Nutrient digestibility, rumen microbial protein synthesis, and growth performance in sheep consuming rations containing sea buckthorn pomace¹

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ABSTRACT: This experiment was conducted to investigate nutrient digestibility, rumen microbial protein synthesis, and growth performance when different proportions of sea buckthorn pomace (SBP) were included in the diet of sheep. A total of forty 1/2 Dorper × 1/2 thin-tailed Han ram lambs (BW = 22.2 ± 0.92 kg, age = 120 ± 11 d; mean ± SD) were selected and divided into four groups in a randomized design and were randomly allocated to one of four treatment diets. Diets were formulated isonitrogenously and contained different levels of SBP: 1) 0% SBP (control), 2) 7.8% of DM SBP (8SBP), 3) 16.0% of DM SBP (16SBP), and 4) 23.5% of DM SBP (24SBP). A portion of corn and forages were replaced with SBP. DMI and ADG increased linearly ($P = 0.001$), but feed efficiency was not affected ($P \geq 0.460$) by

increasing SBP inclusion rate. As the SBP inclusion increased, OM, NDF, and ADF digestibility decreased linearly ($P \leq 0.005$) and that CP increased linearly ($P = 0.012$). Response to inclusion level of SBP was quadratic ($P = 0.003$) for the estimated microbial CP yield with the greatest at intermediate SBP levels. For intestinally absorbable dietary protein, quadratic ($P = 0.029$) effects were observed among treatments. The metabolizable protein (MP) supplies were linearly ($P < 0.0001$) improved with increasing SBP inclusion rate. The results indicated that SBP can be incorporated in the ration of ram lambs and improve MP supply and ADG. However, high content of it in the diet was adverse for nutrient digestibility. The optimal proportion was 16.0% under the condition of this experiment.

Key words: growth performance, nutrient digestibility, sea buckthorn pomace, purine derivative

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INTRODUCTION

Sea buckthorn (*Hippophae rhamnoides* L., Elaeagnaceae family) is a temperate deciduous bush native to Europe and Asia (Dániel et al., 2007). It has orange pearl-shaped berries, which have high content of vitamin C and antioxidant phytonutrients, and has often been used in the clinical treatment of radiation damage, wounds, cancer, heart disease, etc. (Gao et al., 2000; Yang and Kallio, 2002; Guliyev et al., 2004). Besides its medical use, a large quantity of sea buckthorn berries is processed into products such as juice, marmalade, and food additives for candies and jellies

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(Tang et al., 2001; Negi et al., 2006). Sea buckthorn pomace (SBP) is a coproduct of juice processing from the fleshy berries tissue, which still contains many valuable vitamins, tocopherols, flavonoids, special fatty acids, and abundant AAs (Dániel et al., 2007). Additionally, it contains highly digestible carbohydrate, especially nonfiber carbohydrate (NFC), and is high in ether extract (EE) and low in starch (Dániel et al., 2007; Nuernberg et al., 2015). Previous studies have focused on the effects of SBP as energy and functional feed on fattening pigs (Nuernberg et al., 2015). Available research data in terms of using SBP as a nonforage source to substitute for corn and roughage in sheep diets are less common.

Nutritional methods that improve the supply of metabolizable protein (MP) to ruminants should attempt to manipulate RUP and microbial CP (MCP) synthesis (NRC, 2001). The AA profile of MCP is commendable match to the animal's requirements and is believed to be highly digestible (Clark et al., 1992). Therefore, the MCP flow in the small intestine directly affects the performance of animals. The objectives of this experiment were to explore feed digestibility, MCP synthesis, MP supply, and growth performance in response to different levels of SBP in growing sheep diets.

MATERIALS AND METHODS

Animals, Diets, and Experimental Design

The use of the animals was approved by the Animal Care Committee, Shanxi Agricultural University (Taigu, China), and experimental procedures used in this study were in accordance with the university's guidelines for animal research (Protocol number: SXAU-[2014]-8). In the present study, SBP was obtained from a local sea buckthorn juice factory in dry form.

Forty 1/2 Dorper × 1/2 thin-tailed Han ram lambs (BW = 22.2 ± 0.92 kg, age = 120 ± 11 d; mean ± SD) were randomly distributed into four groups and allocated to one of four dietary treatments (Table 1). Diets were formulated to be isonitrogenous with different levels of SBP (on a DM basis): 1) 0% SBP (control), 2) 7.8% of DM SBP (8SBP), 3) 16.0% of DM SBP (16SBP), and 4) 23.5% of DM SBP (24SBP). A portion of forages and corn were replaced with SBP in treatment diets.

Diets were fed as total mixed pelleted feed, which were pelleted using a horizontal feed mixer (9SJW-300; National Science Makoto Farming Equipment Co. Ltd., Beijing, China). The experiment was conducted over 90 d, with the first 10 d for adaptation.

Table 1. Ingredients and chemical composition¹ (% of DM) of experimental diets

Item	Treatment ²			
	Control	8SBP	16SBP	24SBP
Ingredients				
SBP	0	7.8	16.0	23.5
Ground corn	28.9	24.2	23.0	14.5
Wheat shorts	5.0	5.0	5.0	5.0
Wheat bran	3.0	3.0	3.0	3.0
Soybean meal	13.4	12.3	12.3	12.3
Oil cake of flax seed	4.7	4.7	4.7	4.7
Oat straw	25.0	27.0	20.0	20.0
Potato plants	15.0	11.0	11.0	12.0
Limestone	0.5	0.5	0.5	0.5
Sodium chloride	0.5	0.5	0.5	0.5
Premix ³	4.0	4.0	4.0	4.0
Chemical compositions				
CP	13.2	13.2	13.2	13.5
NDF	44.1	41.9	40.5	38.7
ADF	28.4	28.0	26.8	26.9
EE ⁴	1.09	2.29	2.60	3.46
NFC ⁵	39.6	40.5	41.2	42.0
Ca	0.81	0.75	0.81	0.95
P	0.64	0.63	0.58	0.58
GE, MJ/kg DM	17.7	17.7	17.5	17.8

NFC = nonfiber carbohydrate; SBP = sea buckthorn pomace.

¹Compositions of experimental diets were calculated according to the chemical analysis and inclusion rate of ingredients.

²Control = 0% of DM SBP, 8SBP = 7.8% of DM SBP, 16SBP = 16.0% of DM SBP, 24SBP = 23.5% of DM SBP.

³Premix containing: 30 mg/kg of Se, 60 mg/kg of Co, 2,500 mg/kg of Cu, 5,500 mg/kg of Fe, 51 mg/kg of I, 2,500 mg/kg of Mn, 60,000 mg/kg of S, 11,600 mg/kg of Zn, 1,800,000 IU/kg of vitamin A, 300,100 IU/kg of vitamin D, and 576 IU/kg of vitamin E.

⁴EE = ether extract.

⁵NFC = 100 - %NDF - %CP - %ether extract - %ash.

Lambs were housed in individual stalls (3.0 × 0.8 m) and fed twice daily (0600 and 1600 h) at 105% of ad libitum intake and had free access to drinking water.

Sampling, Measurements, and Analyses of Feed, Feces, and Urine

During the experimental period, feed intake and refusal were recorded daily, and BW was weighed before the morning feeding for each lamb during a 3-d period every 10 d. On day 50 of the experiment period, all the lambs were housed in individual metabolism cages to determine apparent total tract digestibility and the diets offered at 105% of ad libitum consumption. Feces were collected in wire-screen baskets placed under the floor of the metabolism crates, and urine was collected through a funnel into plastic buckets containing 100 mL of 10% (vol/vol) H₂SO₄ to acidify the urine of each lamb (López and Fernández, 2013). Approximately 20% of the diet,

feces, and urine were collected over five consecutive days from day 55 of experiment period. Samples of feeds and orts were dried for 48 h at 60 °C in a forced-air oven and ground to pass through a 1-mm screen in a Wiley mill (Arthur H. Thomas Co., Philadelphia, PA) before analysis. The contents of DM, OM, CP, ADF, lignin, and starch were determined according to the procedures of the AOAC (2000). The NDF content was analyzed using the Ankom A200 fiber analyzer (Ankom Technology, Macedon, NY) by the method of Van Soest et al. (1991). Fecal samples were dried at 65 °C in a forced-air oven, ground to pass through a 1-mm screen in a Wiley mill (Arthur H. Thomas Co.) and stored in sealed plastic containers at 4 °C until analyses. The ground samples were analyzed for DM, N, ash, NDF, and ADF using the same procedures as described for feed. Total tract digestibility of nutrient was calculated as (nutrient consumed – nutrient in feces)/nutrient consumed.

In Situ Degradation

In situ rumen degradation of DM, CP, and NDF of the SBP and four experimental diets was determined using the method described by Wang et al. (2008) with three ruminally cannulated adult 1/2 Dorper × 1/2 small thin-tailed wethers. The basal diet (% of DM) consisted of 40.3% concentrate mixture, 35.5% corn straw, and 24.2% alfalfa hay offered two times daily ad libitum. The diet samples used for rumen degradation analysis were ground to pass through a 3-mm screen in a Wiley mill (Arthur H. Thomas Co.) before analysis. Five grams of samples were weighed and placed into numbered nylon bags (10 × 7 cm, 35-μm pore size; Ankom Technology). All of the nylon bags were placed in duplicate in the ventral sac of the rumen through the ruminal cannula to incubate for 0, 2, 4, 8, 12, 16, 24, 36, and 48 h (two bags per sample × three animals). After incubation, all bags were removed simultaneously from the rumen and rinsed under cold tap water until the water was clear. The 0-h time point represented those bags which were not incubated but were cleaned as other bags upon removal from the rumen. The bags were then dried at 60 °C for 48 h and weighed. The residues and original diet samples were ground for DM and CP analysis. The nonlinear model described by Ørskov et al. (1980): $p = a + b [1 - \exp(-ct)]$ was used to estimate the constants of the in situ degradation, where p was the rate of disappearance at time t (h), a was the rapidly soluble fraction, b was the slowly degradable fraction and degraded at rate c ($c > 0$). The effective degradability (dg) was calculated

according to the equation: $dg = a + bc/(c + kp)$, where a , b , and c are the constants described above, kp is the estimated rate of outflow from the rumen.

Estimation of MCP Yield and MP

Urinary purine derivatives (PD) were used to indirectly estimate the MCP yield in the rumen (Chen and Gomes, 1992). The urine volume was determined when total urine sample was collected through a plastic bucket under the floor of the metabolism crates. The PD (allantoin, uric acid, xanthine, and hypoxanthine) contents were analyzed according to the method described by Chen and Gomes (1992).

The MP was estimated as the sum of the intestinally absorbable MCP (IAMCP) and intestinally absorbable dietary protein (IADP). The IAMCP was calculated by the following equation: $IAMCP = MCP \times 0.56$ (NRC, 2007), and the IADP was estimated according to the equation: $IADP = RUP \times CP \text{ intake} \times IDP$, where IDP refers to the intestinal digestibility of RUP, determined from the residue of feedstuff incubated in the rumen for 16 h, according to a modified three-step procedure described by Gargallo et al. (2006).

Statistical Analysis

Data were analyzed by PROC MIXED using SAS (version 9.1, SAS Institute Inc., Cary, NC) in a completely random design, where the treatment was considered the fixed effect, and the sheep was random effect. Each sheep was defined as the experimental unit. In addition, the linear and quadratic effects of treatment were tested by an orthogonal polynomial contrast. For the regression analysis between ADG and MP, the REG procedure was used. Means were considered significantly different at $P < 0.05$, and tendencies for treatment effects were defined as $P < 0.10$.

RESULTS

Chemical Composition and Degradation Parameters of SBP

The chemical composition and constants of DM and CP degradation for SBP are listed in Table 2. The CP, NDF, ADF, and NFC contents of SBP on DM basis were $7.9 \pm 1.50\%$, $29.7 \pm 1.26\%$, $22.9 \pm 0.98\%$, and $49.7 \pm 1.09\%$. The effective degradability in the rumen of DM and CP was $67.5 \pm 1.60\%$ and $58.6 \pm 0.83\%$, respectively.

Table 2. Chemical composition (% of DM unless otherwise noted) and constants of DM and CP degradation based on $p = a + b [1 - \exp(-ct)]^1$ and their effective degradability (dg) of SBP used in the experimental diets ($n = 5$)

Item	DM	CP	NDF	ADF	EE ²	NFC ³	Starch
Values, %	90.2 ± 0.31	7.9 ± 1.50	29.7 ± 1.26	22.9 ± 0.98	10.1 ± 0.72	49.7 ± 1.09	4.53 ± 0.88
Rumen degradation parameters							
a , %	30.6 ± 1.23	29.9 ± 2.36					
b , %	66.5 ± 2.16	48.5 ± 1.04					
c , %	3.83 ± 0.11	4.5 ± 0.21					
dg , % ⁴	67.5 ± 1.60	58.6 ± 0.83					

SBP = sea buckthorn pomace.

¹ p = the rate of disappearance at time t (h), a = the rapidly degradable fraction in the rumen, and b = the fraction slowly degraded at rate c ($c > 0$).

²EE = ether extract.

³NFC = 100 - %NDF - %CP - %ether extract - %ash.

⁴ dg = degradability; $dg = a + bc/(c + kp)$ (Ørskov et al., 1980), assuming a passage rate (kp) of 3.1%/h (García et al., 1995).

Table 3. BW, DMI, and growth performance in lambs fed four experimental diets based on SBP ($n = 10$)

Items	Treatment ¹				SEM	Contrasts	
	Control	8SBP	16SBP	24SBP		Linear	Quadratic
Initial BW, kg	22.5	22.7	22.4	22.2	0.53	0.840	0.593
Final BW, kg	38.2	38.8	43.6	41.4	1.24	0.023	0.263
DMI, g/d	1511.0	1548.4	1816.8	1828.9	67.39	0.001	0.853
ADG, g/d	221.2	221.7	257.3	258.9	6.61	0.001	0.933
Feed efficiency ²	0.15	0.14	0.14	0.14	0.01	0.460	0.787

SBP = sea buckthorn pomace.

¹Control = 0% of DM SBP, 8SBP = 7.8% of DM SBP, 16SBP = 16.0% of DM SBP, 24SBP = 23.5% of DM SBP.

²Feed efficiency = ADG/DMI.

Feed Intakes and Lamb Performances

The DMI and growth performance are shown in Table 3. The initial BW of lambs was similar, but the final BW linearly ($P = 0.023$) increased with the increase of SBP proportion in diets. Feeding SBP at increasing inclusion levels resulted in a linear response ($P = 0.001$) for DMI and ADG. Feed efficiency was not affected by treatment ($P = 0.460$).

In Situ Rumen Digestion

The results for the in situ degradation of the DM, NDF, and CP are presented in Table 4. For the DM degradation, a quadratic ($P = 0.026$) effect was observed on the rapidly degradable fraction (a) with the greatest value at 16SBP. The b , c , and dg values linearly ($P \leq 0.001$) improved with increasing SBP inclusion. Additionally, a linear ($P \leq 0.020$) improvement was also observed in a , b , and dg values of NDF. For the CP degradation, SBP displayed a quadratic ($P = 0.050$) response on the rapidly degradable fraction, with the greatest value for 8SBP and 16SBP. A similar quadratic ($P = 0.001$) effect on dg for CP was observed. Therefore, a quadratic ($P = 0.001$) effect was also

observed on RUP with the lowest value at 8SBP and 16SBP.

Nutrient Digestibility

Digestibility coefficients are presented in Table 5. Total tract apparent digestibility of DM tended to decrease linearly ($P = 0.085$) with increasing SBP concentration. Moreover, total tract apparent digestibility of OM, NDF, ADF, and GE linearly ($P \leq 0.005$) declined with increasing SBP inclusion. However, increasing SBP proportions in the diet improved CP digestibility linearly ($P = 0.012$).

Intestinal Digestibility of RUP and Estimated MCP

The daily excretion of PD, estimated ruminal MCP, IDP, IADP, and MP are listed in Table 6. The daily urinary excretion of allantoin ($P = 0.015$) xanthine + hypoxanthine ($P = 0.038$) and total PD ($P = 0.003$) responded quadratically. There were also quadratic trends on the MCP yield with the greatest at intermediate SBP levels. The IADP values increased as the SBP proportion in the diet increased, and both

Table 4. Constants of main nutrient degradation and RUP of the four experimental diets ($n = 5$)

	Treatment ¹					Contrasts	
Items ²	Control	8SBP	16SBP	24SBP	SEM	Linear	Quadratic
DM degradation							
a,%	15.1	15.1	16.4	15.0	0.42	0.410	0.026
b,%	56.3	58.2	59.3	61.9	1.26	0.001	0.685
c,%	2.77	2.8	2.84	3.18	0.06	<0.0001	0.072
dg	41.7	42.8	44.8	46.3	0.88	0.001	0.803
NDF degradation							
a,%	4.62	4.17	5.59	5.17	0.223	0.003	0.927
b,%	67.4	68.5	72.3	74.7	2.82	0.001	0.212
c,%	2.08	2.30	2.30	2.54	0.149	0.020	0.929
Dg	31.7	33.2	36.4	38.8	1.31	<0.0001	0.370
CP degradation							
a,%	20.6	22.6	22.2	20.6	1.12	0.674	0.050
b,%	63.3	63.2	66.3	63.1	1.61	0.950	0.092
c,%	3.37	3.35	3.59	3.50	0.139	0.843	0.238
dg	53.6	56.0	57.7	53.9	0.95	0.570	0.001
RUP.% of CP	46.4	44.0	42.3	46.1	0.95	0.570	0.001

SBP = sea buckthorn pomace.

^{a-c}Means within a row with different superscripts differ ($P < 0.05$).

¹Control = 0% of DM SBP, 8SBP = 7.8% of DM SBP, 16SBP = 16.0% of DM SBP, 24SBP = 23.5% of DM SBP.

² a = the rapidly degradable fraction in the rumen and b = the fraction slowly degraded at rate c ($c > 0$), dg = degradability; $dg = a + bc/(c + kp)$ (Ørskov et al., 1980), assuming a passage rate (kp) of 3.1%/h (García et al., 1995).

Table 5. Digestibility coefficients (%) of major nutrients for the four experimental diets ($n = 10$)

Items	Treatment ¹				SEM	Contrasts	
	Control	8SBP	16SBP	24SBP		Linear	Quadratic
DM	63.4	62.0	63.6	59.8	1.03	0.085	0.360
OM	66.7	64.1	65.0	61.2	1.01	0.005	0.651
CP	65.3	65.9	69.2	68.5	1.06	0.012	0.759
NDF	41.5	40.9	39.1	34.4	1.02	0.0003	0.066
ADF	32.9	30.9	29.8	26.2	0.84	0.0001	0.348
GE	63.4	61.3	62.2	58.8	0.91	0.007	0.468

SBP = sea buckthorn pomace.

¹Control = 0% of DM SBP, 8SBP = 7.8% of DM SBP, 16SBP = 16.0% of DM SBP, 24SBP = 23.5% of DM SBP.

the linear and quadratic effects were significant ($P \leq 0.029$). The MP supply increased linearly ($P < 0.0001$) in lambs as the level of SBP was increased in the diet. A significant correlation was observed between ADG and MP supply (Fig. 1) in growing lambs.

DISCUSSION

The CP content of SBP in this experiment (7.9% of DM) was lower than that published in previous literature (14.6%; Nuernberg et al., 2015), and the NDF (29.7% of DM) and ADF (22.9% of DM) contents were also lower than the values reported by Nuernberg et al. (2015): 39.7% and 36.2% of DM, respectively. Therefore, the NFC proportion of SBP was relatively high in this study. Peyraud and Astigarraga (1998) reported that effects of

the cultivation techniques (i.e., N supply from the soil and harvesting date) could cause a difference in the nutrients in fruit. The varieties and processing methods of sea buckthorn are also important factors for nutrient content of coproduct. The CP content of SBP used in present study was similar to corn (NRC, 2001). Available research data in terms of ruminal degradation of SBP are less common. In this study, the rumen degradation characteristics of SBP were measured using three ruminally cannulated wethers. The soluble fraction and potential degradable fraction of DM were relatively high, which revealed high energy might be supplied for ruminant. The diets containing SBP reduced the proportions of corn, oat straw, and potato plants. Thus, the NDF and ADF levels were decreased, and EE content was increased in 16SBP and 24SBP,

Table 6. Intestinal N digestibility of the dietary protein, urinary PD, and estimated MP supply to the lambs fed four experimental diets ($n = 10$)

	Treatment ¹					<i>P</i>	
Items	Control	8SBP	16SBP	24SBP	SEM	Linear	Quadratic
Urinary PD, mmol/d							
Allantion	6.81	7.88	7.96	7.26	0.314	0.321	0.015
Uric acid	1.70	1.84	1.71	1.61	0.067	0.410	0.066
Xanthine + hypoxanthine	0.75	0.84	0.8	0.71	0.040	0.344	0.038
Total PD	9.21	10.56	10.47	9.58	0.297	0.461	0.003
MCP, ² g/d	33.6	38.5	38.1	34.9	1.09	0.457	0.003
IAMCP, ³ g/d	18.8	21.6	21.4	19.6	0.61	0.458	0.003
IDP, ⁴ % of RUP	47.1	48.9	52.1	51.5	1.25	0.024	0.050
IADP, g/d	43.8	43.9	52.8	58.7	1.22	<0.0001	0.029
MP, g/d	62.6	65.4	74.2	78.4	1.40	<0.0001	0.628

MCP = microbial CP; MP = metabolizable protein; PD = purine derivatives; SBP = sea buckthorn pomace.

^{a-c}Means within a row with different superscripts differ ($P < 0.05$).

¹Control = 0% of DM SBP, 8SBP = 7.8% of DM SBP, 16SBP = 16.0% of DM SBP, 24SBP = 23.5% of DM SBP.

²MCP was calculated according to the equation (Chen and Gomes, 1992), $MCP = (\text{allantion} + \text{uric acid} + \text{xanthine} + \text{hypoxanthine}) \times 70 \times 6.25 / (0.116 \times 0.83 \times 1,000)$.

³IAMCP = intestinally absorbable MCP.

⁴IDP = intestinal digestibility of RUP, which was measured according to a modified three-step procedure (Gargallo et al., 2006).

⁵IADP = intestinally absorbable dietary protein, which was calculated by the equation: $IADP = RUP \times CP \text{ intake} \times IDP$.

⁶MP = IAMCP + IADP.

Figure 1. Regression of the ADG on the metabolizable protein (MP) in growing lambs.

which would be possible to increase the rumen degradation rate. Although diets containing SBP had low starch level, the GE values were similar for diets because of the high NFC content in SBP.

The DMI and ADG linearly increased with the supplementation of SBP to the diet. The higher DMI may be attributed to the higher rumen degradation of DM and NDF as the level of SBP increased in the diets. Compared with roughages in control diet, diets containing SBP had smaller particle size and higher solubility. Feedstuffs that have small size might also have a lower rumen fill effect (Seoane et al., 1981) and a shorter retention time in the digestive tract (Gigerreverdin, 2000). In consequence, the lower proportions of oat straw and

potato plants decreased the fill effect of diets on the rumen, which would improve the DMI. Compared with control diet, 24SBP had lower NDF and ADF content in current experiment. According to a review by Allen (2000) from 15 studies, DMI generally declined with increasing NDF content in rations. Kagiwal et al. (2012) reported that high amounts of secondary plant metabolites and different vitamins are abundant in sea buckthorn fruit pulp. Therefore, the improvement of DMI and ADG may also be due to the functional components in SBP. The true concentration and effects of these functional ingredients in SBP should be analyzed and researched in the future. Previous studies found that ADG is closely related to the dietary supply of nitrogen, rumen fermentable carbohydrates, and MP in the small intestine (Zhu et al., 2013; Siverson et al., 2014). With the linear increase of nutrient intake, the retention of energy and nitrogen might be improved accordingly. Moreover, energy supply plays an important role on MCP synthesis and MP supply for ruminants. The greater estimated MCP yield in the present study contributed to the improvement of ADG when inclusion of SBP was high in the diet.

The DM in SBP was highly degradable; thus, the total diet-effective degradation rate of DM and NDF was increased as the amount of SBP increased in the treatment diets in this study (Table 4), which was consistent with results by Hao et al. (2017). The improvement of b and c was largely attributed

to the greater NFC and lower proportion of potato plants, which was hardly degradable (Kariuki et al., 2001). Additionally, a linear improvement was observed in the potentially degradable fraction and degradation rate for DM and NDF. Thus, sufficient energy substrate may have been available for microbe reproduction. Additionally, the lower CP degradation rate might result in the depression in MCP (Hao et al., 2017). The change of CP degradation characteristics occurred among treatment diets probably because of the difference of CP components between corn and SBP. Whereas, the activity of proteolytic enzymes in the rumen might be decreased or some proteolytic bacteria might be restrained when inclusion of SBP was high in the diet. Although the DM and NDF rumen degradation rate was linearly increased with the increasing of SBP, the MCP estimated yield responded quadratically. The MCP response for high level of SBP might be attributed to lower rumen pH values (the value was not presented) because of the lower forage ratio in diets and the rapid degradation of NFC. On the other hand, some other unidentified factors such as some special fatty acids in SBP may have inhibited the growth and reproduction of rumen microorganism when lambs consumed high proportion of SBP.

In the current study, the apparent digestibility of DM, OM, and NDF in sheep that consumed high proportions of SBP was linearly decreased (Table 5). As reported by Gehman and Kononoff (2010), the diet containing high content of NDF made NDF digestibility play a more important role in determining DM or OM digestibility than those with low NDF concentrations. Therefore, the linear decreases for DM and OM digestibility resulted from the decreasing of NDF digestibility. Because of the high concentration ratio in 24SBP, we infer that rumen microbes, especially cellulolytic bacteria, might be the main reason for the NDF digestibility depression. The higher nutrient intake and digestibility offered sufficient metabolic substrates for bacteria, which promote their growth and increase the estimated MCP yield. Furthermore, the positive associative effect might occur when lambs were fed a diet at an optimum level of SBP. Dixon and Stockdale (1999) reported that positive effect on fiber digestibility often occurs when forages are combined with concentrates in the proper proportion. As we know, SBP contains low starch and is high in soluble carbohydrate and pectin (Canteri-Schemin et al., 2005). The pectin in SBP might regulate the rumen environment and promote digestion of nutrients when the inclusion

proportion of SBP was appropriate (Guo et al., 2006). Therefore, the linearly increased tendency of CP digestibility was observed with increasing inclusion of SBP. Meanwhile, the increase of IADP and MP might further explain the rise of ADG. In present experiment, a significant relationship existed between the MP and ADG (Fig 1). Our results indicated that the higher MP was due to both MCP and IADP.

CONCLUSIONS

Results from this study show that supplementing sheep diets with SBP can increase the DM intake, degradation of DM and NDF, MCP flow to the duodenum, and ADG. However, the diet including 23.5% of DM SBP had the lowest nutrients digestibility. Feed efficiency was not affected by treatments. Consequently, we infer that SBP can be incorporated in the ration of ram lambs, and the optimal proportion was 16.0% under the condition of this study. Moreover, the economic advantages and sustainability of this recommendation should be evaluated.

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