

Correlation Analysis Between In Vitro Gas Production and Effective Degradation Rate of Commonly Used Concentrate Feeds for Meat Sheep in Southern Xinjiang (Postprint)

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Abstract

This study analyzed the correlation between in vitro gas production and effective degradability of common concentrate feeds for meat sheep in southern Xinjiang, aiming to establish a simplified evaluation method for the effective degradability of dry matter in these feeds. Using six protein feeds and seven energy feeds commonly used for meat sheep in southern Xinjiang as experimental materials, the in vitro gas production method and continuous artificial rumen fermentation method were employed to simultaneously measure gas production (GP) and effective degradability of dry matter, analyze their correlation and the influence of routine nutritional components on effective degradability of dry matter, and establish prediction models for effective degradability of dry matter using GP and routine nutritional components. The results showed: 1) Potential gas production and gas production at 8, 16, 24, 36, and 48 h were all positively correlated with effective degradability of dry matter ($P < 0.05$); using the three most strongly correlated predictive values—potential gas production and gas production at 24 and 36 h—as predictors, prediction models for effective degradability of dry matter were established, with coefficients of determination (R^2) of 0.553, 0.613, and 0.612, respectively. 2) In the correlation analysis between routine nutritional component contents and effective degradability of dry matter, effective degradability of dry matter was significantly negatively correlated with neutral detergent fiber (NDF) content ($P < 0.05$) and extremely significantly negatively correlated with acid detergent fiber (ADF) content ($P < 0.01$); simple and multiple prediction models were established for predicting feed effective degradability of dry matter using ADF and NDF contents, with the multiple prediction model [EDIVDMD=88.481-0.484ADF-0.231NDF ($P < 0.01$) (EDIVDMD is effective degradability of dry matter)] having the highest R^2 of 0.855. In conclusion,

the in vitro gas production method can replace the nylon bag method for predicting the effective degradability of dry matter of common concentrate feeds for meat sheep, enabling rapid, reasonable, and effective evaluation of feed degradability; the method of using fiber content in feeds to predict the degradability of other major nutrients in the rumen is practical and feasible.

Full Text

Correlation Analysis Between in Vitro Gas Production and Effective Degradation Rate of Common Concentrates for Mutton Sheep in Southern Xinjiang

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Abstract: This study analyzed the correlation between in vitro gas production and effective degradation rate of common concentrates for mutton sheep in southern Xinjiang to identify a simple evaluation method for the effective degradation rate of dry matter. Six protein feedstuffs and seven energy feedstuffs commonly used for mutton sheep in southern Xinjiang were selected as experimental materials. Gas production (GP) and effective degradation rate of dry matter were measured using the in vitro gas production method and continuous artificial rumen fermentation method. The correlation between GP and effective degradation rate was analyzed, along with the effects of conventional nutrient components on effective degradation rate. Prediction models for effective degradation rate based on GP and conventional nutrients were established. The results showed that: (1) Potential GP and GP at 8, 16, 24, 36, and 48 h were positively correlated with effective degradation rate of dry matter ($P < 0.05$). Using the three most strongly correlated predictors—potential GP, GP at 24 h, and GP at 36 h—prediction models for effective degradation rate were established with coefficients of determination (R^2) of 0.553, 0.613, and 0.612, respectively. (2) In the correlation analysis between conventional nutrient contents and effective degradation rate, effective degradation rate showed a significant negative correlation with neutral detergent fiber (NDF) content ($P < 0.05$) and a highly significant negative correlation with acid detergent fiber (ADF) content ($P < 0.01$). Single-factor and two-factor prediction models for effective degradation rate were established based on ADF and NDF contents. The two-factor model [EDIVDMD = 88.481 - 0.484ADF - 0.231NDF ($P < 0.01$) (EDIVDMD represents effective degradation rate of dry matter)] achieved the highest R^2 of 0.855. In conclusion, the in vitro gas production method can

replace the nylon bag method for predicting effective degradation rate of dry matter in common concentrates for mutton sheep, enabling rapid, reasonable, and effective evaluation of feed degradation characteristics. Using fiber content to predict the ruminal degradation rate of other major nutrients is also feasible.

Keywords: in vitro gas production; continuous artificial rumen fermentation; gas production; effective degradation rate of dry matter; concentrate; prediction model

Introduction

The Xinjiang Uygur Autonomous Region covers one-sixth of China's total land area. The area south of the Tianshan Mountains, known as southern Xinjiang, spans approximately 1.08 million km² and is the primary settlement region for Muslim populations. Unique geographical conditions and cultural traditions have shaped a livestock production structure dominated by cattle and sheep farming, which holds significant importance in the implementation of China's "Belt and Road" initiative. Southern Xinjiang lies in a warm temperate zone with a typical continental climate, representing an inland arid and windy region. While abundant sunlight and heat resources, large diurnal temperature variations, and a long frost-free period favor crop growth, severe land salinization limits crop diversity, leading to forage shortages that constrain local animal husbandry development. Therefore, the development and evaluation of concentrate and roughage resources for mutton sheep in southern Xinjiang are essential.

Due to the unique rumen environment of ruminants, evaluating the nutritional value of single concentrate feeds often involves adverse reactions such as rumen acidosis, presenting a challenge for researchers. Recent studies have addressed this issue. Zhao Jiangbo used the substitution method to evaluate wheat digestion and utilization in the rumen, demonstrating the feasibility of this approach for assessing the nutritional value of single concentrate ingredients for mutton sheep and determining appropriate substitution levels. Wu Duanqin conducted digestion-metabolism trials, in vitro gas production experiments, and Cornell Net Carbohydrate-Protein System (CNCPs) measurements on various concentrate feeds for sheep, showing strong correlation between in vitro predicted and in vivo measured effective energy values, enabling rapid and effective prediction of feed energy values. Norman et al. compared in vitro methods (pepsin-cellulase and gas production) with the semi-in vivo nylon bag method for measuring organic matter degradation of 11 Australian native perennial shrubs, finding that in vitro gas production showed the strongest correlation with in vivo organic matter degradation ($R^2 = 0.904$), while pepsin-cellulase prediction accuracy was relatively poor. Ren Peng et al. measured protein degradation rates of six oilseed meals using continuous rumen fermentation, achieving better stability than the nylon bag method with an average coefficient of variation of 2.7% and high correlation with nylon bag results ($R^2 = 0.99$). This study combined conventional nutrient analysis, in vitro gas production, and continuous artificial rumen fermentation methods to analyze six protein feedstuffs and seven energy

feedstuffs, measuring conventional nutrient contents, gas production at various time points, and effective degradation rate of dry matter (DM). Prediction models were established using gas production and conventional nutrients to predict effective degradation rate, providing a theoretical basis for exploring simpler and more practical methods for evaluating concentrate quality and rationally utilizing feed resources in southern Xinjiang.

Materials and Methods

1.1 Experimental Materials

Thirteen concentrate feedstuffs were selected for this experiment, including six protein feedstuffs [soybean meal, cottonseed meal, corn dried distillers grains with solubles (DDGS), corn gluten meal, fish meal, and chicken meal] and seven energy feedstuffs (chrysanthemum meal, corn, sprayed corn husk, unsprayed corn husk, wheat bran, wheat middling, and wheat flour). All feed ingredients were collected from the Aksu region of Xinjiang.

1.2.1 Conventional Nutrient Analysis

Dry matter and crude ash contents were determined according to Zhang Liying's method. Crude protein (CP) content was measured using an automatic Kjeldahl nitrogen analyzer, crude fat (EE) content using an automatic fat analyzer, and neutral detergent fiber (NDF) and acid detergent fiber (ADF) contents using Van Soest's method. Calcium and phosphorus contents were referenced from the "Chinese Feed Composition and Nutritional Value Table" (25th edition, 2014).

1.2.2 In Vitro Gas Production Test

Rumen culture fluid preparation: Artificial rumen fluid was prepared using Menke et al.'s method. Three healthy Duolang sheep weighing (30 ± 1.5) kg and fitted with permanent rumen fistulas were used as rumen fluid donors. Rumen fluid was collected 1 h before morning feeding, filtered through four layers of gauze into a pre-warmed 39°C thermos flask, and quickly transported to the laboratory. Artificial rumen fluid consisted of trace element solution (Solution A), buffer solution (Solution B), macro element solution (Solution C), resazurin solution, and reducing agent solution. Artificial rumen fluid and rumen fluid were mixed at a 2:1 ratio as the in vitro rumen culture fluid.

In vitro fermentation procedure: Fourteen concentrate feedstuff samples (two replicates per sample) were weighed and placed in clean gas production bottles after grinding and sieving, with two blank samples prepared simultaneously. Bottles containing samples were placed in a constant temperature shaker for incubation and connected to an in vitro gas production monitoring system (ANKOM RFS gas production measurement system). Data were recorded every 0.5 h for 48 h. For statistical analysis, 24 time points at even integer intervals from 2 to 48 h were selected.

1.2.3 Continuous Artificial Rumen Fermentation Test

The preparation of in vitro rumen culture fluid was the same as described in section 1.2.2.

Sample preparation: Weighed samples were placed in nylon bags using paper strips, tied tightly with nylon string, and weighed. Blank samples (nylon bags without feed) were prepared simultaneously. Samples were then dried in an oven at 60°C.

Sample distribution and incubation: Incubation time points were set at 2, 4, 8, 16, 24, 36, and 48 h. Four fermentation bottles were numbered 1-4. Bottle 1 contained nylon bags for 2 and 48 h, bottle 2 for 4 and 36 h, bottle 3 for 8 and 36 h, and bottle 4 for 16 h. Fermentation jars were preheated in a rumen in vitro simulation device (ANKOM Daisy automatic in vitro incubator). Each fermentation bottle received 1,200 mL of prepared in vitro rumen culture fluid, followed by CO₂ flushing for approximately 30 s before sealing and transferring to the artificial rumen incubator.

Nylon bag removal and processing: After placing nylon bags in the incubator, incubation time was recorded. At each time point, corresponding nylon bags were removed, immersed in ice water, and immediately rinsed with tap water. During rinsing, bags were gently squeezed by hand until the water ran clear, taking care to prevent loss of residues. Washed nylon bags (with residues) were dried to constant weight in a 60°C oven and weighed to 0.0001 g precision.

1.3.1 In Vitro Gas Production Test Calculations

Gas production parameters were calculated based on Ørskov et al.'s model: $GP = a + b(1 - e^{-ct})$, where GP is gas production at time t (mL/g), a is gas production from the rapidly fermentable fraction (mL/g), b is gas production from the slowly fermentable fraction (mL/g), c is gas production rate (%/h), and a+b is potential gas production (mL/g). Values for a, b, and c were calculated using the NLIN (Nonlinear regression) procedure in SAS 9.3 software.

1.3.2 Continuous Artificial Rumen Fermentation Test Calculations

The degradation rate of dry matter at different time points was calculated using the formula: $A = 100 \times (B - C)/B$, where A is the disappearance rate of DM at a given time point (%), B is the DM content in the sample (%), and C is the DM content in the nylon bag residue (%).

Effective degradation rates of DM at various time points and overall effective degradation rate were calculated using Ørskov et al.'s rumen kinetic model: $dP = a + b(1 - e^{-ct})$ and $ED = a + bc/(k + c)$, where dP is the degradation rate of DM at time t (%), a is the rapidly degradable fraction content (%), b is the slowly degradable fraction content (%), c is the degradation rate of the slowly degradable fraction (%/h), t is rumen incubation time (h), ED is effective

degradation rate (%), and k is rumen outflow rate, which was set at 0.0221%/h in this experiment.

1.4 Statistical Analysis

All data were initially processed using Excel 2016. Significance testing was performed using one-way ANOVA in SAS 9.3 software. Duncan's multiple comparison test was used to identify differences, with $P < 0.05$ indicating significant difference and $P > 0.05$ indicating no significant difference. After organizing data from in vitro gas production and continuous artificial rumen fermentation tests, Pearson correlation analysis and linear regression analysis were conducted using SPSS 22.0.

Results

The conventional nutrient contents of the six protein feedstuffs and seven energy feedstuffs are presented in and , respectively.

2.1 Gas Production and Parameters of Protein Feedstuffs

As shown in , gas production from all six protein feedstuffs increased over time. At 2 h, gas production varied considerably among feedstuffs. At 48 h, differences were significant ($P < 0.05$), with soybean meal showing the highest gas production (87.44 mL/g) and chicken meal the lowest (39.75 mL/g). Cottonseed meal gas production was not significantly different from soybean meal at 4 h ($P > 0.05$), stabilized after 36 h, and reached 63.64 mL/g at 48 h, ranking second and similar to corn gluten meal. DDGS showed significantly lower gas production at 2 h (19.78 mL/g) compared to corn gluten meal, soybean meal, cottonseed meal, and fish meal ($P < 0.05$), but reached 54.78 mL/g at 48 h. Fish meal and chicken meal produced 49.51 and 39.75 mL/g at 48 h, respectively.

presents the gas production parameters of the six protein feedstuffs. Potential gas production ranked from highest to lowest as: soybean meal (81.00 mL/g), cottonseed meal (54.66 mL/g), DDGS (54.10 mL/g), corn gluten meal (53.77 mL/g), fish meal (41.38 mL/g), and chicken meal (33.98 mL/g). Gas production rate ranked as: fish meal > cottonseed meal > corn gluten meal > chicken meal > DDGS > soybean meal.

2.2 Gas Production and Parameters of Energy Feedstuffs

As shown in , gas production from all seven energy feedstuffs increased over time. Chrysanthemum meal produced 43.38 mL/g at 2 h and reached 107.66 mL/g at 48 h, significantly higher than the other six energy feedstuffs at all time points ($P < 0.05$). Wheat bran produced 15.33 mL/g at 2 h and 60.53 mL/g at 48 h, significantly lower than the other six energy feedstuffs ($P < 0.05$). Wheat flour produced 30.43 mL/g at 2 h, reached 83.90 mL/g at 8 h, and gradually stabilized thereafter, with the greatest increase occurring during the first 6 h. Corn showed

significantly higher gas production than the other six energy feedstuffs at 24 h ($P < 0.05$), reaching 95.62 mL/g before stabilizing.

shows the gas production parameters of the seven energy feedstuffs. Potential gas production ranked from highest to lowest as: chrysanthemum meal (101.50 mL/g), corn (96.76 mL/g), wheat flour (87.32 mL/g), sprayed corn husk (83.65 mL/g), unsprayed corn husk (82.67 mL/g), wheat middling (76.97 mL/g), and wheat bran (60.04 mL/g). Gas production rate ranked as: wheat flour > wheat bran and wheat middling > corn > chrysanthemum meal and sprayed corn husk > unsprayed corn husk.

2.3 Dry Matter Degradation Rate of Protein Feedstuffs

As shown in , soybean meal had significantly higher DM degradation rates than other protein feedstuffs at all time points ($P < 0.05$), except at 4 h where it did not differ significantly from corn gluten meal ($P > 0.05$), reaching 97.79% at 48 h. Chicken meal had significantly lower DM degradation rates than the other five plant protein feedstuffs at all time points ($P < 0.05$), reaching 32.67% at 48 h, second only to fish meal at 54.54%. The effective degradation rates of DM for the six protein feedstuffs ranked as: soybean meal > corn gluten meal > DDGS > cottonseed meal > fish meal > chicken meal.

2.4 Dry Matter Degradation Rate of Energy Feedstuffs

As shown in , chrysanthemum meal had the lowest DM degradation rate at 48 h (74.16%). Corn DM degradation rate increased rapidly during the first 6 h, reaching 88.44% at 24 h before stabilizing. Sprayed and unsprayed corn husks showed continuous substantial increases in DM degradation rate over time, reaching 90.88% and 89.07% at 48 h, respectively. Wheat middling reached 80.24% DM degradation at 36 h. Wheat flour DM degradation rates at 36 and 48 h (90.65% and 90.91%) did not differ significantly from sprayed corn husk at the same time points ($P > 0.05$) but were significantly higher than the other six energy feedstuffs at all other time points ($P < 0.05$). The effective degradation rates of DM for the seven energy feedstuffs ranked as: wheat flour > sprayed corn husk > corn > wheat middling > wheat bran > unsprayed corn husk > chrysanthemum meal.

2.5 Correlation Analysis Between Gas Production and Effective Degradation Rate

As shown in , GP at 8 h showed a significant positive correlation with effective degradation rate of DM ($P < 0.05$), while GP at 16, 24, 36, and 48 h and potential GP showed highly significant positive correlations ($P < 0.01$). The strongest correlation was with GP at 24 h [correlation coefficient (R) = 0.783], followed by GP at 36 h (R = 0.782) and potential GP (R = 0.744).

Prediction equations for effective degradation rate using GP at 24, 36, and 48 h are presented in . All three predictors yielded valid prediction models, with

GP at 24 h being the best predictor ($R^2 = 0.613$), followed by GP at 36 h ($R^2 = 0.612$) and potential GP ($R^2 = 0.553$).

2.6 Correlation Analysis Between Conventional Nutrients and Effective Degradation Rate

As shown in , effective degradation rate of DM was significantly negatively correlated with NDF content ($R = -0.852$) and highly significantly negatively correlated with ADF content ($R = -0.880$).

Prediction equations for effective degradation rate based on conventional nutrient contents are presented in . Both ADF and NDF contents could predict effective degradation rate, with R^2 increasing as more predictors were included. The best single predictor was ADF content ($R^2 = 0.775$), while the two-factor model using both ADF and NDF contents achieved an R^2 of 0.855.

Discussion

3.1 In Vitro Fermentation Characteristics of Single Protein Feedstuffs

The results showed that gas production and effective degradation rate of DM for all six protein feedstuffs increased over time to varying degrees. Although animal protein feedstuffs (chicken meal and fish meal) had significantly higher CP and EE contents than the four plant protein feedstuffs, their in vitro gas production and effective degradation rates were lower, attributed to the natural rumen bypass protein supplement characteristics of animal protein feedstuffs. Li Yuanfei et al. reported that soybean meal had significantly higher 48 h gas production and DM degradation rate than other oilseed meals, consistent with our findings that soybean meal had the highest potential gas production and effective degradation rate. Kong Ping et al. reported effective degradation rates of corn gluten meal in sheep rumen of 72.86% and 59.66%, lower than our results, possibly due to differences in experimental animals and methods. Li Xiaoyan measured effective degradation rates of DDGS and cottonseed meal at 50.04% and 46.82%, respectively, with no significant difference between them, which differs substantially from our significantly different results (74.86% and 63.62%). These discrepancies may primarily stem from differences in rumen fluid donor sheep breeds, experimental methods, and feed ingredient origins. Although the ranking of potential gas production for corn gluten meal, DDGS, and cottonseed meal differed from their effective degradation rates, the differences in potential gas production among these three feedstuffs were not significant, consistent with Zhang Wenlu et al.'s conclusion that in vitro gas production is highly positively correlated with in vivo DM degradation rate.

3.2 In Vitro Fermentation Characteristics of Single Energy Feedstuffs

The seven energy feedstuffs used in this experiment could be divided into three categories: (1) corn and its by-products (corn, sprayed corn husk, unsprayed

corn husk); (2) bran-type energy feedstuffs (wheat bran, wheat middling, wheat flour); and (3) chrysanthemum meal. In the first category, corn husk is a by-product of corn processing and serves as a high-quality feed resource with amino acid content far exceeding that of corn. Sprayed corn husk had the highest effective degradation rate among the three, mainly because its soaking solution is rich in protein and minerals that substantially increase nutrient content. In the second category, wheat flour had moderate nutrient contents and gas production among the seven energy feedstuffs, but its high gas production rate resulted in significantly higher effective degradation rate than other ingredients. Su Huawei et al. added 6% inexpensive wheat flour to whole milk for Holstein bull calves after 35 days of age, finding that although wheat flour somewhat reduced feed digestibility, it improved growth performance, slaughter performance, and meat quality while reducing production costs. Thus, appropriate wheat flour supplementation offers good nutritional value and economic benefits for young ruminants. Chrysanthemum meal, a regional unconventional energy feedstuff, had lower CP content similar to corn but significantly higher other nutrient contents than the remaining six energy feedstuffs, with NDF and ADF contents of 46.12% and 29.21%, respectively. Liu Jie noted that higher NDF content indicates higher dietary structural carbohydrate content and lower readily digestible non-structural carbohydrate content, reducing rumen microbial utilization of nutrients. This explains why chrysanthemum meal had high potential gas production but lower effective degradation rate than the other six energy feedstuffs.

3.3 Correlation Analysis Between Gas Production and Effective Degradation Rate of Concentrates

Gas production over time reflects feed digestion and utilization by rumen microbes, representing feed nutritional value. Pan Meijuan et al. analyzed correlations between *in vitro* gas production and nylon bag methods using three total mixed rations with different roughage combinations, finding significant positive correlation between *in vitro* gas production and *in vivo* effective degradation rate, suggesting the gas production method could replace the nylon bag method. Hong Jinsuo et al. evaluated local oat hay from Qinghai using both methods, obtaining a correlation coefficient of 0.98, indicating that *in vitro* gas production can replace the nylon bag method for evaluating rumen fermentation characteristics of roughages. Ren Peng et al. measured rumen effective degradation rates of six oilseed meals, finding that continuous fermentation showed better repeatability and stability than the nylon bag method (average coefficient of variation of 2.7%) with R^2 as high as 0.99, demonstrating that continuous artificial rumen fermentation can replace the semi-*in vivo* nylon bag method for measuring effective degradation rate, offering advantages for large-scale feed evaluation, improved efficiency, and better utilization of fistulated animals. Our correlation analysis between gas production and effective degradation rate for six protein and seven energy feedstuffs showed high correlation, similar to previous studies, confirming that among various methods for evaluating rumen effective

degradation rate of single concentrates, the in vitro gas production method is rapid, simple, effective, and low-cost, warranting promotion and application.

3.4 Correlation Analysis Between Conventional Nutrient Contents and Effective Degradation Rate of Concentrates

Nsahlai et al. found that gas production was significantly negatively correlated with NDF content and positively correlated with CP content in Sesbania forages. Ru Caixia reported that effective degradation rate of DM was significantly positively correlated with CP content. Chen Xiaolin established a prediction equation using the nylon bag method: effective degradation rate of DM = $92.6665 + 0.1135\text{CP} - 0.6366\text{NDF} - 0.3506\text{ADF}$ ($R^2 = 0.85$), indicating positive correlation with CP and negative correlation with NDF and ADF. Guo Chunyan et al. found that concentrates with high CP and low crude fiber produced more gas, while those with low CP and high crude fiber produced less gas. Our results are generally consistent with these findings, showing significant negative correlations between effective degradation rate and NDF and ADF contents. However, unlike previous studies, we found no significant correlation between effective degradation rate and CP content, possibly because the large difference in protein content between energy and protein feedstuffs affected the analysis results.

Conclusion

The in vitro gas production method can replace the nylon bag method for predicting effective degradation rate of dry matter in feedstuffs, enabling rapid, reasonable, and effective evaluation of feed degradation performance. Using fiber content to predict the ruminal degradation rate of other major nutrients is a feasible approach.

References

- [1] ZHANG Xiaoyan. Research on sustainable development of characteristic agriculture in southern Xinjiang[D]. Master's thesis. Wuhan: Central China Normal University, 2008.
- [2] LI Bing. Research on coordinated development of regional ecological environment and economy in southern Xinjiang[D]. Master's thesis. Alar: Tarim University, 2015.
- [3] LIANG Yusheng, LI Fadi, LI Fei. Analysis of rumen adaptation mechanisms in ruminants under high-concentrate diets[J]. Chinese Journal of Animal Nutrition, 2016, 28(1): 20-26.
- [4] ZHAO Jiangbo. Study on prediction model of metabolic energy for mutton sheep concentrates[D]. Master's thesis. Lanzhou: Gansu Agricultural University, 2016.
- [5] WU Duanqin. Study on nutritional value evaluation and effective energy prediction models of several concentrate feedstuffs for sheep using CNCPS[D].

- Master' s thesis. Daqing: Heilongjiang Bayi Agricultural University, 2009.
- [6] NORMAN H C, REVELL D K, MAYBERRY D E, et al. Comparison of in vivo organic matter digestion of native Australian shrubs by sheep to in vitro and in sacco predictions[J]. *Small Ruminant Research*, 2010, 91(1): 69-80.
- [7] REN Peng, FENG Yanglian. Study on evaluation of dry matter and protein degradation rates of ruminant feedstuffs by continuous in vitro fermentation[J]. *Chinese Journal of Animal Nutrition*, 1989, 1(1): 16-17.
- [8] ZHANG Liying. Feed analysis and feed quality detection technology[M]. Beijing: China Agricultural University Press, 2003.
- [9] VAN SOEST P J. Development of a comprehensive system of feed analyses and its application to forages[J]. *Journal of Animal Science*, 1967, 26(1): 119-128.
- [10] MENKE K H, RAAB L, SALEWSKI A, et al. The estimation of the digestibility and metabolizable energy content of ruminant feeding stuffs from the gas production when they are incubated with rumen liquor in vitro[J]. *The Journal of Agricultural Science*, 1979, 93(1): 217-222.
- [11] ØRSKOV E R, MCDONALD I. The estimation of protein degradability in the rumen from incubation measurements weighted according to rate of passage[J]. *The Journal of Agricultural Science*, 1979, 92(2): 499-503.
- [12] DIAO Qiyu. Animal protein nutrition for ruminants[J]. *Grass-Feeding Livestock*, 1990(6): 32-35.
- [13] LI Yuanfei, HAO Jianxiang, MA Yanyan, et al. Evaluation of nutritional value of different feed types by in vitro rumen fermentation[J]. *Chinese Journal of Animal Nutrition*, 2013, 25(10): 2403-2413.
- [14] KONG Ping, CHEN Aodong, ZHAO Weili, et al. Evaluation and analysis of degradation kinetics of corn gluten meal and soybean meal in ruminant rumen[J]. *Acta Agriculturae Boreali-occidentalis Sinica*, 2014, 23(11): 30-34.
- [15] LI Xiaoyan. Study on evaluation of feed nutritional value for Shanbei white cashmere goats using NRC and CNCPS systems[D]. Master' s thesis. Yangling: Northwest A&F University, 2013.
- [16] ZHANG Wenlu, LI Jie, LYU Yuanxun. Correlation analysis between in vitro gas production and nylon bag methods for evaluating roughage dry matter degradation rate[J]. *Feed Industry*, 2009, 30(7): 30-32.
- [17] LIN Qian, DAI Qiuzhong, JIANG Guitao, et al. Nutritional value evaluation of corn and its processing by-products[J]. *China Feed*, 2013(4): 18-21.
- [18] SU Huawei, LIU Danli, CAO Binghai, et al. Effects of adding wheat flour to whole milk on slaughter performance and meat quality of Holstein bull calves[J]. *Journal of China Agricultural University*, 2008, 13(6): 66-70.
- [19] LIU Jie. Study on prediction models of metabolic energy and metabolic protein for mutton sheep feedstuffs[D]. Doctoral thesis. Beijing: Chinese Academy of Agricultural Sciences, 2012.
- [20] TAO Chunwei. Evaluation of nutritional value of common roughages for ruminants and establishment of effective energy prediction models[D]. Master' s thesis. Daqing: Heilongjiang Bayi Agricultural University, 2009.
- [21] PAN Meijuan, XU Guozhong, XU Xiaoming, et al. Correlation analysis between in vitro gas production and nylon bag methods for evaluating TMR dry

- matter degradation rate with different roughage combinations[C]//Proceedings of the 5th China Dairy Conference. Xi' an: China Dairy Conference, 2014.
- [22] HONG Jinsuo, LIU Shujie, CHAI Shatuo, et al. Evaluation of nutritional value of local oat hay from Qinghai using in vitro gas production and nylon bag methods[J]. China Animal Husbandry and Veterinary Medicine, 2009, 36(3): 36-38.
- [23] NS AHLAI I V, SIAW D E K A, OSUJI P O. The relationships between gas production and chemical composition of 23 browses of the genus Sesbania[J]. Journal of the Science of Food and Agriculture, 1994, 65(1): 13-20.
- [24] RU Caixia, ZAN Linsen, MA Shanhong. Study on degradation rates of dry matter and neutral detergent fiber of five roughages under simulated rumen conditions[J]. Chinese Journal of Animal Science, 2006, 42(11): 42-44.
- [25] CHEN Xiaolin. Study on nutritional value and rumen degradation characteristics of common roughages for mutton sheep[D]. Master' s thesis. Qingdao: Qingdao Agricultural University, 2014.
- [26] GUO Chunyan, YAN Yunfeng, MA Quanlei, et al. Evaluation of nutritional value of four concentrates based on in vitro rumen gas production[J]. Heilongjiang Animal Science and Veterinary Medicine, 2016(11): 148-150.

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