Effects of Dietary Non-Fibrous Carbohydrate to Neutral Detergent Fiber Ratio on Growth Performance, Apparent Nutrient Digestibility, and Methane Production in Growing Duhan Crossbred Ewes under Different Feeding Systems: Postprint

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Abstract

This experiment aimed to investigate the effects of dietary non-fibrous carbohydrates (NFC)/neutral detergent fiber/(NDF) on growth performance, apparent nutrient digestibility, and methane production in growing Duhan crossbred ewes using an open-circuit respiratory calorimetry system. A single-factor experimental design was adopted, and 30 ewes in good body condition with a body weight of (27.8±0.5) kg were selected and allocated to 3 groups according to the principle of uniform body weight. The dietary NFC/NDF ratios for each group were 0.78 (concentrate-to-forage ratio of 35:65), 1.03 (concentrate-to-forage ratio of 50:50), and 2.17 (concentrate-to-forage ratio of 65:35), with 10 ewes per group. The experimental period lasted 25 days, including a 3-day adaptation period, a 7-day preliminary period, and a 15-day formal experimental period. The results showed that: under the conditions of ad libitum feeding in the NFC/NDF=0.78 group and restricted feeding in the other groups, there was no significant difference in initial and final body weight or average daily gain among the three groups ($P>0.05$). When dietary NFC/NDF increased from 0.78 to 2.17, dry matter intake significantly decreased ($P<0.05$), while the apparent digestibility of dry matter, organic matter, and crude protein significantly increased ($P<0.05$), with no significant difference in the apparent digestibility of NDF and acid detergent fiber (ADF) ($P>0.05$). When dietary NFC/NDF increased from 0.78 to 2.17, methane energy, methane yield per unit dry matter intake, and methane energy yield per unit gross energy intake significantly decreased ($P<0.05$). The results suggest that, under the premise of consistent average daily gain, high NFC/NDF diets have a lower feed conversion ratio and lower methane conversion efficiency; for growing Duhan crossbred ewes, feeding a diet with NFC/NDF of 2.17 under restricted feeding conditions achieved relatively optimal results for improving production efficiency while simultaneously addressing methane mitigation.

Full Text

Effects of Dietary Non-fiber Carbohydrate (NFC)/Neutral Detergent Fiber (NDF) on Growth Performance, Nutrient Apparent Digestibility, and Methane Emissions of Growing Dorper and Thin-tailed Han Crossbred Ewes

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Abstract: This study investigated the effects of dietary non-fiber carbohydrate (NFC)/neutral detergent fiber (NDF) on growth performance, nutrient apparent digestibility, and methane emissions in growing Dorper and thin-tailed Han crossbred ewes using an open-circuit respirometry system. Thirty healthy ewes weighing (27.8±0.5) kg were allocated to three groups following a single-factor experimental design based on consistent body weight. The dietary NFC/NDF ratios were 0.78 (concentrate:forage = 35:65), 1.03 (concentrate:forage = 50:50), and 2.17 (concentrate:forage = 65:35), with 10 ewes per group. The 25-day experimental period consisted of a 3-day adjustment phase, a 7-day preliminary period, and a 15-day formal trial period. The results showed that under ad libitum feeding for the NFC/NDF=0.78 group and restricted feeding for the other groups, no significant differences were observed in initial body weight, final body weight, or average daily gain among the three groups ($P>0.05$). As dietary NFC/NDF increased from 0.78 to 2.17, dry matter intake decreased significantly ($P<0.05$), while apparent digestibility of dry matter, organic matter, and crude protein increased significantly ($P<0.05$). However, apparent digestibility of NDF and acid detergent fiber (ADF) showed no significant differences ($P>0.05$). Methane energy, methane yield per unit of dry matter intake, and methane energy per unit of gross energy intake all decreased significantly as NFC/NDF increased from 0.78 to 2.17 ($P<0.05$). These findings indicate that under similar average daily gain, high NFC/NDF diets result in lower feed conversion ratios and reduced methane conversion efficiency. For growing Dorper

and thin-tailed Han crossbred ewes, feeding a diet with NFC/NDF of 2.17 under restricted conditions optimally balances production efficiency with methane mitigation.

Keywords: methane; non-fiber carbohydrate/neutral detergent fiber; growth performance; digestibility; respirometry

Introduction

China is a major ruminant livestock producer, with cattle and sheep inventories reaching 130 million and 300 million head respectively in 2014 [?]. According to statistics from Min et al. [?], total methane and nitrous oxide emissions from livestock production in China reached 9.00×10 and 0.469×10 tons in 2008. Such substantial greenhouse gas production from livestock operations not only reflects inadequate precision management and low production efficiency in China' s animal agriculture sector but also indicates poor profitability and weak overall risk resistance. Ruminants possess a unique rumen system where rumen methanogens convert hydrogen and carbon dioxide produced during structural carbohydrate fermentation into methane [?]. This methane energy, which cannot be utilized by the animal, accounts for approximately 2–15% of total dietary gross energy. Previous research has demonstrated that methane production in ruminants is influenced by factors including animal breed, physiological stage, rumen microbial community structure, and fermentation patterns. Current studies primarily focus on regulating methane production through dietary nutritional adjustments and exogenous additives. As China' s livestock industry undergoes strategic transformation, intensive confined production systems will become the dominant model for sheep farming, making the emission patterns of greenhouse gases from these systems a key research priority. Investigating greenhouse gas emission patterns in Dorper crossbred mutton sheep and identifying dietary formulations that effectively reduce rumen methane production can significantly decrease greenhouse gas output while improving production efficiency, thereby promoting the development of grain-saving and sustainable agriculture in China. This study examined the effects of dietary NFC/NDF on growth performance, nutrient apparent digestibility, and methane emissions in growing Dorper and thin-tailed Han crossbred ewes to provide a theoretical basis for rational diet formulation and methane mitigation.

1.1 Experimental Location and Duration

The experiment was conducted at the NanKou Pilot Base Sheep Farm of the Chinese Academy of Agricultural Sciences from December 2016 to May 2017.

1.2 Experimental Design

A single-factor experimental design was employed using Dorper ( ) × small-tailed Han ( ) crossbred F1 ewes as experimental animals. Thirty healthy ewes weighing (27.8±0.52) kg were selected and allocated to three groups based on consistent body weight. The dietary NFC/NDF ratios were 0.78 (concentrate:forage = 35:65), 1.03 (concentrate:forage = 50:50), and 2.17 (concentrate:forage = 65:35), with 10 ewes per group. Diets were formulated as total mixed pellets according to NRC (2007) standards, with premix provided by Beijing Precision Animal Nutrition Research Center. Diet composition and nutrient levels are presented in Table 1 . Throughout the trial, the NFC/NDF=0.78 group was fed ad libitum while the other two groups received restricted feeding, with free access to water. The 25-day experimental period included a 3-day adjustment period, a 7-day preliminary period, and a 15-day formal trial period.

1.3 Feeding Management

Ewes were housed individually in pens (2.6 m^2 per ewe). During the trial, ambient temperature ranged from 18.9°C to 21.2°C, with an average of 17.1°C. Prior to the preliminary period, each ewe was administered 2.5 mL of ivermectin solution for deworming. The ad libitum intake for the NFC/NDF=0.78 group was adjusted daily based on the previous day' s intake to ensure approximately 10% refusals remained in the feed trough. Feed was provided twice daily at 08:00 and 17:00, with free access to water. Feed samples were collected before feeding, and refusals from the previous day were weighed accurately and sampled after thorough mixing. Both intake and refusal amounts were recorded meticulously to calculate dry matter intake (DMI) for each group throughout the trial period.

1.4 Digestion and Metabolism Trial

During the formal trial period, feces and urine were collected daily before morning feeding using the total collection method. For fecal collection, fecal bags were removed and weighed to record the previous day' s fecal output. Fecal samples were then thoroughly mixed, and 10% of the total weight was sampled. For urine collection, 100 mL of 10% H SO was added to urine buckets before collection to preserve urinary nitrogen. After collection, urine volume was recorded for each ewe, filtered through four layers of gauze, and 10% of the total volume was sampled.

1.5 Gas Metabolism Trial

Methane production was measured using an open-circuit gas metabolism system (Sable, USA) connected to three respiration chambers, enabling simultaneous measurement of three sheep. Each chamber was equipped with feed and water troughs, allowing ad libitum access during the trial. On days 1, 4, 7, 10, and 13 of the formal trial period, experimental animals were placed in the chambers in five batches (3 sheep per batch, one from each group) for a 24-hour adaptation period followed by 48 hours of methane production measurement. Carbon dioxide production (GGA, Los Gatos Research, USA) and oxygen consumption (FC-10 oxygen analyzer, Sable, USA) were also measured. The system completed four 30-minute cycles per measurement period. Each measurement cycle began with a 2-minute determination of ambient methane levels, followed by a 1-minute system purge, sequential 2-minute measurements from each of the three chambers, a 1-minute purge, and concluded with a final 2-minute ambient methane measurement. This cycle was repeated continuously for 48 hours. Methane production per ewe per day was calculated using the average of the two ambient methane measurements as baseline values, with statistical analysis performed using macro files associated with the open-circuit system. Body weight was measured when ewes entered and exited the chambers, with the average used for metabolic body weight calculations.

1.6.1 Growth Performance

Before daily morning feeding, refusals from the NFC/NDF=0.78 group were recorded and the next day' s intake was adjusted to maintain ad libitum feeding levels. The other two groups had their intake adjusted every five days based on weighing results to ensure their weight gain approximated that of the ad libitum group. Intake and refusal amounts were recorded precisely to calculate individual DMI throughout the trial, monitor body weight changes, and calculate average daily gain and feed conversion ratio.

1.6.2 Sample Analysis and Determination

Following digestion and gas metabolism trials, fecal, dietary, and refusal samples from each ewe were dried at 65°C for 48 hours, equilibrated for 24 hours, and weighed to determine initial moisture content. Samples were then ground through a 40-mesh sieve for analysis of dry matter (DM), crude ash, crude protein (CP), ether extract (EE), neutral detergent fiber (NDF), acid detergent fiber (ADF), gross energy (GE), fecal energy (FE), urinary energy (UE), calcium (Ca), and phosphorus (P) according to "Feed Analysis and Feed Quality Detection Technology" [**?**].

1.7 Statistical Analysis

Experimental data were initially processed using Excel 2007. Statistical analysis was performed using SAS 9.4 software with ANOVA for testing data independence, normality, and homogeneity of variance. Duncan' s multiple comparison test was applied when significant differences were detected, with P<0.05 as the significance threshold.

Results

2.1 Growth Performance

The effects of dietary NFC/NDF on growth performance are presented in Table 2 . No significant differences were observed in initial or final body weight among the three groups (P>0.05). Average daily gains for the NFC/NDF=0.78, 1.03, and 2.17 groups were 169.93, 162.47, and 157.10 g/d respectively, with no significant differences between groups (P>0.05). Dry matter intake in the NFC/NDF=2.17 group (1,290.00 g/d) was significantly lower than in the NFC/NDF=0.78 group (1,790.00 g/d, P<0.05) but did not differ significantly from the NFC/NDF=1.03 group (1,412.00 g/d, P>0.05). Additionally, the feed conversion ratio in the NFC/NDF=2.17 group (8.43) was significantly lower than in the NFC/NDF=0.78 group (10.57, P<0.05), while the NFC/NDF=1.03 group did not differ significantly from either of the other groups (P>0.05).

2.2 Nutrient Apparent Digestibility

Table 3 shows the effects of dietary NFC/NDF on nutrient apparent digestibility. As NFC/NDF increased, apparent digestibility of dry matter and organic matter increased, with the NFC/NDF=2.17 group showing significantly higher values than both the NFC/NDF=0.78 and 1.03 groups (P<0.05), which did not differ significantly from each other (P>0.05). Crude protein apparent digestibility increased with NFC/NDF elevation, with the NFC/NDF=0.78 group significantly lower than both the NFC/NDF=2.17 and 1.03 groups, while the latter two groups showed no significant difference (P>0.05). NDF apparent digestibility increased with NFC/NDF but did not differ significantly among the three groups (P>0.05). ADF apparent digestibility decreased with increasing NFC/NDF, with no significant differences among groups (P>0.05).

2.3 Energy Metabolism

The effects of dietary NFC/NDF on energy metabolism are shown in Table 4 . Gross energy intake decreased with increasing NFC/NDF across the three groups, with no significant difference between the NFC/NDF=1.03 and 2.17 groups (25.58 vs. 22.91 MJ/d, P>0.05), though both were significantly lower than the NFC/NDF=0.78 group (P<0.05). Digestible energy intake followed the same trend, while metabolizable energy intake did not differ significantly among groups (P>0.05). The NFC/NDF=0.78 group exhibited significantly higher fecal energy and methane energy than the other two groups (P<0.05), at 15.62 and 3.14 MJ/d respectively, though urinary energy showed no significant differences (P>0.05). Both gross energy apparent digestibility and gross energy metabolic rate increased significantly with increasing dietary NFC/NDF (P<0.05).

2.4 Methane Emissions

Table 5 presents the effects of dietary NFC/NDF on methane emissions. Daily methane production in the NFC/NDF=0.78 group (79.32 L/d) was significantly higher than in the NFC/NDF=1.03 (60.58 L/d) and 2.17 groups (36.07 L/d) (P<0.05). Similarly, methane yield per unit metabolic body weight increased significantly with NFC/NDF (P<0.05), with values of 5.79, 4.36, and 2.57 L/(kg BW· ·d) for the three groups respectively. Methane production per unit of dry matter intake, organic matter intake, digestible organic matter intake, and digestible NDF intake all decreased with increasing NFC/NDF, with no significant differences between the NFC/NDF=0.78 and 1.03 groups ($P>0.05$) but both significantly higher than the NFC/NDF=2.17 group ($P<0.05$). Methane energy per unit gross energy intake was significantly higher in the NFC/NDF=0.78 and 1.03 groups (10.25 and 9.35 respectively) compared to the NFC/NDF=2.17 group (6.32) ($P<0.05$), though the former two groups did not differ significantly ($P>0.05$). Methane energy per unit digestible and metabolizable energy intake followed the same pattern. No significant differences were observed in methane production per unit average daily gain among the three groups ($P>0.05$).

Discussion

Ruminants utilize their unique rumen system to convert indigestible fiber into energy through microbial action. Previous research has demonstrated that physiological stage, feeding regime, and dietary composition can affect nutrient and energy utilization efficiency, rumen fermentation characteristics, and methane production. This study investigated the effects of three dietary NFC/NDF ratios under both ad libitum and restricted feeding conditions on growth performance, nutrient apparent digestibility, and methane emissions in Dorper and thin-tailed Han crossbred ewes.

3.1 Effects of Dietary NFC/NDF on Growth Performance

Feeding regime and dietary nutrient composition influence intake, weight gain, and feed conversion ratio in ruminants. Zhang et al. [?] examined the effects of varying dietary NDF proportions (26.51%, 33.35%, 38.71%, 43.51%, and 48.35%) at constant crude protein levels on growth performance of Dorper and thin-tailed Han crossbred sheep, finding no significant differences in net weight gain or average daily gain, though DMI was positively correlated with dietary NDF proportion ($R^2=0.74$). In the present study, dietary NFC/NDF did not significantly affect initial body weight, final body weight, or average daily gain. However, DMI decreased significantly as NFC/NDF increased from 0.78 to 2.17. Unlike the maintenance level setting in Ding et al. [?], our restricted feeding conditions (NFC/NDF=1.03 and 2.17 groups) enabled ewes to achieve similar average daily gain and final body weight with lower DMI and organic matter intake compared to the ad libitum NFC/NDF=0.78 group. Furthermore, the NFC/NDF=2.17 group under restricted feeding showed significantly lower feed conversion ratio than the ad libitum NFC/NDF=0.78 group, demonstrating that high-concentrate diets under restricted feeding can meet maintenance requirements while directing surplus nutrients toward production, thereby reducing costs. The diets were formulated according to NRC (2007) standards for sheep gaining 250 g/d, but actual average daily gain was lower than targeted, possibly due to applicability issues of NRC (2007) standards for Chinese Dorper crossbred sheep and seasonal temperature effects during the trial.

3.2 Effects of Dietary NFC/NDF on Nutrient Apparent Digestibility and Energy Metabolism

Dietary structure is the primary determinant of nutrient digestibility. Lignin binds hemicellulose through covalent bonds and encapsulates cellulose molecules, making them resistant to rumen microbial degradation. Wang et al. [?] investigated the effects of different concentrate:forage ratios in total mixed pellet diets on nutrient apparent digestibility, nitrogen metabolism, and energy metabolism in ewes, finding that as dietary NDF proportion increased from 33.96% to 53.29%, apparent digestibility of dry matter, organic matter, and crude protein decreased significantly, NDF apparent digestibility initially increased then decreased, total tract nitrogen digestibility increased significantly, and dietary digestible energy, metabolizable energy, and gross energy apparent digestibility showed overall increasing trends. Although our study employed ad libitum and restricted feeding regimes rather than the restricted levels used by Wang et al. [?], increasing dietary NFC/NDF enhanced the content of rapidly degradable substrates for rumen microbes, promoting proliferation of fiber-degrading and protein-degrading bacteria and thereby significantly increasing apparent digestibility of dry matter, organic matter, and crude protein, consistent with Liu et al. [?]. Tyrrell and Moe [?] reported that gross energy intake was positively correlated with fecal energy excretion, a finding supported by Xu et al. [?] and Wang et al. [?]. In our study, gross energy intake, fecal energy, urinary energy, methane energy, digestible energy intake, and metabolizable energy intake all decreased with increasing NFC/NDF. We hypothesize that elevated NFC proportion shifted rumen fermentation from acetate- to propionate-type fermentation, with increased propionate and butyrate from fermentable organic matter degradation stimulating rumen papillae development, increasing papillae density, length, and width per unit area, thereby enhancing rumen epithelial absorption of volatile fatty acids [?] and improving dietary nutrient digestibility. Additionally, increased DMI in our study necessarily increased NDF intake, transferring more nutrients to the hindgut for digestion and increasing total tract NDF digestibility [?]. Although the reduction in rumen NDF digestibility was smaller than the reduction in rumen starch digestibility, the greater impact on crude fiber digestibility explains the observed decrease in ADF apparent digestibility with increasing NFC/NDF.

3.3.1 Effects of Intake on Methane Production

Numerous studies have demonstrated positive correlations between DMI and methane production in ruminants. High intake levels increase rumen digesta passage rate, reducing fermentation substrate-microbe interaction time, contact area, and passage rate, while altering rumen microbial populations and volatile fatty acid fermentation patterns, which can explain 28% of methane emission variation [?]. Benchaar et al. [?] examined the effects of four DMI levels (9, 12, 15, and 17 kg/d) on rumen fermentation and methane production using corn-soybean meal diets, finding that methane energy production increased with DMI

(6.86, 8.83, 10.67, and 11.76 MJ/d) while methane energy per unit gross energy intake tended to decrease (5.33, 5.17, 4.98, and 4.85). Our study employed both ad libitum and restricted feeding regimes, with DMI decreasing from 1,790.00 g/d to 1,290.00 g/d as NFC/NDF increased. Consequently, methane production decreased from 79.32 L/d to 36.07 L/d, and methane yield per unit DMI decreased from 46.85 L/kg to 30.23 L/kg. Guo et al. [?] measured methane emissions from Inner Mongolia white cashmere goats at maintenance and ad libitum feeding levels using sulfur hexafluoride (SF) tracer technique, finding positive correlations between methane production (17.71 and 18.06 g/d) and DMI (0.581 and 0.839 kg/d). Zhao et al. [?] established three feeding levels (ad libitum, 75% ad libitum, and 55% ad libitum) for crossbred sheep and found a significant positive correlation: methane production (L/d) = 44.03 × DMI (kg/d) - 6.52 (R^2=0.68), consistent with findings in dairy and beef cattle by Feng et al. [?]. Benchaar et al. [?] simulated rumen liquid and solid passage rates at different DMI levels, finding 37.5% and 39.6% increases respectively with higher intake, confirming that rumen digesta passage rate correlates positively with DMI [?]. Higher DMI increases substrate availability for methanogenesis [?], allowing adequate fermentation of fibrous materials and promoting acetate-type fermentation that favors fiber-degrading bacteria and methanogens, resulting in higher methane production.

3.3.2 Effects of Nutrient Apparent Digestibility and Energy Utilization Efficiency on Methane Production

Methane yield per unit DMI [?] and methane energy per unit gross energy intake [Intergovernmental Panel on Climate Change (IPCC), 2006] are primary indicators for assessing methane conversion efficiency. Methane energy per unit gross energy intake is mainly affected by feeding level [?]. Mould et al. [?] proposed that high-concentrate diets increase rumen acidity and starch effects, negatively impacting fiber-degrading bacterial activity. Sang et al. [?] investigated the effects of different concentrate:forage ratios with low- and high-quality roughage on methane emissions from Xinjiang fine-wool sheep, finding that methane production efficiency from low-quality roughage decreased significantly with increasing concentrate ratio, while high-quality roughage with higher digestible fiber content was not significantly affected by concentrate ratio. In our study, the NFC/NDF=2.17 group showed significantly lower methane yield per unit DMI and methane energy per unit gross energy intake compared to the NFC/NDF=0.78 group, indicating that high NFC/NDF favors propionate-type fermentation, promotes rumen microbial uptake of soluble carbohydrates and proteins, increases hydrogen clearance from pyruvate metabolism, and inhibits fiber-degrading bacteria and methanogens. Since fiber components produce 2–5 times more methane than non-fiber components, gastrointestinal methane production was substantially reduced. Additionally, compared to the NFC/NDF=0.78 group, the NFC/NDF=1.03 group reduced fecal energy, urinary energy, and methane energy while increasing gross energy apparent digestibility and metabolic rate, demonstrating that carbohydrate fermentation rate and content affect energy utilization in microbial growth [?]. Higher dietary fermentability can increase microbial biomass production and enhance energy utilization efficiency, thereby reducing energy loss as methane and decreasing gastrointestinal methane production.

3.3.3 Effects of Dietary NFC/NDF on Methane Production

Dietary concentrate:forage ratio affects volatile fatty acid production and acetate:propionate ratio in the rumen, altering pyruvate metabolism substrates and ultimately influencing methanogenesis. Previous research suggests that concentrate:forage ratio poorly represents fermentable carbohydrates and fiber in diets and cannot serve as a decisive factor for evaluating methane production [?]. NFC primarily consists of nitrogen-free extracts including starch, sugars, pectin, vitamins, and organic acids—readily fermentable carbohydrates that objectively reflect easily fermentable carbohydrate content. Roughage contains high fiber content; while ruminants cannot utilize lignin, they can efficiently use cellulose and hemicellulose from crude fiber, with NDF effectively reflecting fiber content and digestibility characteristics. Therefore, NFC/NDF more accurately represents the carbohydrate:fiber ratio in diets. Ding et al. [?] found that decreasing dietary NFC/NDF reduced daily methane production, consistent with Chandramoni et al. [?] and Moss et al. [?], likely because: (1) increased NFC proportion shifts rumen fermentation from acetate- to propionate-type, reducing acetate:propionate ratio and hydrogen concentration—the substrate for methanogens—thereby decreasing methane production; and (2) rumen methanogens and protozoa have a symbiotic relationship where protozoa provide hydrogen to methanogens. Increased NFC proportion alters dominant rumen bacterial populations and structure, inhibiting protozoa and reducing methane production [?]. Liu et al. [?] conducted trials in sheep with rumen and duodenal cannulas, finding that increasing dietary non-structural carbohydrate (NSC)/structural carbohydrate (SC) ratio slightly increased propionate proportion (non-significantly) while significantly decreasing acetate proportion in total volatile fatty acids, indicating that propionate-type fermentation became dominant with increasing NSC/SC, inhibiting fiber-degrading bacteria and methanogens and reducing methane production. Hu et al. [?] investigated the effects of different NFC/NDF ratios on rumen pH, volatile fatty acids, and lactate in dairy goats with permanent rumen cannulas, finding that increasing NFC/NDF altered rumen fermentation patterns with decreasing acetate and increasing propionate, suggesting that NFC proportion can modify rumen fermentation type—consistent with Weng [?]. In our study, methane production per kilogram of diet consumed was 46.85 L for the NFC/NDF=0.78 group compared to 43.36 L/d and 30.23 L/d for the NFC/NDF=1.03 and 2.17 groups, respectively, primarily due to differences in DMI and NFC/NDF among groups and their subsequent effects on rumen fermentation patterns and methanogenic capacity.

Conclusions

1. Under conditions of similar average daily gain, both feeding level and dietary NFC/NDF influence methane production. High NFC/NDF diets result in lower feed conversion ratios and reduced methane conversion efficiency.
2. For growing Dorper and thin-tailed Han crossbred ewes, feeding a diet with NFC/NDF of 2.17 under restricted conditions optimally balances production efficiency with methane mitigation.

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