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Effects of Dietary Digestible Energy and Digestible Crude Protein Levels on Nutrient Apparent Digestibility in Yanshan Cashmere Goats (Postprint)

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Abstract

This experiment was conducted to investigate the effects of dietary digestible energy (DE) and digestible crude protein (DCP) levels on nutrient apparent digestibility in housed Yanshan cashmere goat kids. Ninety 4-month-old weaned Yanshan cashmere goat kids with good body condition and an initial body weight of (16.17±1.90) kg were randomly allocated to 9 groups with 10 goats per group. A 3×3 completely randomized design was employed, with DE formulated at three levels: low (11.6 MJ/kg), medium (12.8 MJ/kg), and high (14.0 MJ/kg), and DCP also formulated at three levels: low (8.5%), medium (9.5%), and high (10.5%), resulting in 9 experimental diets. Each group was randomly assigned to one diet. When the average body weight of the goats in each group reached 20 kg, 4 goats per group were selected for a digestion-metabolism trial, consisting of a 7-day preliminary period followed by a 3-day formal collection period. The results showed that: 1) With increasing dietary DE level, fecal energy decreased significantly ($P<0.05$), while apparent digestibility of gross energy increased significantly ($P<0.05$); dietary DCP level and the DE × DCP interaction had no significant effects on gross energy intake, fecal energy, urinary energy, digestible energy, or apparent digestibility of gross energy ($P>0.05$). 2) Nitrogen intake and fecal nitrogen decreased significantly with increasing dietary DE level ($P<0.05$); apparent digestibility of nitrogen in the low and medium DE groups was significantly lower than that in the high DE group ($P<0.05$); nitrogen intake and apparent digestibility of nitrogen in the low DCP group were significantly lower than those in the high DCP group ($P<0.05$), and digestible nitrogen in the low and medium DCP groups was significantly lower than that in the high DCP group ($P<0.05$); the DE × DCP interaction had no significant effects on any nitrogen metabolism parameters ($P>0.05$). 3) With increasing di-

etary DE level, apparent digestibility of dry matter (DM), organic matter (OM), ether extract (EE), and calcium (Ca) gradually increased, wherein apparent digestibility of DM and OM differed significantly among all groups (P<0.05), apparent digestibility of EE in the high DE group was significantly higher than that in the low DE group (P<0.05), and apparent digestibility of Ca in the high and medium DE groups was significantly higher than that in the low DE group (P<0.05); dietary DCP level and the DE × DCP interaction had no significant effects on apparent digestibility of DM, OM, EE, neutral detergent fiber (NDF), acid detergent fiber (ADF), Ca, or phosphorus (P) (P>0.05). In conclusion, increasing dietary DE level continuously improved apparent digestibility of DM, OM, EE, Ca, gross energy, and nitrogen in Yanshan cashmere goats; dietary DCP level significantly affected nitrogen intake, digestible nitrogen, and apparent digestibility of nitrogen; when dietary DE and DCP levels were 14.0 MJ/kg and 10.5%, respectively, Yanshan cashmere goats exhibited the highest apparent digestibility of gross energy, digestible energy, and apparent digestibility of nitrogen, whereas when DE and DCP levels were 12.8 MJ/kg and 10.5%, respectively, retained nitrogen was highest in Yanshan cashmere goats.

Full Text

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Abstract

This study investigated the effects of dietary digestible energy (DE) and digestible crude protein (DCP) levels on nutrient apparent digestibility in stall-fed male Yanshan cashmere goat kids. Ninety 4-month-old weaned male Yanshan cashmere goats with good body condition and an initial body weight of (16.17±1.90) kg were randomly allocated to 9 groups of 10 animals each. A 3×3 completely randomized design was employed, with DE levels set at low (11.6 MJ/kg), medium (12.8 MJ/kg), and high (14.0 MJ/kg), and DCP levels set at low (8.5%), medium (9.5%), and high (10.5%), resulting in 9 experimental diets. Each group received one diet. When the average body weight reached 20 kg, four goats per group were selected for a digestion and metabolism trial consisting of a 7-day preliminary period followed by a 3-day collection period. The results showed: (1) Fecal energy decreased significantly (P<0.05) while gross energy apparent digestibility increased significantly (P<0.05) with increasing dietary

DE level. Dietary DCP level and the DE×DCP interaction had no significant effects on gross energy intake, fecal energy, urinary energy, digestible energy, or gross energy apparent digestibility (P>0.05). (2) Nitrogen intake and fecal nitrogen decreased significantly with increasing DE level (P<0.05). Nitrogen apparent digestibility in low and medium DE groups was significantly lower than in the high DE group (P<0.05). The low DCP group exhibited significantly lower nitrogen intake and nitrogen apparent digestibility compared to the high DCP group (P<0.05), and digestible nitrogen in low and medium DCP groups was significantly lower than in the high DCP group (P<0.05). The DE×DCP interaction showed no significant effects on any nitrogen metabolism indices (P>0.05). (3) Apparent digestibility of dry matter, organic matter, ether extract, and calcium increased gradually with DE level. Dry matter and organic matter digestibility differed significantly among all groups (P<0.05). Ether extract digestibility in the high DE group was significantly higher than in the low DE group (P<0.05). Calcium digestibility in high and medium DE groups was significantly higher than in the low DE group (P<0.05). Dietary DCP level and the DE×DCP interaction had no significant effects on apparent digestibility of dry matter, organic matter, ether extract, neutral detergent fiber, acid detergent fiber, calcium, or phosphorus (P>0.05). In conclusion, increasing dietary DE level continuously improved apparent digestibility of dry matter, organic matter, ether extract, calcium, gross energy, and nitrogen in Yanshan cashmere goats. Dietary DCP level significantly affected nitrogen intake, digestible nitrogen, and nitrogen apparent digestibility. The highest gross energy apparent digestibility, digestible energy, and nitrogen apparent digestibility were achieved at DE and DCP levels of 14.0 MJ/kg and 10.5%, respectively, while maximum nitrogen retention occurred at DE and DCP levels of 12.8 MJ/kg and 10.5%.

Keywords: Yanshan cashmere goat; digestible energy; digestible crude protein; nutrient; apparent digestibility

Introduction

Yanshan cashmere goats are primarily distributed in the Yanshan mountainous region of Hebei Province, with concentrated production in Qinglong County, Kuancheng County, and surrounding areas. Developed through over 30 years of selective breeding based on local indigenous goats (commonly known as "shanbengzi" goats), this new genetic group serves dual purposes for both cashmere and meat production. Currently, Yanshan cashmere goats account for 85% of the local goat population.

Digestibility is a crucial indicator for evaluating feed nutritional value and serves as a foundation for diet formulation. An optimal diet should enhance nutrient utilization efficiency, reduce feeding costs, and improve production efficiency. Dietary energy and protein levels play vital roles in feed utilization efficiency. Appropriate protein-to-energy ratios accelerate animal growth and maximize feed conversion efficiency, whereas imbalanced ratios produce the opposite effect. With the development of large-scale and intensive farming systems, im-

proving feed efficiency while reducing emissions has become a research priority. Most previous studies on cashmere goat nutrition have focused on nutrient requirements, with limited research on dietary energy-to-nitrogen ratios. Kong [1], Chai et al. [2], and Yang et al. [3] investigated energy and protein requirements in Shaanbei and Liaoning cashmere goats, but examined only single-factor effects. Therefore, this study was designed to investigate the effects of different DE and DCP levels on nutrient apparent digestibility in stall-fed Yanshan cashmere goats, providing data support for practical diet formulation.

Materials and Methods

1.1 Experimental Location and Duration

The experiment was conducted from January 21 to March 21, 2017 at Kuancheng Lidong Breeding Co., Ltd. in Chengde City, Hebei Province.

1.2 Animals and Grouping

Ninety 4-month-old weaned male Yanshan cashmere goats with good health status and initial body weight of (16.17±1.90) kg were randomly divided into 9 groups of 10 goats each.

1.3 Experimental Design and Diets

A 2-factor, 3-level design was employed with DE and DCP as experimental factors. DE levels were set at low (11.6 MJ/kg), medium (12.8 MJ/kg), and high (14.0 MJ/kg), while DCP levels were set at low (8.5%), medium (9.5%), and high (10.5%). Following a 3×3 completely randomized design , nine experimental diets with varying DE and DCP levels were formulated. Diet composition and nutrient levels are presented in Table 2 . All diets were total mixed rations (TMR) in pellet form. Medium DE (12.8 MJ/kg) and DCP (9.5%) levels were formulated according to NRC (2007) [4] nutrient requirements for goats. DE level intervals were set at 1.2 MJ/kg and DCP level intervals at 1%. Each group received one experimental diet. When average body weight approached 20 kg, goats were transferred to metabolic cages for digestion and metabolism trials with a 7-day preliminary period followed by a 3-day collection period. Goats were fed twice daily at 08:00 and 16:00 with free access to water. Total fecal collection method was used to evaluate nutrient apparent digestibility.

1.4 Sample Collection and Processing

During the collection period, daily feed offered and refusals were recorded and diet samples were collected. Feed samples from three days were thoroughly mixed and frozen for subsequent nutrient analysis. Daily fecal output was weighed, and 10% of the total weight was sampled. Fecal samples from each goat over three days were pooled, labeled, and frozen for nutrient determination. Urine was collected in plastic buckets containing 100 mL of 10% H SO (v/v)

to prevent nitrogen loss. Daily urine volume was recorded, filtered through four layers of gauze, and 10% of the volume was sampled. Urine samples from each goat over three days were pooled and frozen for gross energy and nitrogen analysis.

1.5 Measurements and Calculations

Dry matter, organic matter, ether extract, and crude ash in feed, refusals, feces, and urine were determined according to "Feed Analysis and Feed Quality Detection Technology" (2nd edition) [5]. Gross energy was measured using an oxygen bomb calorimeter, crude protein by automatic Kjeldahl nitrogen analyzer, and neutral detergent fiber (NDF) and acid detergent fiber (ADF) by automatic fiber analyzer.

Nutrient apparent digestibility (%) = 100 × (nutrient intake - fecal nutrient) / nutrient intake
Gross energy apparent digestibility (%) = digestible energy / gross energy intake
Digestible nitrogen (g/d) = nitrogen intake - fecal nitrogen
Retained nitrogen (g/d) = nitrogen intake - fecal nitrogen - urinary nitrogen
Nitrogen apparent digestibility (%) = 100 × digestible nitrogen / nitrogen intake
Net protein utilization (%) = 100 × retained nitrogen / nitrogen intake

1.6 Statistical Analysis

All data were initially processed using Excel 2007 and then subjected to general linear model (GLM) multi-factor ANOVA using SPSS 21.0. Single-factor comparisons were performed using one-way ANOVA with Duncan' s multiple comparison test. The statistical model included DE level, DCP level, and DE×DCP interaction. Significance was declared at $P<0.05$. Data are presented as mean±standard deviation (mean±SD).

Results

2.1 Effects of Dietary DE and DCP Levels on Energy Digestion and Metabolism

As shown in Table 3 , dietary DE level significantly affected gross energy intake, fecal energy, urinary energy, and gross energy apparent digestibility ($P<0.05$). Gross energy intake in the low DE group was significantly higher than in the high DE group ($P<0.05$), while urinary energy was significantly higher than in medium and high DE groups ($P<0.05$). Fecal energy decreased significantly with increasing DE level ($P<0.05$). Digestible energy did not differ significantly among the three DE levels ($P>0.05$). Gross energy apparent digestibility increased significantly with DE level ($P<0.05$). Group IX exhibited the highest gross energy apparent digestibility, which was 27.65% higher than the lowest group (Group II) ($P<0.05$). Dietary DCP level and the DE×DCP interaction

had no significant effects on gross energy intake, fecal energy, urinary energy, digestible energy, or gross energy apparent digestibility (P>0.05).

2.2 Effects of Dietary DE and DCP Levels on Nitrogen Metabolism

As shown in Table 4 , dietary DE level significantly affected nitrogen intake, fecal nitrogen, urinary nitrogen, and nitrogen apparent digestibility (P<0.05), but had no significant effects on digestible nitrogen, retained nitrogen, or net protein utilization (P>0.05). Nitrogen intake and fecal nitrogen decreased significantly with increasing DE level (P<0.05). Urinary nitrogen and digestible nitrogen showed decreasing trends with DE level, with urinary nitrogen in the low DE group significantly higher than in the high DE group (P<0.05), though digestible nitrogen did not differ significantly among groups (P>0.05). Nitrogen apparent digestibility in low and medium DE groups was significantly lower than in the high DE group (P<0.05), while retained nitrogen did not differ significantly among DE levels (P>0.05). Dietary DCP level significantly affected nitrogen intake, digestible nitrogen, and nitrogen apparent digestibility (P<0.05). The low DCP group had significantly lower nitrogen intake and nitrogen apparent digestibility compared to the high DCP group (P<0.05), and digestible nitrogen in low and medium DCP groups was significantly lower than in the high DCP group (P<0.05). Group IX showed the highest nitrogen apparent digestibility, 21.33% higher than the lowest group (Group I) (P<0.05). Dietary DCP level had no significant effects on fecal nitrogen, retained nitrogen, or net protein utilization (P>0.05), though Group VI exhibited the highest retained nitrogen. The DE×DCP interaction showed no significant effects on any nitrogen metabolism indices (P>0.05).

2.3 Effects of Dietary DE and DCP Levels on Other Nutrient Apparent Digestibility

As shown in Table 5 , dietary DE level significantly affected apparent digestibility of dry matter, organic matter, ether extract, and calcium (P<0.05). Apparent digestibility of dry matter, organic matter, ether extract, and calcium increased gradually with DE level. Dry matter and organic matter digestibility differed significantly among all groups (P<0.05). Ether extract digestibility in the high DE group was significantly higher than in the low DE group (P<0.05). Calcium digestibility in high and medium DE groups was significantly higher than in the low DE group (P<0.05). Dietary DE level had no significant effects on apparent digestibility of neutral detergent fiber, acid detergent fiber, or phosphorus (P>0.05). Dietary DCP level and the DE×DCP interaction showed no significant effects on apparent digestibility of dry matter, organic matter, ether extract, neutral detergent fiber, acid detergent fiber, calcium, or phosphorus (P>0.05).

Discussion

3.1 Effects of Dietary DE and DCP Levels on Energy Digestion and Metabolism

Energy is fundamental for all metabolic and productive activities in animals. Ruminants lose 20-50% of ingested dietary energy through feces and 4-5% through urine. Mahgoub et al. [6] reported gross energy apparent digestibility values of 66.8%, 67.2%, and 73.3% in Omani sheep fed diets with low, medium, and high DE levels (12.2, 12.6, and 13.9 MJ/kg), respectively. Huang et al. [7] observed gross energy apparent digestibility values of 69.92%, 65.81%, 72.11%, and 88.05% in male Shaanbei white cashmere goats and 45.80%, 51.45%, 69.50%, and 69.07% in females fed diets with DE levels of 9.33, 10.49, 11.66, and 12.61 MJ/kg. Our results demonstrate that increasing dietary DE level significantly reduced fecal energy and increased gross energy apparent digestibility, indicating that elevating DE level within a certain range improves energy digestibility. However, Chen [8] found no significant difference in gross energy apparent digestibility between high and medium energy groups in Dorper × Han fattening lambs, with diarrhea occurring in the high energy group, suggesting that energy digestibility does not continue to increase beyond a certain threshold and that excessive energy may impair normal rumen function and nutrient digestion.

In our study, gross energy apparent digestibility in high and medium DE groups increased with dietary DCP level, while low DE group showed no significant response to DCP level. Si et al. [9] reported that gross energy apparent digestibility tended to increase with dietary crude protein level in Dorper × Han crossbred lambs fed TMR diets containing 10.4%, 13.0%, and 15.7% crude protein. Some studies indicate that increasing dietary crude protein level improves energy digestibility, but beyond a certain range, energy digestibility decreases [3,10]. Others report that energy digestibility declines with increasing protein digestibility, showing a negative correlation [11,12]. These discrepancies may arise because dietary crude protein level affects rumen function: insufficient protein limits microbial proliferation, while excessive protein increases metabolic waste excretion, burdening the liver and kidneys and impairing nutrient digestion. Furthermore, for ruminants, dietary energy and protein must maintain an appropriate ratio. Optimal energy-nitrogen balance promotes microbial protein synthesis and energy utilization, creating positive associative effects, whereas imbalance reduces nutrient efficiency and may cause nutritional disorders. In our trial, Groups II and VI had identical energy-nitrogen ratios (DE/DCP), as did Groups I, V, and IX, yet gross energy apparent digestibility differed substantially, indicating that DE level, DCP level, and energy-nitrogen ratio all influence energy digestion and utilization. The relatively small gradients in DE and DCP levels in this study may explain why no significant nutritional disorders affecting gross energy apparent digestibility were observed.

3.2 Effects of Dietary DE and DCP Levels on Nitrogen Metabolism

Chowdhury et al. [13] demonstrated that increasing dietary energy level promotes nitrogen retention and improves protein digestibility, consistent with our findings. In our study, nitrogen intake decreased with increasing DE level, while nitrogen retention remained unchanged and nitrogen apparent digestibility continuously improved. This may be attributed to reduced non-fibrous carbohydrate proportion and increased fiber content when dietary neutral detergent fiber increases. High fiber content reduces rumen retention time, accelerates gastrointestinal transit, decreases dry matter and organic matter degradation, and consequently reduces small intestine and total tract digestibility of other nutrients [14]. Research also shows that increasing dietary fermentable carbohydrate proportion enhances urea recycling to the rumen and reduces urea transfer to post-ruminal tissues [15]. Therefore, supplementation with grains, starch, dried fruit pulp, and sucrose to increase concentrate proportion, reduce neutral detergent fiber content, and elevate fermentable carbohydrate proportion can improve ruminal protein degradation and protein digestibility.

Fecal nitrogen originates primarily from undigested dietary nitrogen, undigested microbial nitrogen, and endogenous nitrogen, showing a positive correlation with nitrogen intake (R^2=0.93) and relatively stable excretion [16]. Sultan et al. [17] in Thalli sheep and Karim et al. [18] in Dorset × Malpura crossbred lambs both reported that increased nitrogen intake improves nitrogen apparent digestibility. Our results show that nitrogen intake increased with dietary DCP level, but fecal nitrogen remained unchanged, while digestible nitrogen and nitrogen apparent digestibility were significantly higher in the high DCP group. Urinary nitrogen, primarily urea, is the main source of nitrogen emissions from ruminant operations, with almost all nitrogen exceeding animal requirements excreted in urine, making it highly responsive to dietary protein level. Li et al. [19] reported that urinary nitrogen increased significantly with dietary protein level in Tan sheep. Kebreab et al. [20] conducted a meta-analysis of 580 nitrogen balance trials in lactating dairy cows, showing that nitrogen intake significantly affected fecal and urinary nitrogen. As dietary nitrogen increased, both fecal and urinary nitrogen increased, but when nitrogen intake reached 420 g/d, a breakpoint occurred where fecal nitrogen plateaued while urinary nitrogen continued to increase significantly. In our trial, urinary nitrogen showed no significant change with increasing DCP level, though numerically increasing, likely due to the relatively small DCP gradient. Gao et al. [12] reported that increasing dietary protein level significantly increased retained nitrogen in Shaanbei cashmere goats. In our study, retained nitrogen did not differ significantly among DCP levels within the same DE level, possibly because dietary protein already met Yanshan cashmere goat requirements, with excess nitrogen excreted in feces and urine. Additionally, nitrogen utilization in ruminants is influenced by multiple factors including dietary protein level, protein quality, and animal breed, leading to variable results.

3.3 Effects of Dietary DE and DCP Levels on Other Nutrient Apparent Digestibility

Increasing dietary DE level significantly improved dry matter apparent digestibility in Yanshan cashmere goats, consistent with findings by Chen [8] and Sayed [21], likely due to increased dietary concentrate proportion accompanying higher DE levels. Valdes et al. [22] investigated the effects of forage-to-concentrate ratios of 20:80, 40:60, 60:40, and 80:20 on nutrient digestion in sheep, reporting that decreasing forage-to-concentrate ratio reduced dry matter and organic matter apparent digestibility. This may occur because increased dietary neutral detergent fiber reduces rumen retention time, accelerates gastrointestinal transit rate, decreases dry matter and organic matter degradation, and consequently reduces small intestine and total tract digestibility. Dietary DCP level showed no significant effects on apparent digestibility of dry matter, organic matter, ether extract, neutral detergent fiber, acid detergent fiber, calcium, or phosphorus, possibly because the DCP levels used did not alter the dynamic balance between gastrointestinal content flow and digestion.

In our trial, dietary neutral detergent fiber and acid detergent fiber contents decreased with increasing DE level, yet their apparent digestibility did not differ significantly among groups, consistent with results from Ren et al. [23] and Ou et al. [24]. Some studies report that apparent digestibility of neutral detergent fiber and acid detergent fiber in high-energy diets is significantly higher than in medium and low-energy diets, with no difference between the latter two [25]. These discrepancies may relate to fiber source and dietary neutral detergent fiber content. Research shows that increasing dietary concentrate proportion to 90% does not affect acid detergent fiber disappearance [26], and increasing grain-to-roughage ratio does not affect neutral detergent fiber disappearance [27].

Few studies have examined dietary energy and protein effects on calcium and phosphorus absorption, with highly variable results. In our trial, calcium apparent digestibility in the low DE group was significantly lower than in medium and high DE groups, while dietary DE level had no significant effect on phosphorus apparent digestibility. Dietary DCP level showed no significant effects on calcium or phosphorus apparent digestibility. Calcium and phosphorus digestibility is influenced by multiple factors including content, ratio, and chemical form in feed, particularly phosphorus, which exists primarily as phytate phosphorus in plants, substantially reducing phosphorus absorption.

Conclusion

(1) Increasing dietary DE level continuously improved apparent digestibility of dry matter, organic matter, ether extract, calcium, gross energy, and nitrogen in Yanshan cashmere goats.

(2) Dietary DCP level significantly affected nitrogen intake, digestible nitrogen, and nitrogen apparent digestibility.

(3) The highest gross energy apparent digestibility, digestible energy, and nitrogen apparent digestibility were achieved at dietary DE and DCP levels of 14.0 MJ/kg and 10.5%, respectively, while maximum nitrogen retention occurred at DE and DCP levels of 12.8 MJ/kg and 10.5%.

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