUN concentrations are important indicators of rumen function and the stability of the rumen. Temperature and PCV were not altered among treatments, and the values were stable temperatures of 39.10 to 39.35 °C and PCV of 28.63% to 29.25%. The temperature and PCV were within the range considered optimal for microbial digestion of fiber and protein (Firkins, 1996). In the current study, supplementation with SMCM decreased ruminal pH, NH₃-N, and BUN compared to the control group. Similarly, supplementation of ACT linearly decreased ruminal pH, NH₃-N, and BUN concentrations (Li et al., 2017). In addition, Li et al. (2009) reported that administration of *Cordyceps sinensis* (CS) also significantly decreased the urea nitrogen in the serum of patients. Ruminal NH₃-N is a major source of N for microbial protein synthesis (Erdman et al., 1986). Ruminal NH₃-N concentrations were 12.32 to 16.61 mg/dL. It was found that increasing level supplementation of SMCM (100 to 300 g/d) can provide continuously adequate concentrations of NH₃ for persistent growth of rumen microorganisms, thereby more effectively utilizing fiber and protein in feedstuff. These results were close to those previously reported by Church and Santos (1981) and Wanapat and Cherdthong

(2009). According to numerous reports, the optimal ruminal ammonia concentration for efficient digestion is 5.0 to 25.0 mg/dL (Satter and Slyter, 1974; Preston and Leng, 1987; Cherdthong et al., 2011). Additionally, increased in situ DM and CP degradation rates were reported when rumen ammonia concentration increased from 9.7 to 21.4 mg/dL in the rumen fluid (Wallace, 1979). There is considerable evidence that SMCM may affect rumen microbial fermentation. These results were similar to previous work by McEwan et al. (2002), who supplemented essential oils in ammonia production. Similarly, Wallace et al. (2002) found that the main mechanism of action of essential oils was the inhibition of bacterial attachment to feed particles, and subsequently, NH_3 production (deamination) from AA was decreased. These data suggest that SMCM may modulate the blood metabolism of goats.

Decreasing rumen NH_3 -N concentrations also resulted in decreasing concentrations of BUN. Concentrations of BUN are highly correlated with the concentration of NH_3 production in the rumen (Lewis, 1975). BUN is one of the key indicators of renal function, as it increases when the kidney is damaged. A previous study reported that a Chinese herb (*Panax ginseng*) can reduce nephrotoxicity and decrease the BUN content in the serum (Kalkan et al., 2012). Li et al. (2009) found that administration of CS significantly decreased the concentrations of BUN in the serum of patients and dairy cows (Li et al., 2017), a finding consistent with the current results.

Plasma GLU, NEFA, and BHBA are the most common important indicators of energy metabolism in animals, such as dairy cows and dairy goats. Researchers have reported that plasma NEFA and BHBA correlate negatively with energy balance in dairy cows (Butler et al., 2006). In the current study, the increase in plasma glucose with increasing SMCM supplementation demonstrates the glucogenic capacity of this additive (Grummer et al., 1994). In addition, supplementation with SMCM decreased concentrations of NEFA and BHBA in plasma. These results suggest that SMCM can slow the mobilization of body fat and improve negative energy balance and milking capacity in dairy cows (Drackley, 1999; Zheng et al., 2012). The lower NEFA in the equally high SMCM treatment group may be related to greater propionate concentrations in the rumen. It was hypothesized that SMCM supplementation would increase the supply of energy intake, a finding in agreement with that of the current study, and therefore reduce the concentration of NEFA and BHBA circulating in the blood. The

improved negative energy balance associated with SMCM provides the basis for its application in goats, but its mechanism remains to be elucidated.

Data of plasma parameters of goats (such as TG, CHOL, TP, red blood cell [RBC], and white blood cell [WBC]) after SMCM supplementation are scarce. In the current study, supplementing SMCM linearly decreased the plasma concentration of CHOL and TG but did not affect other indicators such as HDL, TP, ALB, GLB, RBC, and WBC. The data are very relevant in the prevention of hyperlipidemia and helping to protect the heart and liver because total cholesterol (TC) and TG concentrations in the blood are strongly associated with cardiovascular diseases (Abdel-Maksoud et al., 2008). These results were similar to the results of a previous study by Kiho et al. (1996), who tested intracellular polysaccharides (IPSSs) (CS-F30) in normal mice and found that a reduction in the plasma TG and CHOL 3 to 6 h after administration. Similarly, Li et al. (2009) administered CS to the treated group, which resulted in decreased TC content when compared to the control group ($P = 0.01$). Furthermore, Guo et al. (2010) found that in male Syrian golden hamsters fed a high-fat diet, daily administration of cordycepin effectively reduced the accumulation of serum TC, TG, and low-density lipoprotein cholesterol (LDL-c). More recently, Li et al. (2017) reported that supplementation of ATC could linearly decrease TG significantly in dairy cows. These data suggest that SMCM may modulate the blood metabolism of goats. However, the reason for the reduction of CHOL and TG remains obscure. These effects may be related to effects of cordycepin or adenosine which are likely attributable to a direct inhibition of TC and TG synthesis in the liver. Previously, adenosine has been reported to be an effective activator of AMP-activated protein kinase (AMPK) (Aymerich et al., 2006). As cordycepin is a structural analogue of adenosine, an activator of AMPK, it is reasonable to speculate that it is also an AMPK activator. It has been widely reported that AMPK plays an important role in fat metabolism. As AMPK activity can have profound effects on preventing hyperlipidemia as well as cardiovascular diseases, these results suggest that cordycepin could be used in the treatment of hyperlipidemia. Their results indicated that the cordycepin of *C. militaris* might be a promising candidate to prevent hyperlipidemia and help to protect the heart and liver. In contrast with current findings, Li et al. (2017)'s supplementation of ATC did not affect CHOL and a tendency to increase CHOL in dairy cows was observed.

It was found that N intake, fecal N excretion, urinary N excretion, total N excretion, and N absorption were not altered by SMCM. Nitrogen retention was not affected by 100 to 200 g/d of SMCM but decreased when 300 g/d of SMCM was supplemented. Supplementation at 100 to 200 g/d of SMCM resulted in the greatest nitrogen retention (% of N intake). Similarly, Wanapat et al. (2008) reported that N intake, excretion of N, N absorption, and N retention were not affected by 100 g/d of lemongrass powder (LGP) supplementation but decreased when 200 or 300 g/d of LGP was supplemented. Regards to N utilization, Owens and Zinn (1988) stated that N excretion and N retention should reflect differences in N metabolism, because N retention was the most important index of the protein nutrition status of ruminants. In the current study, supplementation of 100 to 200 g/d of SMCM decreased N excretion and increased N retention and proportion of N retention to N intake at 10.75; 10.59 g/d and 61.16; 58.96%, respectively. This could be due to supplementation of SMCM, which could control the rate of N degradation in the rumen and lead to slow rates of N excretion when compared with the control diet. Excess N, largely excreted in the form of urea via urine, is rapidly hydrolyzed to NH_3 by ruminal bacterial urease. NH_3 is very volatile and disperses easily into the surrounding air (Hünerberg et al. 2013). Additionally, excess N can also be lost through runoff and leaching during storage and application, possibly acting as a pollutant of ground and surface water (IPCC 2006).

CONCLUSIONS

Results from this study show that supplementing goat diets with SMCM at 100 to 200 g/d resulted in improved apparent digestibility of nutrients, and glucose concentration, decreased ruminal pH, and decreased concentrations of NH_3 -N, BUN, NEFA, BHBA, TG, and CHOL in plasma, suggesting that under the experimental conditions of this study, SMCM has positive functions as a feed additive to improve energy substance metabolism and contribute to glyconeogenesis, and it has no negative effects on plasma metabolism. Further research and long-term studies should be conducted to validate the effects of supplementing SMCM in finishing goats and to determine the optimal feeding rates in dairy goats. More work is required to elucidate that the biologically active components in SMCM can be transferred to the end products of livestock such as milk and meat, can increase the market value of livestock products and can affect

immune and antioxidant functions in finishing goat and dairy goats.

Conflict of interest statement. None declared.

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