

## Effects of Mannan Oligosaccharide Supplementation in Diets with Different Concentrate-to-Forage Ratios on Rumen Nutrient Degradability in Sheep: Postprint

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### Abstract

This experiment employed the nylon bag method to investigate the effects of dietary concentrate to forage ratio and mannan oligosaccharide (MOS) supplementation on nutrient degradation rates in the rumen of sheep. Six wethers (White Suffolk × Small-tailed Han ) fitted with permanent rumen fistulas were used in a 4×6 two-factor factorial experimental design, with dietary concentrate to forage ratio and MOS supplementation level as the two factors. The dietary concentrate to forage ratios were 20:80 (A1), 30:70 (A2), 40:60 (A3), and 50:50 (A4), and MOS supplementation levels were 0 (B1), 0.4% (B2), 0.8% (B3), 1.2% (B4), 1.6% (B5), and 2.0% (B6). The results showed that dietary concentrate to forage ratio significantly affected ( $P<0.05$ ) the degradation rates of dry matter (DM), organic matter (OM), and crude protein (CP) in sheep rumen at different time points, the degradation parameters [for DM and OM: rapidly degradable fraction (a), slowly degradable fraction (b), and degradable fraction (a+b); for CP: a, b, and degradation rate of fraction b (c)], and the effective degradation rates, all of which increased with increasing dietary concentrate proportion and reached the maximum in group A4. MOS supplementation level only significantly affected ( $P<0.05$ ) the degradation rates of CP at different time points and the degradable fraction parameter a+b, both of which increased initially and then decreased with increasing MOS supplementation level, reaching the maximum in group B5. There was no significant interaction ( $P>0.05$ ) between dietary concentrate to forage ratio and MOS supplementation level on nutrient degradation rates in sheep rumen. It was concluded that the effective degradation rates of DM, OM, and CP in sheep rumen were highest at a dietary concentrate to forage ratio of 50:50, and the degradation rate of CP was highest at an MOS supplementation level of 1.6%.

## Full Text

# Effects of Adding Mannan-Oligosaccharides to Diets with Different Concentrate to Roughage Ratios on Nutrient Degradation Rates in Sheep Rumen

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## Abstract

This experiment investigated the effects of adding mannan-oligosaccharides (MOS) to diets with different concentrate to roughage ratios on nutrient degradation rates in sheep rumen using the nylon bag technique. Six wethers (white Suffolk  $\times$  small-tailed Han sheep) fitted with permanent rumen fistulas were used in a 4 $\times$ 6 factorial design with two factors: dietary concentrate to roughage ratio [A1 (20:80), A2 (30:70), A3 (40:60), and A4 (50:50)] and MOS supplementation level [B1 (0%), B2 (0.4%), B3 (0.8%), B4 (1.2%), B5 (1.6%), and B6 (2.0%)]. The results showed that dietary concentrate to roughage ratio significantly affected the rumen degradation rates, degradation parameters [for DM and OM: immediately degraded fraction (a), slowly degraded fraction (b), and degradable fraction (a+b); for CP: a, b, and degradation rate of b (c)], and effective degradation rates of dry matter (DM), organic matter (OM), and crude protein (CP) at different time points ( $P < 0.05$ ). All these parameters increased with higher concentrate proportions, reaching maximum values in group A4. MOS supplementation level only significantly affected the rumen degradation rate of CP and the a+b parameter of CP degradation at different time points ( $P < 0.05$ ), showing a trend of initial increase followed by decrease with rising MOS levels, with peak values observed in group B5. No significant interaction was found between dietary concentrate to roughage ratio and MOS supplementation level on rumen nutrient degradation rates ( $P > 0.05$ ). In conclusion, the effective degradation rates of DM, OM, and CP in sheep rumen were highest at a dietary concentrate to roughage ratio of 50:50, while the degradation rate of CP peaked at a MOS supplementation level of 1.6%.

**Keywords:** sheep; concentrate to roughage ratio; mannan oligosaccharides; nylon bag technique; rumen degradation rate

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Mannan-oligosaccharides (MOS) are novel feed additives that have received considerable attention in recent research. These linear or branched low-degree polymerized sugars consist of 2-10 glucose, mannose, or galactose molecules linked by  $\beta$ -1,4-D-mannopyranoside bonds or  $\alpha$ -1,2,  $\alpha$ -1,3, or  $\alpha$ -1,6 glycosidic bonds, and are primarily obtained through fermentation of yeast cell walls rich in MOS.

MOS not only promote the proliferation of beneficial bacteria but also adsorb pathogenic bacteria, improve intestinal microecology, enhance non-specific immunity, and increase animal resistance. Additionally, MOS serve as intestinal regulators with advantages over antibiotics, including no pollution, no residue, and no side effects. While numerous studies have investigated MOS application in monogastric animal production, research on their use in ruminant production remains limited.

Dietary concentrate to roughage ratio significantly influences rumen environment and digestive metabolism in ruminants, with ratios that are too low or too high adversely affecting health status and production performance. Appropriate roughage supplementation not only increases satiety and reduces feed costs but also promotes gastrointestinal motility, improves digestibility, and offers potential benefits for optimizing rumen environment. Feeding diets with suitable concentrate to roughage ratios is crucial for improving nutrient utilization and production performance. Therefore, this study employed the nylon bag technique to determine the degradation rates of dry matter (DM), organic matter (OM), and crude protein (CP) in sheep rumen for diets with different concentrate to roughage ratios supplemented with varying MOS levels, and to explore their interaction, thereby providing fundamental data for MOS application in ruminant production and its interaction with dietary concentrate to roughage ratio.

### 1.1 Experimental Design

A 4×6 factorial design was employed with two factors: dietary concentrate to roughage ratio (A) and MOS supplementation level (B). Factor A comprised four levels: 20:80 (A1), 30:70 (A2), 40:60 (A3), and 50:50 (A4). Factor B comprised six levels: 0% (B1), 0.4% (B2), 0.8% (B3), 1.2% (B4), 1.6% (B5), and 2.0% (B6), resulting in 24 treatment combinations. The experimental design scheme is presented in Table 1 .

**Table 1** The experimental design scheme

Dietary concentrate to roughage ratio	MOS adding level
20:80 (A1)	0 (B1)
30:70 (A2)	0.4 (B2)
40:60 (A3)	0.8 (B3)
50:50 (A4)	1.2 (B4)
	1.6 (B5)
	2.0 (B6)

### 1.2 Experimental Diets

Feed ingredients low in MOS content, including corn, soybean meal, cottonseed meal, alfalfa hay, and oat grass, were selected to formulate four experimental di-

ets with different concentrate to roughage ratios. The composition and nutrient levels are shown in Table 2 .

**Table 2** Composition and nutrient levels of experimental diets (air-dry basis), %

Item	Dietary concentrate to roughage ratio
	20:80 (A1)
<b>Ingredients</b>	
Corn	[values]
Soybean meal	[values]
Cottonseed meal	[values]
Alfalfa hay	[values]
Oat grass	[values]
NaCl	[values]
Premix	[values]
<b>Total</b>	
<b>Nutrient levels</b>	
DM	[values]
DE/(MJ/kg)	[values]
CP	[values]
DE/CP (MJ/g)	[values]
NDF	[values]
ADF	[values]
Ca	[values]

The premix provides the following per kilogram of diets: S 200 mg, Fe 25 mg, Zn 40 mg, Cu 8 mg, I 0.3 mg, Mn 40 mg, Se 0.2 mg, Co 0.1 mg, VA 940 IU, VE 20 IU.

### 1.3 Experimental Animals and Management

Six healthy crossbred wethers (white Suffolk × small-tailed Han sheep ) approximately one year old and weighing ( $28.04 \pm 2.07$ ) kg, fitted with permanent rumen fistulas, were used as experimental animals. During the experimental period, the sheep were fed diet A3 at 1.0 kg/head/day with free access to water.

### 1.4 Nylon Bag Procedure

Approximately 3.0 g of sample was accurately weighed and placed in nylon bags (18 cm × 15 cm, 40 μm pore size), which were then sealed tightly. Each treatment had three replicates. Twelve nylon bags were placed in each sheep's rumen in two repetitions, secured to the fistula opening. The clamped nylon bags were inserted into the rumen ventral sac before morning feeding. Bags were removed at 3, 6, 9, 12, 24, and 48 h post-incubation, rinsed with 37°C

distilled water while controlling water flow rate, temperature, and rinsing time (approximately 5 min). After rinsing, nylon bags and residues were dried to constant weight in a 65-70°C oven. DM, OM, and CP contents in diets and residues were then determined according to Zhang et al. [7], and degradation rates were calculated.

### 1.5 Determination of Rumen Passage Rate K and Effective Degradation Rates of DM, OM, and CP

The chromium marker method [8] was used to determine rumen passage rate K. Based on sampling time points and chromium oxide concentrations in feces, CurveExpert 1.3 software was used for least squares curve fitting to determine K values, which are presented in Table 3. Effective degradation rates of DM, OM, and CP were calculated using the model proposed by Ørskov et al. [9], with SAS software employed for least squares curve fitting to obtain a, b, and c values.

The degradation model is:

$$P_t = a + b(1 - e^{-ct})$$

Where:

$P_t$  = degradation rate of the tested nutrient at time t

$a$  = immediately degraded fraction

$b$  = slowly degraded fraction

$a + b$  = degradable fraction

$c$  = degradation rate of fraction b

$t$  = feed retention time in rumen

The effective degradation rate of the tested nutrient is related to rumen passage rate K as follows:

$$P = a + \frac{b \times c}{c + K}$$

Where:

$P$  = effective degradation rate of the tested nutrient in rumen

$a$  = immediately degraded fraction

$b$  = slowly degraded fraction

$c$  = degradation rate of fraction b

$K$  = rumen passage rate of the diet

**Table 3** K values of diets with different concentrate to roughage ratios

Item	K value
	[values]

## 1.6 Statistical Analysis

Two-way ANOVA was performed using SPSS 16.0 software package. When significant differences were detected, Tukey's test was used for multiple comparisons. Significance was declared at  $P < 0.05$  and  $P < 0.01$ , while  $P \leq 0.20$  was considered to indicate a significant trend. Since the interaction between dietary concentrate to roughage had no significant effect on any parameters, only main effect data are presented.

### 2.1 Effects of MOS Supplementation in Diets with Different Concentrate to Roughage Ratios on Rumen Nutrient Degradation Rates

As shown in Tables 4, 5, and 6, dietary concentrate to roughage ratio significantly affected rumen degradation rates of DM, OM, and CP at all time points ( $P < 0.05$ ). All parameters increased with higher concentrate proportions, with group A4 showing the highest degradation rates at each time point, significantly greater than groups A1 and A2 ( $P < 0.05$ ). MOS supplementation level only significantly affected rumen CP degradation rates at different time points ( $P < 0.05$ ), exhibiting a trend of initial increase followed by decrease with rising MOS levels. Group B5 showed the highest CP degradation rates at all time points, significantly higher than group B1 ( $P < 0.05$ ).

**Table 4** Rumen DM degradation rate at different time points, %

Groups	Time points/h	P-value
	3	6
A1	30.31c	35.90b
A2	33.61b	38.03b
A3	35.80ab	41.26a
A4	36.45a	41.59a
P-value	<0.001	<0.001

*In the same column, values with no letter or the same letter superscripts mean no significant difference ( $P > 0.05$ ), while different small letter superscripts mean significant difference ( $P < 0.05$ ). The same as below.*

**Table 5** Rumen OM degradation rate at different time points, %

Items	Time points/h	P-value
	3	6
A1	28.41b	31.88c
A2	29.05b	32.50c
A3	32.22a	36.34b
A4	34.53a	39.29a
P-value	<0.001	<0.001

**Table 6** Rumen CP degradation rate at different time points, %

Items	Time points/h	P-value
	3	6
A1	32.41c	32.73c
A2	35.44b	34.97c
A3	36.60ab	38.31b
A4	38.77a	39.13ab
B1	34.06bc	34.06bc
B2	37.07bc	37.07bc
B3	40.17bc	40.17bc
B4	44.20ab	44.20ab
B5	45.95a	45.95a
B6	47.01a	47.01a
P-value	<0.001	<0.001

## 2.2 Effects of MOS Supplementation in Diets with Different Concentrate to Roughage Ratios on Rumen Nutrient Degradation Parameters and Effective Degradation Rates

As shown in Tables 7, 8, and 9, dietary concentrate to roughage ratio significantly affected the a, b, a+b fractions and effective degradation rates of DM and OM, as well as the a, b, c fractions and effective degradation rate of CP ( $P < 0.05$ ). All parameters increased with higher concentrate proportions, with group A4 showing the highest effective degradation rates for DM, OM, and CP, significantly greater than groups A1, A2, and A3 ( $P < 0.05$ ). MOS supplementation level only significantly affected the a+b fraction of CP degradation ( $P < 0.05$ ), showing a trend of initial increase followed by decrease with rising MOS levels. Group B5 had the highest a+b value for CP, significantly greater than groups B1, B2, and B3 ( $P < 0.05$ ).

**Table 7** Rumen degradation parameters and effective degradation rate of DM

Item	a	b	c	a+b	Effective degradation rate	P-value
A1	18.23d	43.94b	[value]	62.17d	46.38d	<0.001
A2	21.14c	44.13b	[value]	65.26c	51.58c	<0.001
A3	23.67b	43.89b	[value]	67.56b	56.31b	<0.001
A4	24.32a	44.51a	[value]	68.84a	58.12a	<0.001
P-value	<0.001	<0.001	[value]	<0.001	<0.001	

**Table 8** Rumen degradation parameters and effective degradation rate of OM

Item	a	b	c	a+b	Effective degradation rate	P-value
A1	18.44c	36.48d	0.553	54.92d	41.11d	<0.001
A2	17.79d	42.25c	[value]	60.04c	46.05c	<0.001
A3	21.27b	44.62b	[value]	65.89b	52.44b	<0.001
A4	22.94a	53.91a	[value]	76.85a	60.82a	<0.001
P-value	<0.001	<0.001	0.553	<0.001	<0.001	

**Table 9** Rumen degradation parameters and effective degradation rate of CP

Item	a	b	c	a+b	Effective degradation rate	P-value
A1	26.60c	37.22a	0.043c	62.95d	43.46d	<0.001
A2	30.05b	36.05b	0.044c	64.38cd	48.64c	<0.001
A3	30.61b	36.81ab	0.050b	66.00bc	52.69b	<0.001
A4	32.55a	35.67c	0.055a	67.91ab	55.56a	<0.001
B1	[value]	[value]	[value]	62.95d	[value]	<0.001
B2	[value]	[value]	[value]	64.38cd	[value]	<0.001
B3	[value]	[value]	[value]	66.00bc	[value]	<0.001
B4	[value]	[value]	[value]	67.91ab	[value]	<0.001
B5	[value]	[value]	[value]	69.24a	[value]	<0.001
B6	[value]	[value]	[value]	67.86ab	[value]	<0.001
P-value	<0.001	<0.001	<0.001	<0.001	<0.001	

Rumen nutrient degradation rate reflects the digestibility and utilization difficulty of feed ingredients, serving as an important indicator of nutrient utilization by the animal body and a measure of feed value. Higher effective degradation rates signify better utilization by rumen microorganisms and body tissues, and dietary concentrate to roughage ratio is one of the key factors determining rumen nutrient degradation rate.

Wang et al. [11] used the nylon bag technique to study nutrient degradation rates in lactating cows fed diets with different concentrate to roughage ratios, finding that DM and OM degradation rates in rumen increased significantly with higher concentrate proportions. Getachew et al. [12] measured DM degradation rates of alfalfa hay, corn silage, and wheat straw silage after 72 h of in vitro incubation, reporting higher DM degradation for alfalfa hay than for corn silage and wheat straw silage. Castrillo et al. [13] demonstrated that increased concentrate proportion and barley supplementation in diets elevated rumen DM and OM degradation rates in sheep. Zhao [14] investigated the dynamic degradation patterns and effective degradation rates of DM, CP, and fiber fractions in several commonly used dairy cow forages, showing that DM, CP, NDF, and ADF degradation rates of alfalfa hay and alfalfa hay cubes were higher than other forages. Our findings are consistent with these conclusions. This study confirmed that rumen degradation rates of DM, OM, and CP in sheep increased

with higher dietary concentrate proportions, with the highest effective degradation rates observed at a 50:50 concentrate to roughage ratio. When dietary concentrate proportion increases, more fermentable nutrients are supplied to rumen microorganisms, promoting their growth and proliferation, which subsequently enhances degradation rates of various nutrients. At similar nutrient levels, altering the concentrate to roughage ratio inevitably changes diet composition, affecting rumen microbial populations and thus nutrient degradation rates. Furthermore, neutral detergent fiber (NDF) content in feed is negatively correlated with *in vitro* digestibility. Bo et al. [18] found in nylon bag experiments that vinegar residue had lower DM digestibility than distilled spirits residue, which was attributed to its relatively higher NDF content. Liu et al. [19] reported that relatively high crude fiber (CF) content in feed might lead to decreased CP degradation rates in rumen. International studies have also found that a considerable portion of protein in roughage is tightly bound to lignin, making it less degradable in rumen.

This study also found that dietary concentrate to roughage ratio significantly affected the a, b, and a+b fractions and effective degradation rates of DM and OM, as well as the a, b, c fractions and effective degradation rate of CP, all increasing with higher concentrate proportions and peaking in group A4. Bo et al. [18] observed in nylon bag experiments that distilled spirits residue had higher a values than vinegar residue, possibly due to its higher content of readily degradable CP. Research indicates that a values are positively correlated with CP content, while b values are primarily positively correlated with NDF content and digestibility, and that a considerable portion of protein in roughage is tightly bound to lignin. Therefore, as concentrate proportion increases, a values gradually increase while b values gradually decrease.

Protein in roughage primarily exists in cell contents, and its degradation rate depends on the fiber structure of plant cell walls. Consequently, fiber degradation significantly influences protein degradation rates. This study confirmed that MOS significantly promoted CP degradation in sheep rumen and significantly increased the a+b fraction of CP. This improvement may be attributed to exogenous oligosaccharides enhancing rumen fermentation function, stabilizing and improving the rumen environment, providing favorable conditions for rumen microbial growth, promoting microbial proliferation, and thereby increasing degradation rates of CP and fiber fractions in rumen. Appropriate MOS supplementation in diets can also increase activities of proteases and fiber-degrading enzymes in rumen, further improving CP degradation rates.

In this study, the two factors—dietary concentrate to roughage ratio and MOS supplementation level—showed no significant interaction on rumen degradation rates of DM, OM, and CP at any time point or on their effective degradation rates. This is likely because dietary concentrate to roughage ratio exerted strong main effects on rumen degradation rates of DM, OM, and CP, thus masking any potential interaction effects.

## Conclusion

As dietary concentrate proportion increased, rumen degradation rates and effective degradation rates of DM, OM, and CP in sheep all increased, reaching maximum values at a concentrate to roughage ratio of 50:50.

Dietary MOS supplementation improved rumen CP degradation rates in sheep, with the highest values observed at a MOS supplementation level of 1.6%.

No significant interaction was found between dietary concentrate to roughage ratio and MOS supplementation level on rumen degradation rates of DM, OM, and CP in sheep.

## References

- [1] ALTAMIMI M, ABDELHAY O, RASTLL R A. Effect of oligosaccharides on the adhesion of gut bacteria to human HT-29 cells[J]. *Anaerobe*, 2016, 39: 136-142.
- [2] ZHU Z Y, CUI D, GAO H, et al. Efficient synthesis and activity of beneficial intestinal flora of lactulose-derived oligosaccharides[J]. *European Journal Medicinal Chemistry*, 2016, 114: 8-13.
- [3] CHEN X B, DING H B, QIAO Y. Prebiotic effects, immune mechanisms and application technologies of mannan oligosaccharides[J]. *China Animal Husbandry & Veterinary Medicine*, 2015, 32(8): 6-8.
- [4] HU J, YU Z Y, ZHU Y J, et al. Effects of fructooligosaccharides on rumen microflora and degradation rates of common roughages in dairy goats[J]. *Chinese Journal of Animal Nutrition*, 2014, 26(7): 1988-1995.
- [5] HOU Z G, WANG Z Y, CHAI T J, et al. Effects of diets with different concentrate to roughage ratios on oxidative stress and rumen internal environment stability in dairy cows[J]. *Acta Veterinaria et Zootechnica Sinica*, 2008, 39(4): 455-459.
- [6] ZHANG Y Y, WANG C, LIU Q, et al. Effects of diets with different concentrate to roughage ratios on rumen fermentation characteristics and nutrient digestion and metabolism in Jinnan cattle[J]. *Chinese Journal of Animal Nutrition*, 2014, 26(8): 2365-2372.
- [7] ZHANG L Y, SUI L M, YANG W J. Rapid determination of crude fat and total fat in feed by filter bag method[J]. *Feed Industry*, 2010, 31(5): 35-36.
- [8] GAO M, WANG Z M, AO D, et al. Study on improving nutrient utilization of ammoniated wheat straw using system-wide regulation technology[J]. *Inner Mongolia Animal Science*, 1991(2): 1-4.
- [9] ØRSKOV E R, GRUBB D A, SMITH J S, et al. Efficiency of utilization of volatile fatty acids for maintenance energy retention sheep[J]. *British Journal Nutrition*, 1979, 41(3): 541-551.

- [10] GAO W, CHEN A D, ZHANG B W, et al. Rumen Degradability and post-ruminal digestion of dry matter, nitrogen and amino acids of three protein supplements[J]. *Asian-Australasian Journal of Animal Sciences*, 2015, 28(4): 485-493.
- [11] WANG J F, WANG J Q, LI S C, et al. Effects of different diets on rumen fermentation patterns and lactation performance in dairy cows[J]. *Acta Veterinaria et Zootechnica Sinica*, 2005, 36(6): 569-573.
- [12] GETACHEW G, ROBINSON P H, DEPETERS R J, et al. Relationships between chemical composition, dry matter degradation and in vitro gas production of several ruminant feeds[J]. *Animal Feed Science and Technology*, 2004, 111(1/2/3/4): 57-71.
- [13] CASTRILLO C M, FONDEVILA J A, GUADA J A, et al. Effect of ammonia treatment and carbohydrate supplementation on the intake and digestibility of barley straw diets by sheep[J]. *Animal Feed Science and Technology*, 1995, 51(1/2): 73-90.
- [14] ZHAO T Z. Study on rumen degradation patterns of protein and fiber fractions in main feedstuffs for dairy cows[D]. Master' s thesis. Inner Mongolia: Inner Mongolia Agricultural University, 2007.
- [15] XU X N, LI W L. Effects of dietary concentrate to roughage ratio on rumen microorganisms, environment and feed digestibility in sheep[J]. *Cereal & Feed Industry*, 2013, 12(1): 57-59.
- [16] ZHU S H. Effects of dietary carbohydrate structure on rumen fermentation and nitrogen metabolism in goats[D]. Master' s thesis. Yangzhou: Yangzhou University, 2010.
- [17] GRILLI D J, FLIEGEROVÁ K, KOPEČNÝ J, et al. Analysis of the rumen bacterial diversity of goats during shift from forage to concentrate diet[J]. *Anaerobe*, 2016, 42: 17-26.
- [18] BO Y K, YANG H J, WANG W X, et al. Evaluation and comparison of nutritional value of distilled spirits residue and vinegar residue using nylon bag and in vitro gas production methods[J]. *Grass-feeding Livestock*, 2011(3): 34-38.
- [19] LIU H X, LIU D S, SUI M X, et al. Study on rumen degradation characteristics of dry matter and crude protein in common roughages for sheep[J]. *Chinese Journal of Animal Science*, 2010, 46(21): 37-42.
- [20] GRANT R J, MERTENS D R. Influence of buffer pH and raw corn starch addition on in vitro fiber digestion kinetics[J]. *Journal of Dairy Science*, 1992, 75(10): 2762-2768.
- [21] CONE J W, GELDER A H. Influence of protein fermentation on gas production profiles[J]. *Animal Feed Science and Technology*, 1999(76): 251-264.

[22] YAO X B, YANG H J, XIE C Y, et al. Evaluation of rumen degradation characteristics and small intestinal digestibility of protein and amino acids in common feeds for ruminant livestock[J]. Chinese Journal of Animal Nutrition, 2007, 19(3): 225-231.

[23] LIN Y T, QI R, WANG L H, et al. Effects of exogenous oligosaccharides on rumen fluid enzyme activities and roughage degradation rates in goats[J]. Chinese Journal of Animal Nutrition, 2014, 26(12): 3616-3624.

[24] QI R, WEN J X, CHENG M, et al. Effects of different exogenous oligosaccharides on rumen microflora in Laoshan dairy goats[J]. Chinese Journal of Animal Nutrition, 2012, 24(2): 349-357.

[25] ZHANG X F. Study on degradation, transformation, utilization and flow patterns of exogenous oligosaccharides in sheep digestive tract and their effects on rumen microflora, immunity and nutrient digestion[D]. PhD thesis. Hohhot: Inner Mongolia Agricultural University, 2007.

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