Postprint: Evaluation of the Feeding Value of Sugarcane Tops for Meat Sheep

Authors: Wang Shiqin, Zhang Naifeng, Deng Kaidong, Jiang Chenggang, Diao Qiyu

Date: 2018-12-24T00:00:00+00:00

Abstract

This study evaluated the feeding value of sugarcane tops in meat sheep through three aspects: conventional nutrient composition analysis, in situ trial, and in vivo digestion trial. The in situ trial utilized three Dorper × Small-tailed Han F1 adult wethers fitted with permanent rumen fistulas to determine the ruminal degradation characteristics of main nutrients in sugarcane tops using the nylon bag technique. The in vivo digestion trial employed six Dorper × Small-tailed Han F1 adult rams with a body weight of (67.0±5.1) kg. The preliminary period lasted 10 d, and the formal experimental period lasted 6 d, during which sugarcane tops were fed ad libitum. Dry matter intake (DMI) and apparent digestibility of nutrients were measured using the total fecal collection method. The results showed: 1) The contents of gross energy (GE), crude protein (CP), ether extract (EE), neutral detergent fiber (NDF), acid detergent fiber (ADF), ash (Ash), calcium (Ca), and phosphorus (P) in sugarcane tops [on a dry matter (DM) basis] were 16.58 MJ/kg, 7.26%, 1.23%, 68.15%, 34.54%, 7.02%, 0.52%, and 0.14%, respectively; 2) The effective degradability of DM, OM, CP, NDF, and ADF of sugarcane tops in the rumen of meat sheep was 45.53%, 44.14%, 49.33%, 33.02%, and 35.26%, respectively; 3) The DMI of sugarcane tops by meat sheep was 942.95 g/d, accounting for 1.39% of body weight, and the potential intake capacity of sugarcane tops was 39.98 g/(kg W0.75d); 4) The digestible energy of sugarcane tops for meat sheep was 8.32 MJ/kg; 5) The apparent digestibility of DM, OM, CP, EE, NDF, ADF, Ca, and P of sugarcane tops in meat sheep was 52.48%, 54.17%, 50.96%, 55.84%, 54.83%, 47.57%, 8.79%, and 0.84%, respectively, with a nitrogen retention rate of 20.09% and a biological value of nitrogen of 38.68%; 6) The forage grading index of sugarcane tops was 1.16, belonging to Grade 4. These results indicate that sugarcane tops can be consumed and utilized by meat sheep and are classified as a medium-quality roughage. It is recommended that when formulating diets for meat sheep, consideration should be given to the characteristics of low CP

content and high fiber content of sugarcane tops, as well as supplementation of Ca and P.

Full Text

Feeding Value Assessment of Sugarcane Tops and Leaves in Mutton Sheep

WANG Shiqin[1], ZHANG Naifeng[1], DENG Kaidong[2], JIANG Chenggang[1], DIAO Qiyu[1]*

[1]Key Laboratory of Feed Biotechnology of the Ministry of Agriculture, Feed Research Institute, Chinese Academy of Agricultural Sciences, Beijing 100081, China
[2]College of Animal Science and Technology, Jinling Institute of Technology, Nanjing 210038, China

Abstract

This study evaluated the feeding value of sugarcane tops and leaves in mutton sheep through three approaches: conventional nutrient composition analysis, in situ (semi-in vivo) trials, and in vivo digestion experiments. The in situ trial utilized three Dorper × Small-tailed Han F adult wethers fitted with permanent rumen fistulas to determine ruminal degradation characteristics of major nutrients in sugarcane tops and leaves using the nylon bag technique. The in vivo digestion trial employed six Dorper × Small-tailed Han F adult rams with a body weight of (67.0±5.1) kg. Following a 10-day adaptation period, a 6-day formal trial was conducted with ad libitum feeding of sugarcane tops and leaves. Dry matter intake (DMI) and nutrient apparent digestibility were measured using the total feces collection method. The results showed that: 1) The gross energy (GE) and contents of crude protein (CP), ether extract (EE), neutral detergent fiber (NDF), acid detergent fiber (ADF), crude ash (Ash), calcium (Ca), and phosphorus (P) on a dry matter (DM) basis were 16.58 MJ/kg, 7.26%, 1.23%, 68.15%, 34.54%, 7.02%, 0.52%, and 0.14%, respectively; 2) The ruminal effective degradability of DM, OM, CP, NDF, and ADF in mutton sheep were 45.53%, 44.14%, 49.33%, 33.02%, and 35.26%, respectively; 3) The DMI of sugarcane tops and leaves by mutton sheep was 942.95 g/d, accounting for 1.39% of body weight, with an intake potential of 39.98 g/(kg W · ·d); 4) The digestible energy of sugarcane tops and leaves for mutton sheep was 8.32 MJ/kg; 5) The apparent digestibility of DM, OM, CP, EE, NDF, ADF, Ca, and P in mutton sheep were 52.48%, 54.17%, 50.96%, 55.84%, 54.83%, 47.57%, 8.79%, and 0.84%, respectively, with a nitrogen retention rate of 20.09% and a nitrogen biological value of 38.68%; 6) The roughage grading index of sugarcane tops and leaves was 1.16, classifying it as Grade 4. These results indicate that sugarcane tops and leaves can be consumed and utilized by mutton sheep and are considered a medium-quality roughage. When formulating diets for mutton sheep, consideration should be given to the low CP content and high fiber

characteristics of sugarcane tops and leaves, as well as the need for Ca and P supplementation.

Keywords: mutton sheep; sugarcane tops and leaves; feeding value; ruminal degradability; apparent digestibility; digestible energy

1 Materials and Methods

1.1 Sample Collection and Preparation

Sugarcane tops and leaves samples were collected in August 2016 from a sugarcane plantation base operated by Jintaifeng Agriculture and Animal Husbandry Technology Co., Ltd. in Wuxuan County, Guangxi Province. Fresh sugarcane tops and leaves (the top 2–3 tender nodes and green leaves) were harvested after sugarcane maturation, naturally sun-dried, and approximately 500 kg was collected. The material was chopped into 1–2 cm segments using a forage chopper. About 10 kg was collected for conventional nutrient composition analysis and in situ trials, while the remainder was used for animal feeding experiments. The 10 kg sample was ground to a particle size of 2.5 mm, then divided into 2.5 kg portions using the quartering method. One portion was used for the in situ trial, while the other was ground through a 40-mesh sieve for chemical analysis.

1.2 Conventional Nutrient Composition Analysis

Gross energy (GE) was determined using an oxygen bomb calorimeter (Parr 6400, USA). Dry matter (DM), organic matter (OM), crude ash (Ash), calcium (Ca), and phosphorus (P) contents were measured according to Zhang Liying' s methods. Crude protein (CP) content was determined using an automatic Kjeldahl nitrogen analyzer (kdy-9830, China), and ether extract (EE) content was measured using an automatic fat analyzer (ANKOM XT15, USA). Neutral detergent fiber (NDF) and acid detergent fiber (ADF) contents were analyzed using the Van Soest method.

1.3 In Situ Trial

1.3.1 Experimental Animals and Management Three Dorper × Small-tailed Han F adult wethers with a body weight of (67.0±1.2) kg, fitted with permanent rumen fistulas, were used in this experiment. The animals were adapted for 2 weeks prior to the trial. Each sheep was housed individually and fed a diet at 1.3 times the NRC maintenance requirement level, with a concentrate-to-forage ratio of 4:6. Feed was provided twice daily at 08:00 and 18:00, with additional hay offered at 12:00. Water was available ad libitum. The diet composition and nutrient levels are presented in Table 1 .

1.3.2 Nylon Bag Technique for Ruminal Degradation Characteristics Following the method of Chen Xiaolin et al., nylon cloth with a mesh size of 300

mesh (0.05 mm) was cut into 12 cm × 8 cm pieces, folded in half, and sewn with double seams using fine polyester thread to create 8 cm × 6 cm nylon bags. The edges were singed with an alcohol lamp to prevent fraying. Approximately 2 g of test sample was accurately weighed into each nylon bag, with two replicates per time point. Two nylon bags were attached to a semi-flexible plastic tube approximately 20 cm long with an opening at one end, which was inserted into the ventral sac of the rumen using a thin wooden stick. The other end of the tube was secured to the fistula plug with nylon rope. Incubation times in the rumen were 0, 12, 24, 36, 48, and 72 hours. Bags were placed in the rumen 1 hour before morning feeding and removed at the same time on the final day. Upon removal, bags were immediately placed in cold water to stop fermentation, then rinsed with tap water until the rinse water was clear. Washed bags were dried in a 65°C oven for 48 hours to constant weight, conditioned for 24 hours, and the residues from the two replicate bags at each time point were combined and stored in sealed bags for later analysis.

1.3.3 Calculation of Degradation Parameters and Effective Degradability 1.3.3.1 Degradation Rate at Different Time Points

The degradation rate at each time point was calculated as:

$$A(\%) = [(B–C)/B] \times 100$$

where A is the degradation rate (%) of DM or CP in the test feed at a given ruminal incubation time, B is the DM or CP content (g) in the test sample, and C is the DM or CP content (g) in the nylon bag residue.

1.3.3.2 Degradation Parameters and Effective Degradability

Degradation parameters and effective degradability were calculated using the rumen kinetic mathematical model proposed by Ørskov et al.:

$$dP = a + b(1–e^{-ct})$$

$$ED = a + bc/(k + c)$$

where dP is the degradation rate (%) of DM or CP in the test feed at ruminal incubation time t (h); a is the rapidly degradable fraction (%); b is the slowly degradable fraction (%); c is the degradation rate of the slowly degradable fraction (%/h); ED is the effective degradability (%); and k is the rumen outflow rate (%/h), which was set at 0.031/h in this experiment.

1.4 In Vivo Digestion and Metabolism Trial

Six Dorper × Small-tailed Han F adult rams with a body weight of (67.0±5.1) kg were used, with six replicates (one sheep per replicate). Animals were ear-tagged, vaccinated with a triple vaccine, dewormed, and then moved into metabolism cages. The trial consisted of a 10-day adaptation period followed by a 6-day formal collection period. Sheep were fed sugarcane tops and leaves twice daily at 08:00 and 18:00, with ad libitum access to water. Daily feed allowance was adjusted to maintain refusals at approximately 15% of total feed offered. The DMI during the formal period was considered the voluntary intake of sugarcane tops and leaves. During the collection period, total feces and urine were collected using the total collection method, with daily feed offered and refusals recorded to calculate DMI. Fecal samples were collected at 10% of daily fecal output, pooled for each sheep over the 6 days, and stored at -20°C. Fecal samples were dried at 65°C for 48 hours, conditioned for 48 hours, weighed to determine DM content, ground through a 40-mesh sieve, and stored for nutrient and fecal nitrogen/energy analysis. Urine was collected in plastic buckets containing 100 mL of 10% H SO , diluted to 5 L to prevent uric acid precipitation, mixed thoroughly, filtered through gauze, and 20 mL was sampled daily. Urine samples were pooled for each sheep over 6 days and stored at -20°C for urine energy and nitrogen analysis. Initial and final body weights were recorded at the start and end of the formal period.

The following formulas were used for calculations:

- Apparent digestibility of a nutrient (%) = 100 × (amount of nutrient intake - amount of nutrient in feces) / amount of nutrient intake
- Nitrogen retention (g/d) = nitrogen intake - fecal nitrogen - urinary nitrogen
- Nitrogen retention rate (%) = 100 × nitrogen retention / nitrogen intake
- Nitrogen biological value (%) = 100 × nitrogen retention / absorbed nitrogen

1.5 Calculation of Roughage Grading Index

The roughage grading index (GI) of sugarcane tops and leaves was calculated according to the method specified in *Forage Nutritional Quality Assessment–GI Method* (GB/T 23387-2009):

$$Grading\ Index = Metabolizable\ Energy\ (MJ/kg) \times DMI\ (kg/d) \times CP\ (\%)/NDF\ (\%)$$

where metabolizable energy = digestible energy × 0.82 (digestible energy was measured in this experiment), DMI was the measured value corrected to a standard 40-kg sheep, and CP and NDF contents were measured values from this experiment.

1.6 Statistical Analysis

The nonlinear regression (NLIN) procedure in SAS 9.2 was used to obtain parameters a, b, and c in the rumen kinetic mathematical model.

---

2 Results

2.1 Conventional Nutrient Composition of Sugarcane Tops and Leaves

The conventional nutrient composition is presented in Table 2 . Sugarcane tops and leaves contained 16.58 MJ/kg GE, 7.26% CP, 1.23% EE, 68.15% NDF, 34.54% ADF, 7.02% Ash, 0.52% Ca, and 0.14% P on a DM basis.

2.2 Ruminal Degradation Characteristics of Nutrients

As shown in Figure 1 [Figure 1: see original paper], the degradation rates of DM, OM, CP, NDF, and ADF in sugarcane tops and leaves increased over time. DM and OM degradation rates increased rapidly between 12–48 hours, reaching 56.62% and 55.48% at 48 hours, respectively, after which they plateaued. CP degradation increased rapidly between 6–24 hours, reaching 51.23% at 24 hours, then stabilized. The 48-hour degradation rates for NDF and ADF were both 45.90%.

The degradation parameters of nutrients in the rumen of mutton sheep are shown in Table 3 . The rapidly degradable fractions of DM, OM, CP, NDF, and ADF were 22.49%, 20.44%, 23.72%, 5.41%, and 7.65%, respectively. The undegradable fractions were 34.40%, 35.34%, 30.78%, 42.24%, and 44.21%, respectively. The effective degradability values were 45.53%, 44.14%, 49.33%, 33.02%, and 35.26%, respectively.

2.3 Apparent Digestibility of Nutrients in Mutton Sheep

The voluntary intake and apparent digestibility of nutrients from sugarcane tops and leaves are presented in Table 4 . Under ad libitum feeding conditions, DM and OM intake were 942.95 and 869.75 g/d, respectively, with apparent digestibility of 52.48% and 54.17%. EE intake was 12.78 g/d with an apparent digestibility of 55.84%. NDF and ADF intake were 710.85 and 360.22 g/d, respectively, with apparent digestibility of 54.83% and 47.57%. Ca and P intake were 5.38 and 1.46 g/d, respectively, with apparent digestibility of 8.79% and 0.84%.

Energy and nitrogen metabolism are shown in Table 5 . GE intake was 17.29 MJ/d with an apparent digestibility of 50.15%, resulting in a digestible energy value of 8.32 MJ/d from sugarcane tops and leaves. Nitrogen intake was 12.12 g/d, nitrogen retention was 2.51 g/d, nitrogen retention rate was 20.09%, and nitrogen biological value was 38.68%.

2.4 Roughage Grading Index

Based on the measured nutrient composition, voluntary intake, and digestible energy, the calculated roughage grading index for sugarcane tops and leaves was 1.16, classifying it as Grade 4.

---

3 Discussion

3.1 Conventional Nutrient Composition

Conventional nutrient composition forms the basis for evaluating feed nutritional value. The CP content of sugarcane tops and leaves measured in this study was 7.26%, similar to the 7% reported by Xiao Yi et al. and 7.06% reported by Gao Yufei et al. However, NDF and ADF contents were higher than those reported by Gao Yufei et al. (55.42% and 25.14%), while EE content was lower than their value (4.05%). Ash, Ca, and P contents were similar to their findings. These differences may be attributed to variations in harvest time, variety, and origin of the sugarcane tops and leaves. Compared with commonly used roughages for mutton sheep, the CP content of sugarcane tops and leaves was lower than alfalfa (14.3%–19.1%), similar to Leymus chinensis (7.0%), slightly higher than corn stover (5.0%) and soybean straw (5.0%), and higher than rice straw (4.0%) and wheat straw (3.0%). NDF and ADF contents were similar to Leymus chinensis (67% and 47%). These results demonstrate that sugarcane tops and leaves can provide protein and energy for ruminants and serve as a roughage source for mutton sheep.

3.2 Ruminal Degradation Characteristics

The in situ method is a rapid, inexpensive, and effective approach for evaluating the nutritional value of ruminant feeds. Its primary advantage is the integration of feed nutritional value assessment with rumen microbial activity. By analyzing the degradation rates and parameters of different feed nutrients in the rumen, this method can reflect the nutritional characteristics of feeds.

The ruminal degradation rate of DM indicates the ease of feed digestion. The degradation rate of sugarcane tops and leaves increased over time, reaching 56.60% at 48 hours and then stabilizing, consistent with the findings of Yang Shiping et al. The effective degradability of DM was 45.53%, higher than that of Leymus chinensis (31.59%) but lower than alfalfa (67.50%). The ruminal degradation of OM depends on plant structure and composition and is closely related to CP and fiber content. The degradation pattern of OM in sugarcane tops and leaves was similar to that of DM, primarily occurring within 6–48 hours, with effective degradability of 44.14%.

Protein ruminal degradability is a crucial indicator for evaluating the nutritional value or availability of ruminant feeds and represents a key determinant of feed

nutritional value. Feed protein degradation in the rumen depends primarily on fermentation difficulty, rumen retention time, and the composition and chemical characteristics of CP. The CP degradation rate of sugarcane tops and leaves increased rapidly between 6–24 hours, then stabilized, reaching 60.99% at 48 hours with an effective degradability of 49.33%.

NDF and ADF are fundamental components of plant cell walls with complex structures and compositions. The extent of fiber digestion in the rumen depends on the degree of lignification; higher lignification reduces microbial digestibility. In this study, NDF and ADF degradation rates were low during 0–6 hours but increased gradually over time, reaching 45.90% at 48 hours. The rapidly degradable fractions of NDF and ADF were low because fiber components have minimal solubility and require close attachment of rumen microbes to the substrate before digestion can occur, resulting in a lag phase. This lag phase caused minimal changes in NDF and ADF degradation rates during the initial digestion period, followed by gradual increases that plateaued after 48 hours, reaching 54.83% and 47.57% at 72 hours. The effective degradability of NDF and ADF was relatively low at 33.02% and 35.26%, respectively. The lower degradable components and effective degradability of NDF and ADF compared with DM, OM, and CP may be related to the difficulty of microbial digestion of NDF in sugarcane tops and leaves and potentially high lignification that limits microbial utilization.

3.3 Voluntary Intake

Intake is a primary factor determining forage quality and subsequently affecting livestock performance. Evaluating a feed crop should consider not only its yield but also its feeding value, which depends on animal intake and nutrient utilization. In vivo digestion trials represent a major method for studying nutrient utilization in animals and hold an important position in animal nutrition research. The total collection method directly measures feed intake and nutrient apparent digestibility in animals, accurately reflecting feeding value. Among factors affecting animal intake, feed palatability is a key evaluation criterion, and voluntary intake is a primary method for assessing palatability by comparing intake amounts of different feeds within a given time.

Under the conditions of this experiment, sheep DMI was 942.95 g/d, representing 1.39% of average body weight (67.64 kg). When expressed relative to metabolic body weight, the intake potential of sugarcane tops and leaves was 39.98 g/(kg W · ·d). Yuan Cuilin et al. estimated DMI values for alfalfa, Leymus chinensis, and corn stover silage at 91.05, 62.85, and 41.73 g/(kg W · ·d), respectively, all higher than that of sugarcane tops and leaves. Major factors influencing animal intake include individual animal differences and feed characteristics. Previous studies have identified low digestibility and low protein content as characteristics of sugarcane feeds. The relatively low intake of sugarcane tops and leaves by mutton sheep may be related to its fiber content and composition, as higher crude fiber content generally reduces palatability and intake.

3.4 Apparent Digestibility

Chemical composition analysis only indicates nutrient content but cannot reveal the extent to which nutrients can be digested and utilized by animals. After ingestion, feed is partially digested, absorbed, and utilized, while undigested residues are excreted as feces. Therefore, accurate determination of nutrient digestibility is essential. This study found apparent digestibility of DM, OM, NDF, and ADF to be 52.48%, 54.17%, 54.83%, and 47.57%, respectively, indicating that over half of the nutrients in sugarcane tops and leaves can be utilized by mutton sheep. Tang Zhenhua et al. fed water buffalo only sugarcane top silage and reported apparent digestibility values of 50.00%, 55.43%, 75.12%, and 60.76% for DM, OM, NDF, and ADF, respectively, with DM and OM digestibility similar to our results but higher NDF and ADF digestibility. However, Yu Mei et al. reported lower apparent digestibility values for DM, OM, NDF, and ADF (46.67%, 48.00%, 43.62%, and 40.24%) in adult water buffalo fed sugarcane top silage, and noted that concentrate supplementation improved intake and digestibility when sugarcane top silage was the basal diet. In sheep studies, when sugarcane top silage was the sole roughage with concentrate supplementation, Hainan black goats showed apparent digestibility of 59.54% and 56.03% for NDF and ADF, respectively. Differences in nutrient apparent digestibility may be related to animal species and processing methods of sugarcane tops and leaves. Sousa et al. noted that sugarcane feeds are characterized by high soluble sugars and low fiber digestibility, recommending silage to improve NDF digestibility. Further research is needed on effective methods to enhance the digestive utilization efficiency of sugarcane tops and leaves.

Calcium and phosphorus are essential macro-minerals for normal growth and development, primarily excreted through feces. The apparent digestibility of Ca and P from sugarcane tops and leaves was only 8.79% and 0.84%, respectively. The low apparent digestibility may be because sheep in this experiment consumed only sugarcane tops and leaves without additional Ca and P supplements, resulting in low intake of these minerals and influence from endogenous Ca and P excretion.

Energy is the foundation of all metabolic and productive activities in animals, and feed energy represents the source of nutrients for livestock, with partial energy loss during ingestion, digestion, absorption, and metabolism. Fecal energy represents the largest portion of energy loss. In this study, fecal energy accounted for approximately 49.85% of GE intake, with an apparent digestibility of 50.15%, similar to the 49.11% reported by Zhao Mingming et al. for a total Leymus chinensis diet. Ingested nitrogen is partially deposited as body protein, while the remainder is excreted in feces and urine as metabolic waste. Nitrogen retention rate reflects the degree of dietary protein utilization and can accurately indicate protein digestibility and utilization in animals. In this study, nitrogen intake was 12.12 g/d, nitrogen retention was 2.51 g/d, nitrogen retention rate was 20.09%, nitrogen biological value was 38.68%, and nitrogen apparent digestibility was 50.96%, slightly higher than the 48.2% reported for

Leymus chinensis by Zhao Mingming et al. The nitrogen biological value was higher than that reported for complete diets by Wan Fan et al., possibly because CP intake from sugarcane tops and leaves was lower than the protein requirement of mutton sheep, promoting protein digestion and utilization.

3.5 Roughage Grading Index

Single nutrient indicators cannot scientifically evaluate roughage quality due to differences among feeds; multiple indicators including CP, NDF, metabolizable energy, and animal DMI must be considered. The roughage grading index principle calculates consumable effective energy based on effective energy and voluntary intake in ruminants, with corrections for CP and NDF effects to provide an overall nutritional quality assessment. A higher grading index indicates better nutritional quality. Based on measured parameters, the roughage grading index of sugarcane tops and leaves was 1.16, which falls within the range of 1.03–1.55 specified for sheep roughage grading standards, classifying it as Grade 4. Zhang Jikun et al. reported grading indices of 1.72, 1.10, and 0.57 for alfalfa hay, grass hay, and Leymus chinensis, respectively, while Yuan Cuilin et al. reported values of 3.55, 0.76, 0.74, and 0.43 for alfalfa, Leymus chinensis, peanut vine, and corn stover, respectively. These comparisons indicate that sugarcane tops and leaves fall in the middle range, confirming its status as a medium-quality roughage.

Current research and application of sugarcane tops and leaves have focused primarily on conventional nutrient analysis and production applications, with limited studies on biological value assessment. This study only measured basic data related to digestion and utilization; further research is needed on amino acid content and optimal inclusion levels of sugarcane tops and leaves in mutton sheep diets.

---

4 Conclusion

1. Sugarcane tops and leaves contain relatively abundant nutrients but are characterized by low CP content and high fiber content. The DMI of sugarcane tops and leaves by mutton sheep was 1.39% of body weight, with an intake potential of 39.98 g/(kg W · ·d), and the digestible energy value was 8.32 MJ/kg.
2. According to roughage grading index evaluation standards, sugarcane tops and leaves are classified as a medium-quality roughage.
3. When formulating mutton sheep diets with sugarcane tops and leaves as the primary roughage, concentrate supplementation and Ca and P supplementation should be considered.

References

[1] National Bureau of Statistics. National Data [EB/OL]. http://data.stats.gov.cn/easyquery.htm?cn=C01.
[2] Gao YF, Li LZ, Ouyang KH, et al. Development and utilization of sugarcane tops as feed resources [J]. Feed China, 2014(21):44-45.
[3] Ribeiro RCO, Villela SDJ, Valadares Filho SC, et al. Effects of roughage sources produced in a tropical environment on forage intake, and ruminal and microbial parameters [J]. Journal of Animal Science, 2015, 93(5):2363-2374.
[4] Gradiz L, Sugimoto A, Ujihara K, et al. Beef cow-calf production system integrated with sugarcane production: simulation model development and application in Japan [J]. Agricultural Systems, 2007, 94(3):750-762.
[5] Ortiz-Rubio MA, Ørskov ER, Milne J, et al. Effect of different sources of nitrogen on in situ degradability and feed intake of Zebu cattle fed sugarcane tops (Saccharum officinarum) [J]. Animal Feed Science and Technology, 2007, 139(3/4):143-158.
[6] Zhu X, Hao J, Liu HL, et al. Effects of six different additives on fermentation quality of sugarcane leaf and top silage [J]. Acta Agrestia Sinica, 2015, 23(2):407-413.
[7] Zhou X, Zhou LL, Wang DF, et al. Effects of replacing different proportions of king grass with silage sugarcane tail leaves in diets on growth performance, nutrient apparent digestibility and serum biochemical indices of Hainan black goats [J]. China Animal Husbandry & Veterinary Medicine, 2015, 42(6):1443-1448.
[8] Tang ZH, Zhou L, Zou CX, et al. Effects of silage sugarcane tail leaves and silage corn straw on growth performance, digestion and metabolism, and blood biochemical indices of growing water buffaloes [J]. China Animal Husbandry & Veterinary Medicine, 2016, 43(1):92-100.
[9] Chen XL, Liu ZK, Sun J, et al. Study on degradation characteristics of different forages in the rumen of mutton sheep [J]. Acta Prataculturae Sinica, 2014, 23(2):268-277.
[10] Ørskov ER, McDonald IM. The estimation of protein degradability in the rumen from incubation measurements weighted according to the rate of passage [J]. Journal of Agricultural Science, 1979, 92(2):499-503.
[11] Yan PX, Feng YL, Yang YF, et al. Study on ruminal degradation of protein and organic matter in green roughages [J]. Chinese Journal of Animal Science, 1996, 32(4):42-43.
[12] Zhang LY. Feed Analysis and Feed Quality Detection Technology [M]. 3rd ed. Beijing: China Agricultural University Press, 2010.
[13] Van Soest PJ. Development of a comprehensive system of feed analyses and its application to forages [J]. Journal of Animal Science, 1967, 26(1):119-128.
[14] General Administration of Quality Supervision, Inspection and Quarantine of the People' s Republic of China, Standardization Administration of China. GB/T 23387-2009 Forage nutritional quality assessment—GI method [S]. Beijing: Standards Press of China, 2009.
[15] Xiao Y, Lü D, Chen Z, et al. Research progress on sugarcane tops [J].

Sugar Crops of China, 2013(1):65-67.
[16] Xiong BH, Luo QY, Zhao F. Explanation of formulation of China feed composition and nutritive value table (27th edition, 2016) [J]. China Feed, 2016(24):26-36.
[17] Cao ZJ, Shi HT, Li DF, et al. Research progress on feed nutritional value assessment for ruminants in China [J]. Acta Prataculturae Sinica, 2015, 24(3):1-19.
[18] Yang SP, Wen JK, Mao HM, et al. Nutritional value analysis of sugarcane for sugar production after jointing stage [J]. Yunnan Animal Husbandry and Veterinary Medicine, 2002(2):1-3.
[19] Liu J. Study on prediction models of metabolizable energy and metabolizable protein for meat sheep feeds [D]. PhD thesis. Beijing: Chinese Academy of Agricultural Sciences, 2012:35-49.
[20] Zhao TZ, Li HY, Yan SM. Research progress on ruminal degradation of fiber in ruminant feeds [J]. Animal Husbandry and Feed Science, 2011, 32(7):28-31.
[21] Long RJ, Dong SK, Wang Y, et al. Concepts and research methods of feed intake in ruminants [J]. Acta Prataculturae Sinica, 2003, 12(5):8-17.
[22] Yuan CL, Yu ZY, Wang WD, et al. Nutritional value assessment of common roughages for sheep in Shandong Province [J]. Acta Prataculturae Sinica, 2015, 24(6):220-226.
[23] Santos SA, de Campos Valadares Filho S, Detmann E, et al. Different forage sources for F1 Holstein×Gir dairy cows [J]. Livestock Science, 2011, 142(1/2/3):48-58.
[24] Sousa DO, Mesquita BS, Diniz-Magalhães J, et al. Effect of fiber digestibility and conservation method on feed intake and the ruminal ecosystem of growing steers [J]. Journal of Animal Science, 2014, 92(12):5622-5634.
[25] Yu M, Liu JY, Zhao G, et al. Effects of concentrate supplementation on digestion and metabolism of water buffaloes fed sugarcane top silage [J]. Journal of Yunnan Agricultural University (Natural Science), 2013, 28(4):470-475.
[26] Yan QX, Tan ZL. Research progress on endogenous phosphorus excretion and true phosphorus digestibility in ruminants [J]. Acta Agriculturae Boreali-Sinica, 2009, 24(Suppl. 1):231-235.
[27] Zhao MM, Yang KL, Deng KD, et al. Comparative study on metabolizable energy of Leymus chinensis for meat sheep determined by direct and substitution methods [J]. Chinese Journal of Animal Nutrition, 2016, 28(2):436-443.
[28] Wan F, Ma T, Ma C, et al. Effects of different feeding standards on nutrient digestion and utilization in Dorper×thin-tailed Han crossbred mutton sheep [J]. Chinese Journal of Animal Nutrition, 2016, 28(12):3819-3827.
[29] Zhang JK. Modeling of roughage grading index parameters and associative effects of scientific roughage combinations [D]. PhD thesis. Hohhot: Inner Mongolia Agricultural University, 2004.

Note: Figure translations are in progress. See original paper for figures.