Effects of Dietary Non-fibrous Carbohydrate/Neutral Detergent Fiber Ratio on Growth Performance and Nutrient Digestion and Metabolism in Meat-type Bull Calves: Postprint

Authors: Li Lanjie, Cheng Shuru, Diao Qiyu, Fu Tong, Wang Ansi, Li Ming, Tu Yan

Date: 2017-10-23T00:00:00+00:00

Abstract

This experiment aimed to investigate the effects of non-fibrous carbohydrates/neutral detergent fiber (NFC/NDF) ratio on growth performance, serum biochemical indices, and nutrient digestion and metabolism in weaned male beef calves. Sixty healthy weaned male beef calves aged 2–3 months with an average body weight of (94.38±0.25) kg were selected and randomly divided into 4 groups with 15 calves per group. They were fed four types of total mixed rations (TMR) with similar crude protein levels but different NFC/NDF ratios of 1.35 (Group A), 1.23 (Group B), 0.94 (Group C), and 0.80 (Group D). The experimental period lasted 105 days, including a 15-day preliminary period and a 90-day formal experimental period. Feed intake was measured daily, and body weight was measured every 15 days; jugular vein blood samples were collected on days 15, 30, 45, 60, 75, and 90 to determine serum concentrations of glucose (GLU), growth hormone (GH), insulin-like growth factor-I (IGF-I), leptin (LEP), insulin (INS), glucagon (PG), and triglyceride (TG); digestion and metabolism trials were conducted using the total collection of feces and urine method on days 30 and 90. The results showed: 1) High NFC/NDF diets increased the average daily gain of calves, with Group A being significantly higher than the other three groups ($P<0.05$); 2) Serum LEP concentration in Group A was significantly higher than that in Groups C and D ($P<0.05$), while serum IGF-I concentration in Group D was significantly higher than that in all other groups ($P<0.05$); 3) On day 90, the apparent digestibility of dry matter, neutral detergent fiber, and acid detergent fiber, as well as gross energy digestibility, gross energy metabolic rate, and digestible energy metabolic rate decreased with decreasing dietary NFC/NDF ratio, with Group A being significantly higher than Group D ($P<0.05$), methane energy in Group

D being significantly higher than other groups (P<0.05), and urine energy, urine nitrogen, and digested nitrogen in Group A being significantly higher than those in Groups B and C (P<0.05). In conclusion, a diet with NFC/NDF ratio of 1.35 can meet the nutrient requirements of 3–6 month-old beef calves, and feeding this diet not only enables calves to maintain a relatively high average daily gain (1.14 kg/d), but the diet is also easily digested and utilized, with relevant serum biochemical indices remaining within normal ranges, thus not affecting calf health.

Full Text

Effects of Dietary Non-Fiber Carbohydrate/Neutral Detergent Fiber on Growth Performance and Nutrient Digestion and Metabolism of Meat Male Calves

LI Lanjie[1],[2], **CHENG Shuru**[2], **DIAO Qiyu**[1], **FU Tong**[3], **WANG Ansi**[3], **LI Ming**[3], **TU Yan**[1]*

[1]Key Laboratory of Feed Biotechnology of Ministry of Agriculture, Feed Research Institute, Chinese Academy of Agricultural Sciences, Beijing 100081, China
[2]College of Animal Science and Technology, Gansu Agricultural University, Lanzhou 730070, China
[3]College of Animal Husbandry and Veterinary Science, Henan Agricultural University, Zhengzhou 450002, China

Abstract: This study investigated the effects of dietary non-fiber carbohydrate (NFC) to neutral detergent fiber (NDF) ratio on growth performance, serum biochemical indices, and nutrient digestion and metabolism in weaned meat male calves. Sixty healthy 2- to 3-month-old weaned calves with an average body weight of (94.38±0.25) kg were randomly divided into four groups of fifteen animals each. The calves were fed four total mixed rations with similar crude protein levels but different NFC/NDF ratios: 1.35 (Group A), 1.23 (Group B), 0.94 (Group C), and 0.80 (Group D). The experiment lasted 105 days, including a 15-day adaptation period and a 90-day formal experimental period. Daily feed intake was recorded, and body weight was measured every 15 days. Blood samples were collected via jugular vein at 15, 30, 45, 60, 75, and 90 days to determine serum concentrations of glucose (GLU), growth hormone (GH), insulin-like growth factor-I (IGF-I), leptin (LEP), insulin (INS), glucagon (PG), and triglycerides (TG). Digestion and metabolism trials were conducted at 30 and 90 days using total feces and urine collection.

The results showed: (1) High NFC/NDF diets improved average daily gain (ADG), with Group A significantly higher than the other three groups (P<0.05). (2) Serum LEP concentration in Group A was significantly higher than in Groups C and D (P<0.05), while serum IGF-I concentration in Group D was significantly higher than in all other groups (P<0.05). (3) At 90 days, the apparent

digestibility of dry matter, neutral detergent fiber, and acid detergent fiber, as well as gross energy (GE) digestibility, GE metabolic rate, and digestible energy metabolic rate, all decreased with decreasing dietary NFC/NDF; Group A was significantly higher than Group D ($P<0.05$). Methane energy in Group D was significantly higher than in other groups ($P<0.05$), while urine energy, urine nitrogen, and digestible nitrogen in Group A were significantly higher than in Groups B and C ($P<0.05$).

In conclusion, a dietary NFC/NDF ratio of 1.35 can meet the nutritional requirements of 3- to 6-month-old meat calves. This diet not only maintains a high ADG (1.14 kg/d) but is also easily digestible and utilized, with all relevant serum biochemical indices remaining within normal ranges without adversely affecting calf health.

Keywords: meat calves; non-fiber carbohydrate/neutral detergent fiber; growth performance; serum biochemical index; digestion and metabolism

---

Introduction

According to the *China Animal Husbandry Statistical Yearbook* [1], China had 104.205 million head of cattle in 2013, accounting for 10% of the world' s total. The number of cattle slaughtered increased from 46.02 million in 2009 to 48.28 million in 2013, while beef production rose from 6.3554 million tons to 6.89 million tons between 2009 and 2014, representing 7.95% of China' s total meat production and 11.8% of global beef production. This positions China as a major beef-producing nation after the United States and Brazil.

Previous research has shown that high-concentrate diets, rich in fermentable carbohydrates, increase volatile fatty acid (VFA) concentrations in the rumen, particularly propionate and butyrate proportions, which promote rumen epithelial development [2] and enhance nutrient digestion and absorption throughout the digestive tract [3]. However, other studies indicate that dietary concentrate-to-forage ratio affects crude protein (CP) apparent digestibility in male lambs but not other nutrient digestibility parameters [4]. Serum biochemical indices reflect whether dietary nutrients meet animal requirements, metabolic stability, and homeostasis, thereby providing insights into growth and health status [5]. Studies have demonstrated that altering dietary structure influences serum biochemical indices and certain hormones and growth factors [6].

Current research has primarily focused on sheep and adult cattle, with limited reports on 3- to 6-month-old meat male calves. Furthermore, no consensus exists regarding the optimal NFC/NDF ratio for this developmental stage. Since 3- to 6-month-old calves are in a critical growth period with immature gastrointestinal development, selecting an appropriate NFC/NDF ratio is essential for promoting gastrointestinal development, establishing microbial flora, and facilitating subsequent feeding management. This study investigated growth per-

formance, serum biochemical indices, and nutrient digestion and metabolism in meat calves to determine the optimal dietary NFC/NDF ratio for 3- to 6-month-old calves and provide reference data for nutritional requirements of meat male calves.

1.1 Experimental Time and Location

The experiment was conducted from October 2015 to April 2016 at the Xuchang Experimental Base of Henan Agricultural University.

1.2 Experimental Materials

A single-factor experimental design was employed. Sixty 2- to 3-month-old early-weaned meat male calves (crossbred Simmental) with an average body weight of (94.38±0.25) kg were randomly divided into four groups of fifteen animals each. Based on calf body weight and nutritional requirements, and referring to the Chinese *Feeding Standard of Beef Cattle* (NY/T 815–2004) for 150 kg body weight with 1.0 kg/d daily gain, four experimental diets were formulated with approximately 11.70% CP and NFC/NDF ratios of 1.35 (A), 1.23 (B), 0.94 (C), and 0.80 (D). Diet composition and nutrient levels are shown in Table 1 . Diets were fed as total mixed rations (TMR). The experimental period lasted 105 days, including a 15-day adaptation period and a 90-day formal period.

1.3 Feeding Management

Upon arrival, calves were weighed on an empty stomach in the morning, ear-tagged, and dewormed before being housed individually in calf hutches (4.5 m × 1.5 m). Each calf was provided with a water trough and feed bunk. Manure was removed and facilities were disinfected weekly. Feed was provided at 3.3% of body weight on a dry matter (DM) basis as TMR. Residual feed was collected daily before morning feeding to calculate daily feed intake.

1.4.1 Growth Performance Measurement

Residual feed was collected daily before morning feeding to calculate dry matter intake (DMI). Body weight was measured individually before morning feeding on days 1, 15, 30, 45, 60, 75, and 90 to calculate average daily gain (ADG) for each group.

1.4.2 Serum Sample Collection and Analysis

At the start of the experiment, six healthy calves with good body condition were randomly selected from each group. Blood samples were collected via jugular vein before morning feeding on days 15, 30, 45, 60, 75, and 90 into 10 mL centrifuge tubes, centrifuged at 4,000 r/min for 30 minutes, and the serum was transferred to 1.5 mL tubes and stored at -20°C for analysis.

Serum glucose (GLU) and triglyceride (TG) concentrations were determined using a colorimetric method (Hitachi 7160 automatic biochemical analyzer, Japan). Serum growth hormone (GH), leptin (LEP), insulin-like growth factor-I (IGF-I), and glucagon (PG) concentrations were measured using enzyme-linked immunosorbent assay (ELISA) (STAT FAX-2100 automatic microplate reader). Serum insulin (INS) concentration was determined using radioimmunoassay (XH-6020 automatic radioimmunoassay counter).

1.4.3 Feces and Urine Sample Collection and Analysis

Digestion and metabolism trials were conducted at 30 and 90 days using total feces and urine collection in metabolic crates for 6 days (2-day adaptation and 4-day collection). Daily feed intake, total fecal output, and total urine volume were recorded for each calf. Fecal samples (100 g) were collected daily, mixed thoroughly, and preserved with 50 mL of 10% sulfuric acid for nitrogen fixation. Urine samples (100 mL) were collected daily and preserved with 10 mL of 10% sulfuric acid. All samples were stored at -20°C for analysis.

Fecal samples: CP content was determined using a Kjeldahl nitrogen analyzer; neutral detergent fiber (NDF) and acid detergent fiber (ADF) contents were measured using an ANKOM 200 Fiber Analyzer; gross energy (GE) was determined using a PARR-6400 automatic oxygen bomb calorimeter; DM and organic matter (OM) contents were also measured [8].

Urine samples: Urine nitrogen was determined using the Kjeldahl method, and urine energy was measured using a PARR-6400 automatic oxygen bomb calorimeter [8].

Methane energy (CH E) determination: The sulfur hexafluoride (SF) tracer method was used [7]. During the digestion and metabolism trials, exhaled gases were collected continuously for 4 days using gas collection bags (Guangming Chemical Research and Design Institute). SF permeation rate was measured using a gas chromatograph (Shunyu Hengping GC1120, Shanghai) with nitrogen, hydrogen, and air generators (Beijing Huijia Jingyi, GTL-300/500/1000). Methane (CH) emissions were measured using a gas chromatograph (Shanghai Jingke GC-4000A).

CH emission = QSF × [CH]/[SF] [9]
CH E (MJ/d) = 39.75 × CH emission [10]

Where QSF is the SF release rate; [CH] is the methane concentration in the sampled gas; and [SF] is the SF concentration in the sampled gas.

1.6 Statistical Analysis

Experimental data were analyzed for significance using MIXED and ANOVA procedures in SAS 8.1 software. When significant differences were detected, multiple comparisons were performed using LSD and Duncan' s methods. $P<0.05$

was considered statistically significant, and 0.05 P<0.10 indicated a significant trend.

2.1 Growth Performance of Meat Calves

As shown in Table 2 , during the entire experimental period (1-90 days), ADG of calves in Group A was significantly higher than in the other three groups (P<0.05), being 14.00%, 20.00%, and 23.91% higher, respectively. During days 31-45 and 76-90, ADG in Group A was significantly higher than in Group B (P<0.05), with no significant differences among other groups (P>0.05). Dietary NFC/NDF ratio did not affect overall DMI or feed conversion ratio (P>0.05). However, during days 16-30, DMI in Group C was significantly lower than in Group A (P<0.05).

Overall ADG, DMI, and feed conversion ratio were significantly affected by age (P<0.01). ADG and feed conversion ratio were not affected by the group × age interaction (P>0.05), while DMI was significantly affected by the group × age interaction (P<0.05).

2.2 Serum Biochemical Indices of Meat Calves

As shown in Table 3 , dietary NFC/NDF ratio did not affect serum concentrations of GLU, TG, GH, INS, or PG (P>0.05). Serum IGF-I concentration in Group A was not significantly different from Group C (P>0.05), but differed significantly among other groups (P<0.05), with the highest value in Group D. Serum LEP concentration in Group A was significantly higher than in Groups C and D (P<0.05), with no significant differences among other groups (P>0.05).

Serum GLU, GH, and INS concentrations were significantly affected by age (P<0.01). Age significantly affected serum LEP concentration (P<0.05) but did not affect TG, IGF-I, or PG concentrations (P>0.05). Except for INS concentration, which was significantly affected by the group × age interaction (P<0.05), other serum biochemical indices were not affected by this interaction (P>0.05).

2.3 Nutrient Apparent Digestibility of Meat Calves

As shown in Table 4 , at 30 days, dietary NFC/NDF ratio did not affect apparent digestibility of any nutrients (P>0.05). At 90 days, apparent digestibility of DM in Group A was significantly higher than in Groups C and D (P<0.05), with no significant differences among other groups (P>0.05). OM digestibility showed a decreasing trend with decreasing dietary NFC/NDF (P=0.0576). Apparent digestibility of NDF in Group A was significantly higher than in Groups B, C, and D (P<0.05), with no significant differences among the latter three groups (P>0.05). Apparent digestibility of ADF in Group A was significantly higher than in Groups B and D (P<0.05), and Group C was significantly higher than Group D (P<0.05), with no other significant differences (P>0.05).

2.4 Energy Utilization Rate of Meat Calves

As shown in Table 5 , dietary NFC/NDF ratio did not significantly affect any energy parameters at 30 days (P>0.05). At 90 days, CH E in Group D was significantly higher than in Groups A, B, and C (P<0.05), with no significant differences among the latter three groups (P>0.05). Urine energy excretion in Group A was significantly higher than in Groups B and C (P<0.05), with no other significant differences (P>0.05). GE digestibility in Group A was significantly higher than in Groups C and D (P<0.05), with no other significant differences (P>0.05). GE metabolic rate in Groups A and B was significantly higher than in Group D (P<0.05), with no other significant differences (P>0.05). Digestible energy metabolic rate did not differ significantly among Groups A, B, and C (P>0.05) but was significantly higher than in Group D (P<0.05).

2.5 Nitrogen Metabolism of Meat Calves

As shown in Table 6 , dietary NFC/NDF ratio did not significantly affect nitrogen metabolism indices at 30 days (P>0.05). At 90 days, urine nitrogen in Groups A and D was significantly higher than in Groups B and C (P<0.05), and digestible nitrogen in Group A was significantly higher than in Groups B and C (P<0.05).

3.1 Effects of Dietary NFC/NDF on Growth Performance of Meat Calves

Dietary structure influences nutritional value and consequently affects nutrient absorption and utilization, ultimately impacting animal growth and development. During days 1–90, the gastrointestinal tracts of crossbred Simmental calves were not fully developed, limiting nutrient digestion, absorption, and utilization. Feeding low-nutrient diets inhibited growth and development. High-NFC diets ferment more readily in the rumen, increasing propionate concentration, which can be converted to glucose via gluconeogenesis to provide energy and promote calf growth [11]. These results are consistent with Liu et al. [12] but differ from Wang et al. [13], possibly due to different experimental diets, animal breeds, sexes, and ages. DMI is closely related to ADG. In this study, the diet with the highest NFC/NDF ratio had relatively lower NDF content, which was more palatable and contained higher nutrient levels, resulting in the highest ADG of 1.14 kg/d.

3.2 Effects of Dietary NFC/NDF on Serum Biochemical Indices of Meat Calves

IGF-I is secreted by the liver into the bloodstream, where it binds to carrier proteins and is transported to target organs (such as muscle and bone) to exert its effects. GH and IGF-I form the GH-IGF axis that regulates growth and development; GH stimulates hepatic IGF-I production, while IGF-I exerts negative feedback on GH secretion [14]. However, this study did not show a reciprocal

relationship between GH and IGF-I. Calves fed the NFC/NDF 1.35 diet had increased DMI promoting weight gain, but the highest IGF-I concentration occurred in the NFC/NDF 0.80 group, consistent with Dong [15]. This may be because low dietary nutrient levels failed to meet calf requirements, disrupting the GH-IGF axis balance. Additionally, as dietary NFC content decreased, palatability declined, causing selective feeding in some animals.

Leptin is a protein hormone secreted by adipocytes that primarily regulates energy balance [16]. After entering the bloodstream, it participates in glucose, lipid, and energy metabolism while influencing other hormone secretions. Studies have shown that plasma leptin concentration in 4- to 6-month-old calves is affected by dietary nutrient levels [17]. In this study, serum leptin concentration decreased significantly with decreasing dietary NFC/NDF, consistent with trends in energy digestion, metabolism, and weight gain, indicating that high-nutrient diets promote leptin secretion and benefit calf growth.

3.3 Effects of Dietary NFC/NDF on Nutrient Digestion and Metabolism of Meat Calves

The results showed no significant differences in metabolic body weight (W ·) or DMI/W · among groups at both 30 and 90 days, indicating that calves used in metabolism trials met experimental requirements. Previous studies have shown that roughage induces satiety, and DMI decreases as dietary roughage proportion increases [18]. However, at 30 days, DMI in groups other than NFC/NDF 1.35 increased with dietary NDF content, suggesting that as NFC/NDF decreased (from 1.23 to 0.80), calves needed to consume more feed to meet their requirements. The NFC/NDF 1.35 diet had the highest NFC content and best palatability, resulting in higher feed intake than other groups.

Apparent digestibility of DM and OM can reflect animal health and gastrointestinal development status [18]. In this study, all groups were fed according to body weight percentage, and nutrient intake depended on dietary composition. Research has shown that dietary structure significantly affects nutrient digestion and metabolism in ruminants [18]. At 30 days, NFC/NDF ratio did not affect DM and OM apparent digestibility, but the NFC/NDF 1.23 group showed the highest values, indicating that this dietary nutrient level met calf requirements. At 90 days, as readily digestible carbohydrate content increased, more carbon sources were supplied to rumen microbes. With sufficient nitrogen sources, microbial proliferation and metabolism were enhanced, increasing DM and OM apparent digestibility, consistent with Júnior et al. [19].

NDF and ADF digestion and utilization reflect rumen development status. High-NDF diets stimulate rumen motility, reducing feed retention time and decreasing NDF and ADF digestibility [20]. This aligns with Yu et al. [21], who reported that nutrient digestibility in calves decreases with increasing dietary NDF/NFC ratio. However, Blaxter [10] found that when dietary NDF content was 33.26% in 35–50 kg sheep, NDF and ADF apparent digestibility were lowest at 32.76%

and 23.15%, respectively, because fermentation of large amounts of fermentable carbohydrates reduced rumen pH and inhibited fiber-degrading bacterial activity [22-23]. This phenomenon did not occur in our study, likely because the gastrointestinal tracts of 3- to 6-month-old calves were not fully developed, preventing complete nutrient digestion and utilization and thus avoiding excessively low rumen pH that would affect fiber-degrading bacterial activity.

3.4 Effects of Dietary NFC/NDF on Energy Utilization Rate of Meat Calves

At 30 days, GE digestibility and GE metabolic rate remained at approximately 67% and 60%, respectively, across all groups. Although energy utilization efficiency did not differ significantly among groups, it improved to some extent and increased ADG, suggesting that improving energy metabolic rate is key to enhancing energy utilization efficiency [24]. When dietary NDF content increases, rumen microbial fermentation of carbohydrates follows the pattern: 5 glucose $\rightarrow$ 6 acetate + 2 propionate + butyrate + CO + 3 CH + 6 H O [25], and large acetate production increases hydrogen ion availability [26], increasing rumen methane production. Urine energy is affected by protein metabolites; urinary nitrogen in NFC/NDF 1.35 and 0.80 groups was significantly higher than in 1.23 and 0.94 groups, resulting in increased urine energy.

At 90 days, GE digestibility, GE metabolic rate, and digestible energy metabolic rate decreased with decreasing dietary NFC/NDF, averaging approximately 71%, 62%, and 80%, respectively. This occurred because: (1) as NFC/NDF decreased (from 1.35 to 0.80), dietary nutrient level and digestibility decreased, requiring more time for rumination and digestion [3]; and (2) after 90 days of feeding different dietary structures, gastrointestinal changes affected energy utilization efficiency. No significant difference in energy utilization was observed between NFC/NDF 1.35 and 1.23 groups, but NDF and ADF apparent digestibility differed significantly, indicating that nutrient utilization efficiency does not entirely depend on digestibility, particularly apparent digestibility. Furthermore, the NFC/NDF 1.23 diet met nutrient requirements but did not provide excess nutrients, resulting in slower growth compared to the NFC/NDF 1.35 group.

3.5 Effects of Dietary NFC/NDF on Nitrogen Metabolism of Meat Calves

Ruminant nitrogen utilization occurs primarily through nitrogen metabolic pathways, derived from protein degradation and microbial protein synthesis. Calves excrete excess protein as urine nitrogen. In this study, dietary protein levels were similar across groups, but urinary nitrogen and nitrogen apparent digestibility were higher in NFC/NDF 1.35 and 0.80 groups due to higher feed intake. Raven [28] found that increasing dietary nutrient levels significantly increased retained nitrogen. In this study, retained nitrogen was highest in the NFC/NDF 1.35 group, but nitrogen retention rate was highest in the NFC/NDF 1.23 group, possibly because increased nutrient levels in the NFC/NDF 1.35 group increased

fat deposition around visceral organs, affecting kidney function and reducing nitrogen retention rate. This differs from Liu [29], possibly due to different experimental diets and animals.

3.6 Effects of Age on Growth Performance, Serum Biochemical Indices, and Nutrient Digestion and Metabolism

As calf age increases, physiological functions improve, nutrient utilization efficiency increases [3], and growth rate accelerates. Serum biochemical indices related to growth and development correspondingly increase or decrease, following similar patterns as animal growth. Gastrointestinal development directly affects nutrient digestion and metabolism. At 30 days, calves had developing gastrointestinal tracts, immature microbial populations, low digestive enzyme secretion, and low enzyme activity, resulting in poor nutrient and energy utilization. With increasing age and dietary stimulation, gastrointestinal development and microbial enzyme systems were established by 90 days, enabling more complete digestion and absorption of dietary nutrients.

Under the conditions of this study, a dietary NFC/NDF ratio of 1.35 can meet the nutritional requirements of 3- to 6-month-old meat calves. This diet not only maintains high ADG but is also easily digestible and utilized, with all relevant serum biochemical indices remaining within normal ranges without adversely affecting calf health.

References

[1] China Statistical Yearbook Website. China Animal Husbandry Statistical Yearbook [M]. Beijing: China Agriculture Press, Year to be supplemented.
[2] LIU Q, WANG C, ZHANG Y L, et al. Effects of 2-methylbutyrate supplementation on growth performance and ruminal development in pre- and post-weaned dairy calves [J]. Animal Feed Science and Technology, 2016, 216: 129–137.
[3] MAZZENGA A, GIANESELLA M, BRSCIC M, et al. Feeding behaviour, diet digestibility, rumen fluid and metabolic parameters of beef cattle fed total mixed rations with a stepped substitution of wheat straw with maize silage [J]. Livestock Science, 2009, 122(1): 16–23.
[4] MALISETTY V, YERRADODDI R R, DEVANABOINA N, et al. Effect of feeding sorghum straw based complete rations with different roughage to concentrate ratio on dry matter intake, nutrient utilization, and nitrogen balance in Nellore ram lambs [J]. Tropical Animal Health and Production, 2014, 46(5): 759–764.
[5] YANG Y L, ZHANG F S, GAO Z Y, et al. Effects of different concentrate-to-forage ratios in wheat straw-based diets on rumen environment and blood indices [J]. Jiangsu Journal of Agricultural Sciences, 2013, 29(3): 586–591.
[6] SUDRE K, CASSAR-MALEK I, LISTRAT A, et al. Biochemical and transcriptomic analyses of two bovine skeletal muscles in Charolais bulls divergently selected for muscle growth [J]. Meat Science, 2005, 70(2): 267–277.

[7] DONG H M, LI Y E, LIN E D, et al. Technique for measuring methane emissions from ruminants using sulfur hexafluoride (SF) tracer method [J]. Chinese Journal of Agrometeorology, 1996, 17(4): 44-46.
[8] ZHANG L Y. Feed Analysis and Feed Quality Detection Technology [M]. 3rd ed. Beijing: China Agricultural University Press, 2007: 49-151.
[9] DONG R Y. Effects of Roughage Combination on Methane Production, Rumen Fermentation Pattern and Microbial Flora in Lactating and Dry Cows [D]. Master' s Thesis. Zhengzhou: Henan Agricultural University, 2014: 6.
[10] BLAXTER K L. The Energy Metabolism of Ruminants [M]. London: Hutchinson Scientific and Technical, 1962.
[11] YANG F. Animal Nutrition [M]. 2nd ed. Beijing: China Agriculture Press, 2008.
[12] LIU X H, TIAN J D, LIU C, et al. Effects of different concentrate-to-forage ratios on growth and development of Simmental crossbred bulls [J]. China Cattle Science, 2012, 38(3): 37-39.
[13] WANG L, LIU A G, LÜ Z H, et al. Observation on effects of different concentrate-to-forage ratios on beef cattle production performance [J]. China Livestock and Poultry Breeding, 2014, 10(4): 85-86.
[14] YAN Y F, YANG H, YANG Y L, et al. Effects of different dietary protein levels on IGF-1 and GH secretion and gene expression in sheep [J]. Acta Veterinaria et Zootechnica Sinica, 2015, 46(1): 85-95.
[15] DONG W C. Effects of Different Concentrate-to-Forage Ratios on Hepatic Amino Acid Metabolism and Related Hormones in Dry Dairy Goats [D]. Master' s Thesis. Nanjing: Nanjing Agricultural University, 2012.
[16] WANG C Y, DU R P, ZHANG X F, et al. Overview of leptin and its physiological functions [J]. Chinese Journal of Animal Nutrition, 2012, 24(3): 423-427.
[17] CHELIKANI P K, AMBROSE D J, KEISLER D H, et al. Effects of dietary energy and protein density on plasma concentrations of leptin and metabolic hormones in dairy heifers [J]. Journal of Dairy Science, 2009, 92(4): 1430-1441.
[18] LOU C, JIANG C G, MA T, et al. Effects of feeding level on digestion and metabolism of pregnant meat sheep [J]. Chinese Journal of Animal Nutrition, 2014, 26(1): 134-143.
[19] JÚNIOR C S R, MESSANA J D, GRANJA-SALCEDO Y T, et al. Parameters of fermentation and rumen microbiota of Nellore steers fed with different proportions of concentrate in fresh sugarcane containing diets [J]. Archives of Animal Nutrition, 2016, 70(5): 402-415.
[20] XU G S, DIAO Q Y, JI S K, et al. Effects of different feeding levels on energy and protein digestion and metabolism in meat sheep [J]. Chinese Journal of Animal Science, 2012, 48(17): 40-44.
[21] YU A B, WANG L X, ZHUANG T, et al. Effects of different NDF/NFC diets on growth, development and nutrient digestion and metabolism in 3-6 month old replacement calves [J]. Feed Industry, 2012, 33(24): 44-48.
[22] SCHWARTZKOPF-GENSWEIN K S, BEAUCHEMIN K A, GIBB D J, et al. Effect of bunk management on feeding behavior, ruminal acidosis and performance of feedlot cattle: A review [J]. Journal of Animal Science, 2003,

25(5): 571-572.
[23] NAGARAJA T G, TITGEMEYER E C. Ruminal acidosis in beef cattle: the current microbiological and nutritional outlook [J]. Journal of Dairy Science, 2007, 90(S1): E17-E38.
[24] MU A L, WU N K, LIU F X, et al. Study on energy requirements and metabolic patterns in 4-6 month old crossbred calves [J]. Journal of Domestic Animal Ecology, 2007, 28(1): 23-26.
[25] FENG Y L. Ruminant Nutrition [M]. Beijing: Science Press, 2004.
[26] GUO Y Q, HU W L, LIU J X. Rumen methanogens and regulation of methane production [J]. Acta Microbiologica Sinica, 2005, 45(1): 145-148.
[27] ZHANG W B, DIAO Q Y, ZHANG N F, et al. Effects of dietary protein-to-energy ratio on growth performance and nutrient digestibility in 8-10 month old replacement dairy heifers [J]. Scientia Agricultura Sinica, 2010, 43(12): 2541-2547.
[28] RAVEN A M. Nutritional effects of including different levels and sources of protein in milk replacers for calves [J]. Journal of the Science of Food and Agriculture, 1972, 23(4): 517-526.
[29] LIU Q Q. Effects of Dietary Concentrate-to-Forage Ratio on Digestion and Rumen Metabolism in Sheep [D]. Master' s Thesis. Taigu: Shanxi Agricultural University, 2014.

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