Energy and Protein Requirements of Northern Shaanxi White Cashmere Goat Wethers: Postprint

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Abstract

This experiment aimed to investigate the energy and protein requirements of Shanbei white cashmere goat wethers and provide data for establishing their feeding standards. Thirty-six yearling Shanbei white cashmere goat wethers with similar body weight and good health status were selected and allocated to 9 groups according to a 3×3 (energy × protein) completely randomized design, with 4 replicates per group and 1 goat per replicate. Dietary digestible energy and crude protein levels for each group were formulated at 100%, 110%, 120% and 90%, 110%, 130% of NRC (1981) recommendations, respectively. The pre-trial period lasted 7 days, and the formal trial period lasted 46 days. The results showed: 1) Dietary energy level had an extremely significant effect on dry matter intake and average daily gain of yearling wethers ($P<0.01$), while protein level had a significant effect on dry matter intake ($P<0.05$); dietary energy and protein levels exhibited a significant interaction effect on dry matter intake ($P<0.05$). 2) Digestible nitrogen in the low energy level group was significantly lower than that in the medium and high energy level groups ($P<0.05$); nitrogen intake, digestible nitrogen, retained nitrogen, and apparent nitrogen digestibility in the low protein level group were all extremely significantly lower than those in the medium and high protein level groups ($P<0.01$). 3) Both gross energy digestibility and gross energy metabolizability increased extremely significantly with increasing energy level ($P<0.01$); gross energy metabolizability and digestible energy metabolizability in the high protein level group were significantly lower than those in the low protein level group ($P<0.05$); energy and protein levels produced significant or extremely significant interaction effects on gross energy digestibility, gross energy metabolizability, and digestible energy metabolizability ($P<0.05$ or $P<0.01$). This experiment derived regression equations for energy and protein requirements of yearling Shanbei white cashmere goat wethers; dietary digestible energy and metabolizable energy levels of

8.80–10.61 MJ/kg and 7.34–8.76 MJ/kg, respectively, were considered appropriate, and crude protein and digestible crude protein levels of 10.00% and 7.34%, respectively, were recommended.

Full Text

Energy and Protein Requirements of Shanbei White Cashmere Wether Goats

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Abstract

This experiment was conducted to investigate the energy and protein requirements of one-year-old Shanbei white cashmere wether goats to provide data for establishing their feeding standards. Thirty-six healthy wether goats with similar body weight were randomly divided into 9 groups according to a 3×3 (energy × protein) factorial design, with 4 replicates per group and 1 goat per replicate. Dietary digestible energy (DE) and crude protein (CP) levels were set at 100%, 110%, and 120% of NRC (1981) recommendations for DE, and 90%, 110%, and 130% for CP, respectively. The pre-trial period lasted 7 days, followed by a 46-day formal trial period. The results showed: (1) Dietary energy level had extremely significant effects on dry matter intake (DMI) and average daily gain (ADG) ($P < 0.01$), while protein level significantly affected DMI ($P < 0.05$). There was a significant interaction effect between dietary energy and protein levels on DMI ($P < 0.05$). (2) Digestible nitrogen in the low-energy group was significantly lower than in the medium- and high-energy groups ($P < 0.05$). Nitrogen intake, digestible nitrogen, retained nitrogen, and nitrogen apparent digestibility in the low-protein group were extremely significantly lower than in the medium- and high-protein groups ($P < 0.01$). (3) Gross energy (GE) digestibility and metabolic rate increased extremely significantly with increasing energy level ($P < 0.01$). The GE metabolic rate and DE metabolic rate in the high-protein group were significantly lower than in the low-protein group (P <

0.05). Energy and protein levels produced significant or extremely significant interaction effects on GE digestibility, GE metabolic rate, and DE metabolic rate ($P < 0.05$ or $P < 0.01$). Regression equations for energy and protein requirements of one-year-old Shanbei white cashmere wether goats were established. The appropriate dietary DE and ME levels were 8.80–10.61 MJ/kg and 7.34–8.76 MJ/kg, respectively, while CP and digestible CP levels were 10.00% and 7.34%, respectively.

Keywords: Shanbei white cashmere goat; one-year-old wether goat; energy; protein; requirement

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Introduction

China is the world' s largest producer and exporter of cashmere. In the past, cashmere goats were primarily raised on pasture, but with the implementation of national policies prohibiting grazing on hillsides, indoor feeding has gradually become the main production system. The Shanbei white cashmere goat is a new breed developed over 25 years using Liaoning cashmere goats as the paternal line and Shanbei black goats as the maternal line. This breed is characterized by excellent cashmere quality and tender, non-tainted meat, and has become a leading industry in the Shanbei region. Wether goat meat is particularly popular among consumers, with "Hengshan goat meat" being designated as a national geographical indication product.

Although nutritional requirements have been studied for some goat breeds, research on cashmere goats remains limited. Zhang et al. reported that the optimal dietary DE level for fattening Zhongwei wether goats was 8.71–9.53 MJ/kg, while Zhang et al. found that medium protein levels yielded the best growth and slaughter performance. However, China has not yet established national feeding standards for cashmere goats under indoor feeding conditions. For wether goats, only calcium and phosphorus requirements have been studied in Inner Mongolia white cashmere goats, with no reports on protein and energy requirements. This gap has led to practical problems such as urinary calculi, indigestion, and acidosis during the fattening period, resulting in excessive waste of protein feed, increased feed costs, and environmental pollution, which severely constrain the healthy and scientific development of the cashmere goat industry.

This study combined feeding trials with digestion and metabolism experiments to investigate the energy and protein requirements of Shanbei white cashmere wether goats under indoor feeding conditions. The results will provide a foundation for establishing national feeding standards for cashmere goats and offer theoretical support for maximizing health, production performance, and feed utilization efficiency.

Materials and Methods

1.1 Experimental Animals and Design Thirty-six healthy one-year-old wether goats with moderate body condition and similar body weight were selected from the Shanbei Cashmere Goat Engineering Technology Research Center and randomly divided into 9 groups according to a 3×3 (energy × protein) factorial design, with 4 replicates per group and 1 goat per replicate. The experiment was conducted at the experimental goat farm of the Life Science Research Center of Yulin College. The total experimental period lasted 53 days, including a 7-day pre-trial period and a 46-day formal trial period.

This study employed the factorial method to investigate energy and protein requirements of one-year-old wether goats. According to nutritional principles, energy or protein requirements consist of two components: maintenance requirements and growth requirements, which have linear relationships with metabolic body weight (W・ , kg) and average daily gain (ADG, g/d), respectively. This relationship can be expressed as:

E or P = a × W・ + b × ADG

Where: E represents DE (MJ/d) or metabolizable energy (ME, MJ/d); P represents crude protein (CP, g/d) or digestible crude protein (DCP, g/d); a is the maintenance requirement constant; and b is the growth requirement constant.

1.2 Experimental Diets and Management A 3×3 (energy × protein) factorial design was employed. Based on NRC (1981) recommendations for goat feeding standards, the maintenance requirement plus 100 g/d ADG was used as the reference level. Dietary DE and CP levels were set at 100%, 110%, and 120% of the reference for DE, and 90%, 110%, and 130% for CP, respectively. The composition and nutrient levels of experimental diets are shown in . The concentrate-to-forage ratios were approximately 2:8 for groups I, II, and III; 4:6 for groups IV, V, and VI; and 5:5 for groups VII, VIII, and IX. The goat house was thoroughly disinfected before the experiment, and all experimental goats were uniformly dewormed, vaccinated, and ear-tagged. All goats were housed individually in single pens and fed twice daily at 08:00 and 16:00, with concentrate fed before forage. Feed was provided to ensure slight leftovers for each goat. Clean drinking water was available ad libitum, and feed offered and refused was recorded accurately throughout the trial.

1.3 Digestion and Metabolism Trial During the final 14 days of the feeding trial, a digestion and metabolism trial was conducted using the total collection method (with a 7-day pre-collection period). Three goats with similar body weight and consistent mental status from each group were selected and placed in specialized metabolism cages. Feces and urine were collected twice daily at 07:00 and 19:00, weighed accurately, and recorded.

1.4 Sample Collection and Processing Feed samples were collected using conventional methods. A portion of the refusals was collected daily and stored individually for each goat. At the end of the feeding trial, these samples were mixed uniformly and subsampled using the quartering method at a 10% ratio. Collected feces and urine samples were weighed and mixed thoroughly. Fecal samples were subsampled at 10% of the total weight, treated with 10% hydrochloric acid for nitrogen fixation, dried in a 65°C oven for 8 hours to constant weight, equilibrated for 24 hours, ground, and stored in sample bags. Urine samples were filtered through gauze to remove impurities, subsampled at 10%, treated with 1 mol/L sulfuric acid to adjust pH below 3, labeled with date and animal ID, and stored at -20°C until analysis.

1.5 Measurements and Calculations 1.5.1 Average Daily Gain (ADG)

At the beginning and end of the experiment, goats were weighed on three consecutive days after fasting. The average of the three days was used as the initial and final body weight to calculate ADG during the experimental period.

1.5.2 Conventional Nutrients in Diets, Refusals, Feces, and Urine

Conventional nutrients in diets were determined according to the feed analysis and quality detection techniques described by Yang Sheng. Dry matter, CP, and gross energy (GE) in feces and urine were measured using methods described by He Jianhua.

1.5.3 Nitrogen Apparent Digestibility, GE Digestibility, GE Metabolic Rate, and DE Metabolic Rate

Nitrogen apparent digestibility (%) = 100 × (N intake - fecal N) / N intake
GE digestibility (%) = 100 × (GE - fecal energy) / GE
GE metabolic rate (%) = 100 × (GE - fecal energy - urinary energy - methane energy) / GE
DE metabolic rate (%) = 100 × (GE - fecal energy - urinary energy - methane energy) / (GE - fecal energy)

Methane energy was estimated using the Blaxter method:
Methane energy as percentage of GE (%) = 3.67 + 0.062 × GE digestibility

Based on this estimation, the average methane energy in this experiment was 7.67% of GE.

1.5.4 CP and DCP Intake

Based on experimental records and digestion-metabolism trials, daily CP and DCP intake were calculated as:
CP intake (g/d) = feed intake × dietary CP content
DCP intake (g/d) = CP intake × CP digestibility

1.5.5 DE and ME Intake

Daily DE and ME intake were calculated as:
DE intake (MJ/d) = dry matter intake × dietary energy level × GE digestibility
ME intake (MJ/d) = dry matter intake × dietary energy level × GE metabolic rate

1.6 Data Processing and Analysis Experimental data were initially processed using Excel 2013. Two-way ANOVA was performed using SPSS 17.0 statistical software. Duncan' s multiple range test was used for multiple comparisons and linear regression correlation analysis. Differences were considered significant at $P < 0.05$ and extremely significant at $P < 0.01$. Results are expressed as "mean ± standard deviation (mean ± SD)."

Results

2.1 Growth Performance As shown in , group I had the lowest DMI, which was extremely significantly different from other groups ($P < 0.01$). Group IX had the highest ADG, which was significantly higher than groups I and IV ($P < 0.05$). The low-energy group had extremely significantly lower DMI than the medium-energy group ($P < 0.01$) and significantly lower DMI than the high-energy group ($P < 0.05$). The low-energy group also had significantly lower ADG than the high-energy group ($P < 0.05$). The low-protein group had extremely significantly lower DMI than the medium-protein group ($P < 0.01$) and significantly lower DMI than the high-protein group ($P < 0.05$). Dietary protein level had no significant effect on ADG ($P > 0.05$). There was an extremely significant interaction effect between energy and protein on DMI ($P < 0.01$).

2.2 Nitrogen Metabolism As shown in , energy level had no significant effects on nitrogen intake, fecal nitrogen, urinary nitrogen, retained nitrogen, or nitrogen apparent digestibility ($P > 0.05$). However, digestible nitrogen in the low-energy group was significantly lower than in the medium- and high-energy groups ($P < 0.05$). The low-protein group had extremely significantly lower nitrogen intake, digestible nitrogen, retained nitrogen, and nitrogen apparent digestibility than the medium- and high-protein groups ($P < 0.01$). The medium-protein group had extremely significantly lower nitrogen intake and digestible nitrogen than the high-protein group ($P < 0.01$), but no significant differences in retained nitrogen or nitrogen apparent digestibility ($P > 0.05$). Urinary nitrogen in the low- and medium-protein groups was extremely significantly lower than in the high-protein group ($P < 0.01$), with no significant difference between the former two groups ($P > 0.05$).

2.3 Energy Digestion and Metabolism As shown in , group VII had extremely significantly lower fecal energy than all other groups ($P < 0.01$) and the highest GE digestibility and GE metabolic rate, which were extremely significantly different from other groups ($P < 0.01$). This indicates that group VII had the optimal energy-to-protein ratio, with energy and protein levels more favorable for digestion and metabolism in cashmere goats.

The low-energy group had extremely significantly lower GE than the medium- and high-energy groups ($P < 0.01$). Methane energy, GE digestibility, and GE metabolic rate increased extremely significantly with increasing energy level ($P < 0.01$), while fecal energy decreased extremely significantly ($P < 0.01$). The low-energy group had significantly lower DE metabolic rate than the high-energy group ($P < 0.05$), with no significant difference from the medium-energy group ($P > 0.05$). The high-protein group had significantly higher urinary energy than the medium-protein group ($P < 0.05$) and significantly lower GE metabolic rate and DE metabolic rate than the low-protein group ($P < 0.05$). Energy and protein levels produced significant or extremely significant interaction effects on fecal energy, urinary energy, methane energy, GE digestibility, GE metabolic rate, and DE metabolic rate ($P < 0.05$ or $P < 0.01$).

2.4 Energy and Protein Intake As shown in , dietary nutrient levels had extremely significant effects on GE intake, DE intake, ME intake, and CP intake ($P < 0.01$). Group VII had the highest DE intake and ME intake. GE intake, DE intake, and ME intake increased extremely significantly with increasing dietary energy level ($P < 0.01$). CP intake in the low-energy group was extremely significantly lower than in the medium- and high-energy groups ($P < 0.01$). CP intake increased extremely significantly with increasing dietary protein level ($P < 0.01$). ME intake in the low- and medium-protein groups was extremely significantly higher than in the high-protein group ($P < 0.01$), with the medium-protein group being significantly higher than the low-protein group ($P < 0.05$). GE intake in the medium- and high-protein groups was extremely significantly higher than in the low-protein group ($P < 0.01$), with no significant difference between the former two groups ($P > 0.05$). Energy and protein levels produced extremely significant interaction effects on GE intake, DE intake, and ME intake ($P < 0.01$).

2.5 Energy and Protein Requirements Based on data from and , regression equations for DE and ME requirements of one-year-old Shanbei white cashmere wether goats were established:

DE (MJ/d) = 0.504W · + 0.040ADG ($R^2 = 0.998$)
ME (MJ/d) = 0.396W · + 0.036ADG ($R^2 = 0.997$)

The regression equation for CP requirement was:
CP (g/d) = 1.410W · + 0.881ADG ($R^2 = 0.999$)

Based on data from , the average nitrogen apparent digestibility was 73.46%. Combining this with the CP requirement, the DCP requirement equation was:
DCP (g/d) = 1.036W · + 0.647ADG ($R^2 = 0.999$)

Discussion

3.1 Effects of Dietary Energy and Protein Levels on Growth Performance Different dietary energy levels affect gastrointestinal tension and the composition of digesta and concentration of absorbed nutrients, thereby influencing DMI in goats. For ruminants, when energy level is low (e.g., when consuming roughage), DMI increases with increasing energy level, regulated primarily by gastrointestinal tension. When energy level exceeds a certain threshold, DMI decreases with increasing energy level, regulated mainly by changes in digesta composition and absorbed nutrient concentration.

This study showed that dietary energy level had an extremely significant effect on DMI, which initially increased and then decreased with increasing energy level, consistent with findings by Zhang et al. and Gong et al. Protein level also significantly affected DMI, showing a similar trend of initial increase followed by decrease. However, Zhao et al. fed 3-month-old Chongqing black goats diets with protein levels of 8.23%, 10.42%, and 12.52%, and found that DMI tended to increase with protein level but without significant differences. These discrepancies may be related to differences in experimental animals and protein supplementation levels. Additionally, as energy level increased in this study, the concentrate-to-forage ratio also increased, which may have affected DMI due to palatability differences.

Effects of dietary energy and protein levels on ADG vary across studies. Liu et al. reported that ADG tended to increase with dietary energy level but without significant differences. Liu et al. found that different dietary protein levels had no significant effect on body weight gain of Liaoning cashmere goats. Zhao et al. reported that ADG of Chongqing black goats tended to increase with dietary protein level but without significant differences. Our results are consistent with these findings, showing no significant effects of energy or protein levels on ADG, though ADG tended to increase with energy level. However, Yu et al. reported that body weight of Zhongwei wether goats first increased then decreased with increasing dietary energy level, without significant differences. These discrepancies may be attributed to: (1) excessive energy reducing DMI and thus affecting ADG; (2) breed differences in nutrient requirements and maintenance needs; and (3) differences in diet formulation, such as varying concentrate-to-forage ratios affecting palatability. No reports have been found on the interaction effects of energy and protein on goat production performance, which warrants further investigation.

3.2 Effects of Dietary Energy and Protein Levels on Nitrogen Metabolism Numerous studies have shown that dietary protein level significantly affects nitrogen metabolism. Ma et al. reported that urinary nitrogen and retained nitrogen increased significantly with increasing concentrate-to-forage ratio. Peng et al. found that fecal nitrogen, urinary nitrogen, absorbed nitrogen, retained nitrogen, and total nitrogen utilization increased with feeding level. Similar results were obtained in this study. Nitrogen intake followed the pattern: high-protein > medium-protein > low-protein groups, with extremely significant differences between groups, due to different dietary protein levels. Digestible nitrogen showed the same pattern. Urinary nitrogen in the high-protein group was extremely significantly higher than in other groups, likely due to high nitrogen intake but low utilization efficiency. Retained nitrogen in the medium- and high-protein groups was extremely significantly higher than in the low-protein group, with no significant difference between the former two groups. This is because the low-protein diet could not meet the growth requirements of cashmere goats, while the high-protein group, despite having the highest digestible nitrogen, excreted most nitrogen through urine, resulting in similar retained nitrogen to the medium-protein group. However, Peng et al. reported different results, finding that retained nitrogen reached optimal values when dietary CP was 8.87% for Inner Mongolia white cashmere wether goats. These differences may be due to variations in protein level gradients, energy-to-nitrogen ratios, and nitrogen utilization efficiency.

In this study, nitrogen digestibility, digestible nitrogen, and retained nitrogen all increased with dietary energy level. Shi also found that increasing energy intake promoted nutrient digestion and nitrogen retention in Inner Mongolia white cashmere goats. This indicates that under appropriate energy-to-nitrogen ratios, increasing energy level can promote protein metabolism.

3.3 Effects of Dietary Energy and Protein Levels on Energy Digestion and Metabolism Studying energy utilization efficiency of wether goats under specific feeding conditions and local feed resources is important for diet formulation. Tovar-Luna et al. reported that energy digestibility was higher in goats fed high-nutrient diets than in those fed low-nutrient diets. Wang reported that energy digestibility and metabolic rate of Shanbei white cashmere goats increased gradually with increasing dietary energy intake. Similar results were obtained in this study. However, Zhao et al. reported that when growing Dorper sheep were fed diets with DE levels of 9.78, 10.66, and 11.62 MJ/kg, the medium-energy group had the highest GE digestibility and GE metabolic rate, which were significantly higher than in the low-energy group, but decreased at the high-energy level. This "inflection point" was not observed in our study, possibly because our dietary energy levels did not reach the "critical level" that affects digestive juice secretion and nutrient digestion. Therefore, GE digestibility and metabolic rate increased gradually with dietary DE level.

For ruminants, dietary energy and protein should maintain an appropriate ratio. Excessive or deficient ratios reduce nutrient utilization efficiency and may cause nutritional disorders. Liu et al. reported that energy digestibility decreased with increasing protein digestibility, showing a negative correlation. In this study, GE metabolic rate and DE metabolic rate in the high-protein group were significantly lower than in the low-protein group, consistent with Liu et al. This may be because excessive dietary protein levels affect rumen function, increase excretion of protein metabolites, and burden the liver and kidneys, thereby affecting nutrient digestion and metabolism. This further highlights the importance of appropriate energy-to-protein ratios.

3.4 Comparison with Other Goat Breeds Our results show that maintenance DE and ME requirements for one-year-old Shanbei white cashmere wether goats were 0.504 and 0.396 MJ/kg W · , respectively, with 0.040 MJ DE and 0.036 MJ ME required per gram of ADG. These values are lower than NRC (1981) recommendations for goats (0.424 MJ/kg W · for ME maintenance), though ME requirement for weight gain is similar to NRC (0.030 MJ/g). Nie et al. reported ME maintenance requirements of 0.469 MJ/kg W · for Dorper × Hu crossbred rams, while Fernandes et al. reported 0.431 MJ/kg W · for 20–35 kg Boer crossbred goats, both higher than our results. This is because NRC (1981) primarily studied Angora, meat, and dairy goats, which have higher metabolic activity and maintenance requirements. Dorper × Hu crossbred sheep and Boer crossbred goats are also meat breeds, thus yielding higher values.

NRC (1981) recommended CP and DCP maintenance requirements of 4.15W · and 2.82W · g/d, respectively, and growth requirements of 0.284ADG and 0.195ADG g/d, respectively. Yang et al. reported CP and DCP maintenance requirements of 2.92W · and 1.79W · g/d, respectively, and growth requirements of 0.560ADG and 0.350ADG g/d, respectively, for growing Qing goats. Our results showed CP and DCP maintenance requirements of 1.410W · and 1.036W · g/d, respectively, and growth requirements of 0.881ADG and 0.647ADG g/d, respectively. Compared with NRC (1981), our maintenance requirements were lower but growth requirements were higher. Similar conclusions were drawn compared with Qing goats. Shanbei white cashmere goats, developed under natural environmental conditions in Shanbei, are characterized by cold tolerance, roughage tolerance, and strong disease resistance, resulting in lower protein maintenance requirements. Additionally, being less intensively selected, they have lower protein utilization efficiency, resulting in higher growth requirements.

3.5 Determination of Energy and Protein Requirements Wang reported that appropriate dietary DE and ME levels for non-pregnant Shanbei white cashmere goats were 9.17-10.14 MJ/kg and 7.70-8.60 MJ/kg, respectively. Chai et al. found that the appropriate ME level for Liaoning cashmere goats was 8.6 MJ/kg. Yu et al. reported that the appropriate DE level for growing Zhongwei wether goats was 8.71-10.41 MJ/kg. Under our experimental conditions, with an ADG of 86.50 g/d, the regression equations indicated that DE and ME requirements for 20–30 kg Shanbei white cashmere wether goats were 8.23-9.92 MJ/d and 6.86-8.19 MJ/d, respectively. With an average DMI of 934.61 g/d, dietary DE and ME levels were calculated to be 8.80-10.61 MJ/kg and 7.34-8.76 MJ/kg, respectively. These results are consistent with previous studies, confirming that our dietary design was reasonable and met the nutritional requirements of Shanbei white cashmere goats. This experiment was conducted under indoor feeding conditions with individual pen housing; appropriate adjustments based on feed availability and feeding management in practical production may yield better results.

Zhou et al. reported that appropriate CP and DCP levels for non-pregnant Shanbei white cashmere does were 8.29%-10.43% and 5.43%-6.83%, respectively. Jia et al. suggested that the appropriate CP level for different goat breeds was 8%. Our regression equations indicated that dietary CP and DCP levels for 20–30 kg one-year-old Shanbei white cashmere wether goats were 9.58%-10.09% and 7.04%-7.41%, respectively. Our results also showed that when dietary CP level exceeded 10%, both GE metabolic rate and DE metabolic rate decreased significantly. Therefore, we recommend a CP level of 10% for Shanbei white cashmere wether goats. However, Yu et al. reported that the appropriate protein level for growing Zhongwei wether goats was 11.41%, higher than our results. This discrepancy may be due to differences in breed and physiological stage.

Conclusions

1. The energy and protein requirements for one-year-old Shanbei white cashmere wether goats are:

   DE (MJ/d) = 0.504W · + 0.040ADG (R^2 = 0.998)
   ME (MJ/d) = 0.396W · + 0.036ADG (R^2 = 0.997)

   CP (g/d) = 1.410W · + 0.881ADG (R^2 = 0.999)
   DCP (g/d) = 1.036W · + 0.647ADG (R^2 = 0.999)

2. Under normal growth conditions, appropriate dietary levels for one-year-old Shanbei white cashmere wether goats are: DE 8.80–10.61 MJ/kg, ME 7.34–8.76 MJ/kg, CP 10.00%, and DCP 7.34%.

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