Effects of Different Feeding Standards on Nutrient Digestion and Utilization in Duhan Hybrid Meat Sheep (Postprint)

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Abstract

This study determined the appropriate feeding standard by comparing differences in apparent nutrient digestibility, energy and nitrogen metabolism of Duhan hybrid meat sheep under various feeding standard conditions. A single-factor experimental design was employed, utilizing 600 Duhan hybrid F1 generation meat sheep with a body weight of (28.3$±$0.86) kg, which were randomly allocated into 4 groups with 3 replicates per group and 50 sheep per replicate. The four groups were fed diets formulated according to the following feeding standards: the feeding standard for Duhan hybrid meat sheep proposed by our laboratory (Feed Research Institute, Chinese Academy of Agricultural Sciences, Key Laboratory of Feed Biotechnology, Ministry of Agriculture), United States NRC (2007), United Kingdom AFRC (1993), and China' s agricultural industry standard "Feeding Standard for Meat Sheep" (NY/T 816-2004), designated as CARS, NRC, AFRC, and HB, respectively. The experimental period lasted 81 days. When the average body weight of sheep in the CARS group reached 37 kg, 4 sheep from each group were selected for digestion and metabolism trials, consisting of a 7-day preliminary period and a 5-day formal collection period. The results demonstrated that: apparent digestibility of dry matter and organic matter in the CARS group was significantly higher than in the AFRC and NRC groups ($P<0.05$), and apparent digestibility of acid detergent fiber in the CARS group was significantly higher than in the NRC group ($P<0.05$); digestible energy, metabolizable energy, apparent gross energy digestibility, gross energy metabolic rate, absorbed nitrogen, and apparent nitrogen digestibility in the CARS group were significantly higher than in the AFRC and NRC groups ($P<0.05$), with no significant differences from the HB group ($P>0.05$); retained nitrogen and nitrogen utilization rate showed no significant differences among all groups ($P>0.05$); the biological value of nitrogen in the NRC group was significantly higher than in the CARS and HB groups ($P<0.05$). These results

indicate that, from the perspective of nutrient digestion and utilization as well as energy and nitrogen metabolism in Duhan hybrid meat sheep, the CARS feeding standard exhibits distinct advantages compared with foreign standards.

Full Text

Effects of Different Feeding Standards on Nutrient Digestion and Utilization of Dorper×Thin-tailed Han Crossbred Meat Lambs

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Abstract: This experiment compared the effects of different feeding standards on nutrient apparent digestibility, energy metabolism, and nitrogen metabolism in Dorper×thin-tailed Han crossbred meat lambs to determine an appropriate feeding standard. A single-factor experimental design was employed, in which 600 Dorper×thin-tailed Han crossbred F1 male lambs with a body weight of
(28.3$±0.86)kgwererandomlyallocatedinto4groups, with3replicatespergroupand50lambsperreplicate.Thefou
theDorper×thin−tailedHancrossbredmeatsheepfeedingstandardproposedbyourlaboratory(KeyLaboratoryo
ProducingSheepandGoats"(NY/T816−2004), designatedasCARS, NRC, AFRC, andHB, respectively.Thee
daypreliminaryperiodanda5−dayformalcollectionperiod.Theresultsshowedthatapparentdigestibilityofdrym
0.05), andapparentdigestibilityofaciddetergentfiberintheCARSgroupwassignificantlyhigherthanthatinthe
0.05).Digestibleenergy, metabolizableenergy, apparentdigestibilityofgrossenergy, metabolizabilityofgrossen
0.05), butshowednosignificantdifferencecomparedwiththeHBgroup(P >
0.05).Retainednitrogenandnitrogenutilizationefficiencydidnotdiffersignificantlyamongallgroups(P >
0.05).ThebiologicalvalueofnitrogenintheNRCgroupwassignificantlyhigherthanthatintheCARSandHBgrou
0.05).TheseresultsindicatethattheCARSfeedingstandarddemonstratesclearadvantagesoverforeignstandar
tailed Han crossbred meat lambs.

Keywords: feeding standard; meat sheep; requirement; digestion and metabolism

Introduction

China is the world' s largest sheep-raising country, yet it has long lacked systematic feeding standards. Due to differences in sheep breeds and feed ingredients, foreign feeding standards cannot be fully applied to China' s sheep production. Systematically investigating the nutrient requirements of hybrid meat sheep breeds unique to China and establishing feeding standards are critically important for improving the economic efficiency of the sheep industry, rationalizing feed resource utilization, and developing animal husbandry. The NRC first published sheep feeding standards in 1953, and subsequently, several developed countries with livestock industries formulated and continuously updated their feeding standards based on actual conditions. Currently, representative foreign sheep feeding standards include NRC (2007, USA), AFRC (1993, UK), INRA (1989, France), and CSIRO (2007, Australia).

Research on meat sheep nutrient requirements and feeding standard formulation started relatively late in China, with methodological approaches that lagged behind international standards. Although China proposed the agricultural industry standard "Feeding Standard of Meat-Producing Sheep and Goats" (NY/T 816-2004) in 2004, this standard employed a digestible protein system rather than the current metabolizable protein (MP) system for evaluating protein requirements, and the provided indicators were basically unverified. With the establishment of China's national meat sheep industry technology system in 2009, research on meat sheep nutrient requirements has been continuously developing, particularly systematic studies on nutrient requirements of representative Dorper$\times$Hu and Dorper$\times$thin-tailed Han crossbred meat sheep in northern and southern China. These studies concluded that foreign feeding standards often overestimate the nutrient requirements of Chinese meat sheep, suggesting that formulating diets according to foreign standards may cause nutrient waste.

Our team previously investigated the effects of different feeding standards on production performance and slaughter performance of Dorper$\times$thin-tailed Han crossbred meat lambs from energy and protein perspectives. This study continues to utilize nutrient requirement parameters for Dorper$\times$thin-tailed Han crossbred meat lambs obtained through the national meat sheep industry technology system platform, along with parameters from NRC (2007), AFRC (1993), and "Feeding Standard of Meat-Producing Sheep and Goats" (NY/T 816-2004), to formulate experimental diets. Through digestion and metabolism trials, we compared nutrient apparent digestibility, energy metabolism, and nitrogen metabolism patterns under different feeding standards to provide fundamental data for improving China's meat sheep feeding standards and promoting the development of China's meat sheep industry.

1.1 Time and Location

The experiment was conducted from September to December 2015 at the Inner Mongolia Hetao Agriculture and Animal Husbandry Technology Research Institute breeding base, lasting 81 days.

1.2 Experimental Design

This experiment employed a single-factor design using Dorper$\times$thin-tailed Han crossbred meat lambs as experimental animals. Six hundred healthy male lambs aged 4-6 months with similar body weight [(28.3$\pm$0.86) kg] were randomly divided into 4 groups, with 3 replicates per group and 50 lambs per replicate, totaling
the Dorper$\times$thin-tailed Han crossbred meat sheep feeding standard proposed by our laboratory (Key Laboratory of Feed Biotechnology of the Ministry of Agriculture, Feed Research Institute, Chinese Academy of Agricultural

Sciences), the United States NRC (2007), the United Kingdom AFRC (1993), and the Chinese agricultural industry standard "Feeding Standard of Meat-Producing Sheep and Goats" (NY/T 816-2004), designated as CARS, NRC, AFRC, and HB, respectively.

Experimental diets were formulated based on the energy and protein requirements for 30-40 kg body weight with an average daily gain of 300 g/d according to each standard, and were fed as total mixed rations (TMR). The composition and nutrient levels of experimental diets for the four feeding standards are shown in Table 1 . Throughout the experimental period, lambs had free access to feed and water. When the average body weight of lambs in the CARS group reached 37 kg, 4 lambs near the average weight were selected from each group for a digestion and metabolism trial, consisting of a 7-day preliminary period and a 5-day formal collection period with total collection of feces and urine.

Table 1 Composition and nutrient levels of the 4 experimental diets formulated according to the 4 feeding standards (air-dry basis)

Notes: 1) The premix provided the following per kg of diets: VA 15,000 IU, VD 2,200 IU, VE 50 IU, Fe 55 mg, Cu 12.5 mg, Mn 47 mg, Zn 24 mg, Se 0.5 mg, I 0.5 mg, Co 0.1 mg. 2) Metabolizable energy (ME) (CARS and HB: ME=GE$\times 0.47[5-6]; NRC : ME = GE\times 0.5[9]; AFRC : ME = GE\times 0.69[10]) and metabolizable protein (MP) (CARS and HB : MP = 0.27\times CP intake + 49.88[11]; NRC : MP = 0.7\times CP intake[9]; AFRC : MP = 0.7\times$CP intake[10]) were calculated values, while other nutrient levels were measured values.

1.3 Feeding Management

Before the experiment, all lambs were ear-tagged, vaccinated with a triple vaccine, and dewormed with 2.5 mL of ivermectin solution per lamb. Lambs were housed individually, with each lamb occupying approximately 2.6 m^2. During the experimental period, the maximum temperature in the sheep barn was 10°C, the minimum was -10°C, and the average was 0°C. Lambs were fed twice daily at 07:00 and 17:00, with free access to water throughout. Feed intake was determined based on preliminary feeding trials, and all groups received the same feeding amount, which represented ad libitum intake. After the experiment began, approximately 10% refusals were ensured in the feed trough daily.

1.4 Sample Collection and Processing in Digestion and Metabolism Trial

Before feeding, the amount of feed offered was recorded and diet samples were collected. Diet samples were collected from each group on days 1-5 of the formal collection period, mixed thoroughly, and stored as representative samples for the entire trial period. Refusals collected daily were mixed thoroughly and stored as refusal samples. Feces and urine were collected using the total collection method. Daily fecal output was weighed and recorded for each lamb, with 10%

sampled and the 5-day fecal samples from each lamb mixed and frozen. Urine was collected in plastic buckets containing 100 mL of 10% H_2SO_4 to prevent uric acid precipitation during storage, diluted to 5 L, thoroughly mixed, filtered through gauze, and 30 mL sampled daily. The 5-day urine samples from each lamb were mixed and stored at -20°C for subsequent determination of urine energy (UE)[12].

1.5.1 Nutrient Apparent Digestibility

Representative diet samples collected during the digestion and metabolism trial were analyzed for nutrient composition according to AOAC (2000)[13] methods. Gross energy (GE) was determined using a PARR-6400 automatic oxygen bomb calorimeter; crude protein (CP) content was measured using a KDY-9830 automatic Kjeldahl nitrogen analyzer; and crude fat (EE) content was determined using an ANKOM XT15i automatic fat analyzer. Diet nutrient apparent digestibility was calculated using Adeola' s formula[14]:

Apparent digestibility of a nutrient in the diet (%) = 100 × (nutrient intake in diet - nutrient excretion in feces) / (nutrient intake in diet).

1.5.2 Energy Metabolism Indicators

Fecal energy (FE) and UE were determined according to AOAC (2000)[13] methods using a Parr-6400 oxygen bomb calorimeter. For UE determination, five quantitative filter papers were measured for energy content to calculate the average filter paper energy value. Ten milliliters of urine were dropped onto filter paper in multiple aliquots, dried at 65°C, and the energy value of filter paper plus urine was measured. The UE was obtained by subtracting the filter paper energy value. Diet digestible energy (DE), metabolizable energy (ME), apparent digestibility of GE, metabolizability of GE, and metabolizability of DE were calculated using the following formulas:

DE (MJ/kg) = GE intake - FE;
UE (MJ/kg) = energy value of filter paper with urine - energy value of filter paper;
ME (MJ/kg) = GE intake - FE - UE - methane energy;
Apparent digestibility of GE (%) = DE / GE intake;
Metabolizability of GE (%) = ME / GE intake;
Metabolizability of DE (%) = ME / DE.

The specific value for methane energy was based on our team's previous research, which indicated that methane energy accounted for 8% of GE in Dorper×thin-tailed Han crossbred lambs during the fattening period[7].

1.5.3 Nitrogen Metabolism Indicators

Intake nitrogen, fecal nitrogen, and urinary nitrogen were determined, and total nitrogen excretion, absorbed nitrogen, retained nitrogen, apparent digestibility of nitrogen, nitrogen utilization efficiency, and biological value of nitrogen were calculated using the following formulas:

Total nitrogen excretion (g/d) = fecal nitrogen + urinary nitrogen;
Absorbed nitrogen (g/d) = intake nitrogen - fecal nitrogen;
Retained nitrogen (g/d) = intake nitrogen - (fecal nitrogen + urinary nitrogen);
Apparent digestibility of nitrogen (%) = 100 × absorbed nitrogen / intake nitrogen;
Nitrogen utilization efficiency (%) = 100 × retained nitrogen / intake nitrogen;
Biological value of nitrogen (%) = 100 × [intake nitrogen - (fecal nitrogen + urinary nitrogen)] / (intake nitrogen - fecal nitrogen).

1.6 Data Processing and Analysis

Experimental data were organized using Excel 2010 and analyzed using the ANOVA procedure in SAS 9.1 statistical software for one-way analysis of variance (one-way ANOVA). Duncan' s multiple range test was used for significant differences. $P<0.05$ was used as the criterion for significant difference.

Results

2.1 Effects of Different Feeding Standards on Nutrient Apparent Digestibility of Dorper×thin-tailed Han Crossbred Lambs

As shown in Table 2 , apparent digestibility of dietary dry matter (DM) and organic matter (OM) in the CARS group was significantly higher than that in the NRC and AFRC groups ($P<0.05$), but showed no significant difference compared with the HB group ($P>0.05$). Apparent digestibility of acid detergent fiber (ADF) in the CARS group was significantly higher than that in the NRC group ($P<0.05$), with no significant differences from the other two groups ($P>0.05$). Neutral detergent fiber (NDF) intake in the NRC group was significantly higher than that in the HB group ($P<0.05$), and NDF excretion was significantly higher than that in the CARS and HB groups ($P<0.05$). No significant differences in NDF apparent digestibility were observed among groups ($P>0.05$).

Table 2 Effects of different feeding standards on nutrient intakes and apparent nutrient digestibility of Dorper×thin-tailed Han crossbred lambs

Note: In the same row, values with no letter or the same letter superscripts indicate no significant difference ($P>0.05$), while different lowercase letter superscripts indicate significant difference ($P<0.05$). The same applies below.

2.2 Effects of Different Feeding Standards on Energy Metabolism of Dorper×thin-tailed Han Crossbred Lambs

As shown in Table 3 , dietary DE, ME, apparent digestibility of GE, and metabolizability of GE in the CARS group were significantly higher than those in the NRC and AFRC groups ($P<0.05$), but showed no significant difference compared with the HB group ($P>0.05$). FE in the NRC and AFRC groups was significantly higher than that in the HB group ($P<0.05$), with no significant difference from the CARS group ($P>0.05$). No significant differences were observed among groups in GE intake, UE, or metabolizability of DE ($P>0.05$).

Table 3 Effects of different feeding standards on energy metabolism of Dorper×thin-tailed Han crossbred lambs

2.3 Effects of Different Feeding Standards on Nitrogen Metabolism of Dorper×thin-tailed Han Crossbred Lambs

As shown in Table 4 , intake nitrogen in the CARS group was significantly higher than that in the NRC and HB groups ($P<0.05$), but showed no significant difference from the AFRC group ($P>0.05$). Absorbed nitrogen and apparent digestibility of nitrogen in the CARS group were significantly higher than those in the NRC and AFRC groups ($P<0.05$), with no significant difference from the HB group ($P>0.05$). Fecal nitrogen in the AFRC group was significantly higher than that in the HB group ($P<0.05$), with no significant difference from the CARS and NRC groups ($P>0.05$). Urinary nitrogen in the HB group was significantly higher than that in the NRC and AFRC groups ($P<0.05$), but showed no significant difference from the CARS group ($P>0.05$). Total nitrogen excretion in the HB group was significantly higher than that in the NRC group ($P<0.05$), with no significant difference from the other two groups ($P>0.05$). The biological value of nitrogen in the NRC group was significantly higher than that in the CARS and HB groups ($P<0.05$), but showed no significant difference from the AFRC group ($P>0.05$). No significant differences were observed among groups in retained nitrogen or nitrogen utilization efficiency ($P>0.05$).

Table 4 Effects of different feeding standards on nitrogen metabolism of Dorper×thin-tailed Han crossbred lambs

Discussion

3.1 Effects of Different Feeding Standards on Nutrient Apparent Digestibility of Dorper×thin-tailed Han Crossbred Lambs

Pereira et al.[15] demonstrated that DM intake is a key factor affecting animal performance and is essential for animals to meet their nutritional needs (energy and protein) through nutrient consumption. It is generally accepted that DM intake accounts for 2%-4% of body weight during the fattening stage in sheep[2]. Under the conditions of this experiment, the DM intake/body weight ratio was similar across groups: 3.74% (CARS), 3.63% (NRC), 3.59% (AFRC), and 3.58% (HB). However, apparent digestibility of DM, OM, and ADF differed among groups, primarily due to the influence of varying energy and protein levels in different feeding standards on nutrient apparent digestibility.

Lu Dexun[16] noted that the transformation of various nutrients in the diet within the animal nutrition system is interrelated and coordinately coexistent, with the animal' s self-regulation mechanism ensuring the animal nutrition system maintains an orderly homeostasis. Wang Juan[17] proposed that animals have an optimal range for dietary energy and protein utilization; nutrient digestion is affected when levels are below or above this range. This experiment found that apparent digestibility of DM and OM in the CARS group was higher than in foreign standard groups, indicating that the targeted nutritional parameters proposed by our team based on traditional comparative slaughter trials, nutrient digestion and metabolism trials, and gas metabolism trials using Dorper×thin-tailed Han crossbred lambs[5-7] were significantly superior to other feeding standards.

Furthermore, the apparent digestibility of DM in the CARS group reached 65.4%, similar to the results (64.5%-66.0%) reported by Sormunen-Cristian[18] but higher than previous reports (58.4%-60.8%) from our team by Xu et al.[5] and Deng et al.[6]. The main reason may be that previous trials in our team used pelleted feed, whereas this experiment used total mixed rations, where the longer retention time of roughage and pellets in the rumen could promote rumen fermentation and thus enhance nutrient digestion and absorption.

Ruminants can digest high-fiber diets due to their unique physiological structure, and fiber fermentation products in the rumen are important energy sources for animals. NDF is also considered the best indicator for distinguishing structural carbohydrates (SC) from non-structural carbohydrates (NSC)[19]. NDF degradation primarily depends on fiber-degrading bacteria in the rumen. When dietary roughage content is high and animals consume large amounts of NDF, rumen passage rate increases, leading to incomplete digestion by rumen-degrading bacteria[2]. ADF includes silicates, cellulose, and lignin[20]. This study found significant differences in ADF apparent digestibility among groups, with the CARS group showing the highest value, mainly because the CARS group had higher proportions of soybean meal, greaves, and other ingredients but lower proportions of Chinese wild rye hay compared to the NRC and AFRC groups, resulting in a higher proportion of digestible ADF.

3.2 Effects of Different Feeding Standards on Energy Metabolism of Dorper×thin-tailed Han Crossbred Lambs

Dietary nutrients in ruminants undergo a series of digestive and metabolic processes to produce energy, which is ultimately released in the form of ATP to meet the nutritional needs of the body[21], while unabsorbed energy is excreted in feces and urine. In this experiment, the proportion of FE to GE intake was 35.4%, 44.27%, 43.51%, and 37.37% for the CARS, NRC, AFRC, and HB groups, respectively, which falls within the range reported by previous scholars[2,21]. FE levels are related to dietary ingredient composition and proportions[20]. The concentrate-to-roughage ratios in the experimental diets were 52.5:47.5 (CARS), 45.0:55.0 (NRC), 50.0:50.0 (AFRC), and 52.5:47.5 (HB), resulting in differences in FE/GE intake and reflecting differences in energy digestion and absorption of different feeding standard diets by Dorper×thin-tailed Han crossbred lambs.

DE reflects the apparent digestion and absorption of nutrients by animals, while ME further eliminates energy losses from digestive tract gases and urinary metabolites, better expressing the effective energy contained in feed and more accurately reflecting animal energy absorption and utilization. Additionally, apparent digestibility of GE and metabolizability of GE can reflect animal digestion of ingested GE through dietary consumption[20]. In this experiment, DE, ME, apparent digestibility of GE, and metabolizability of GE were all higher in the CARS group than in other groups, indicating that the CARS standard was significantly superior to other feeding standards for energy metabolism in Dorper×thin-tailed Han crossbred lambs.

3.3 Effects of Different Feeding Standards on Nitrogen Metabolism of Dorper×thin-tailed Han Crossbred Lambs

The efficiency of protein digestion and metabolism in ruminants is primarily influenced by rumen microbial degradation and is also related to nitrogen excretion in feces and urine[2,21]. Most ingested protein is degraded into rumen-degradable protein (RDP) by rumen microorganisms, while the undegraded portion is called rumen-bypass protein (RBPP). Protein-degrading bacteria in the rumen can break down RDP into ammonia, amino acids, and small peptides, which together with energy from carbohydrate degradation in the rumen synthesize microbial protein (MCP). MCP and RBPP then enter the small intestine of ruminants, constituting MP along with a small amount of endogenous protein.

Under these conditions, dietary MP differed significantly among feeding standards. Our team calculated MP using the prediction model from Ma et al.[11]: MP = 0.27 × CP intake + 49.88 ($R^2 = 0.87$). Both NRC and AFRC calculated MP as MP = CP intake × 0.7[9-10]. The HB standard did not use the MP indicator, so the CARS formula was used as a reference. The results showed that intake nitrogen, absorbed nitrogen, and apparent digestibility of nitrogen were highest in the CARS group, indicating that diets formulated according to the CARS feeding standard better promoted nitrogen absorption in Dorper×thin-tailed Han crossbred lambs compared to other standards.

Xu Guishan et al.[2] and Deng et al.[3] studied nitrogen metabolism patterns in 20-50 kg Dorper×thin-tailed Han crossbred lambs, reporting that except for the ad libitum feeding group in the 20-35 kg stage, urinary nitrogen excretion was higher than fecal nitrogen in other groups, with fecal nitrogen excretion being 9.29%-45.94% lower than urinary nitrogen. Devant et al.[22] and Wang Wenqi et al.[21] also reported that fecal nitrogen excretion was lower than urinary nitrogen. However, Sena et al.[23] found that daily fecal nitrogen excretion was higher than urinary nitrogen. This experiment' s results are consistent with the latter finding, as differences in nitrogen intake among groups led to differences in nitrogen excretion, which was eliminated through urinary and fecal nitrogen, ultimately affecting differences in absorbed nitrogen.

The biological value of nitrogen can reflect the relationship between digestible amino acid composition of protein and animal requirements[20]. This experiment found that the NRC group had the highest biological value of nitrogen, indicating that the diet formulated according to the NRC feeding standard for 4-6 month-old early-maturing breed fattening rams with a daily gain of 300 g had the most appropriate digestible amino acid composition for Dorper×thin-tailed Han crossbred lambs compared to diets from other feeding standards. However, overall feeding results showed that the CARS standard improved nitrogen digestion and utilization efficiency in Dorper×thin-tailed Han crossbred lambs better than other standards, promoting nitrogen absorption.

Energy and nitrogen metabolism differed among feeding standards in Dorper×thin-tailed Han crossbred lambs. Based on data analysis of DE, ME, apparent digestibility of GE, absorbed nitrogen, and apparent digestibility of nitrogen, the energy and protein requirement parameters of the CARS standard demonstrated advantages over the NRC, AFRC, and HB standards, improving energy and nitrogen utilization efficiency in meat lambs.

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