Effects of Pelleting Diets with Different Physically Effective Fiber Levels on Nutrient Apparent Digestibility in Goats (Postprint)

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Abstract

This study aimed to investigate the effects of diet pelleting on apparent nutrient digestibility in goats fed diets with different levels of physically effective neutral detergent fiber (peNDF). Four Boer crossbred male goats (Boer goat × Xuhuai goat) weighing approximately 25 kg were used in a 4$×$4 Latin square experimental design, with each goat receiving four different diets. Diets A and B were mash and pellet forms with a peNDF level of 22.69%, respectively, while diets C and D were mash and pellet forms with a peNDF level of 31.69%, respectively. The four diets had equal or similar contents of neutral detergent fiber, crude protein, and gross energy. The trial consisted of four periods, each 15 days in duration, comprising a 10-day preliminary period and a 5-day formal collection period. The results demonstrated that: 1) At the low peNDF level, diet B significantly increased the apparent digestibility of acid detergent fiber, crude protein, dry matter, organic matter, calcium, and phosphorus, as well as nitrogen retention, nitrogen retention rate, and nitrogen biological value compared to diet A ($P<0.05$); 2) At the high peNDF level, diet D significantly improved the apparent digestibility of neutral detergent fiber, acid detergent fiber, crude protein, dry matter, organic matter, calcium, and gross energy, and nitrogen retention rate compared to diet C ($P<0.05$); 3) Under the same diet form, low-peNDF diets (diets A and B) significantly enhanced all nutrient apparent digestibility compared to high-peNDF diets (diets C and D), with the exception of calcium apparent digestibility ($P>0.05$). It was concluded from this experiment that diet pelleting improved apparent nutrient digestibility in goats at both high and low peNDF levels.

Full Text

Effects of Pelleted Diets with Different Physically Effective Neutral Detergent Fiber Levels on Nutrient Apparent Digestibility in Goats

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Abstract

This study investigated the effects of pelleted diets with different physically effective neutral detergent fiber (peNDF) levels on nutrient apparent digestibility in goats. Four male hybrid goats (Boer × Xuhuai) weighing approximately 25 kg were used in a 4$×$4 Latin square design, with each goat receiving four different dietary treatments. Diets A and B were powder and pelleted forms with a low peNDF level (22.69%), while diets C and D were powder and pelleted forms with a high peNDF level (31.69%). All four diets had equivalent or similar levels of neutral detergent fiber (NDF), crude protein (CP), and gross energy (GE). The experiment consisted of four periods, each lasting 15 days (10-day preliminary period and 5-day collection period). The results showed: (1) At the low peNDF level, diet B significantly improved apparent digestibility of acid detergent fiber (ADF), CP, dry matter (DM), organic matter (OM), calcium (Ca), phosphorus (P), nitrogen retention, nitrogen retention rate, and nitrogen biological value compared to diet A ($P<0.05$). (2) At the high peNDF level, diet D significantly increased apparent digestibility of NDF, ADF, CP, DM, OM, Ca, GE, and nitrogen retention rate compared to diet C ($P<0.05$). (3) Within the same diet form, low peNDF diets (A and B) significantly enhanced apparent digestibility of all nutrients except Ca compared to high peNDF diets (C and D) ($P<0.05$). These findings indicate that pelleting improves nutrient apparent digestibility in goats at both high and low peNDF levels.

Keywords: physically effective fiber; pelleting; goats; apparent digestibility

Introduction

With increasing national emphasis on environmental and ecological issues, the transformation of livestock production toward intensive housing systems has become inevitable. Confined feeding of ruminants requires adequate forage resources. Although China produces vast quantities of crop straw annually, direct feeding results in low intake and selective eating, leading to insufficient dietary fiber supply or reduced utilization efficiency, which can trigger metabolic disorders such as ketosis and pregnancy toxemia [**?**]. Using pelleted complete diets

facilitates intensive sheep farming and offers advantages for large-scale industrial production, including improved palatability, increased feed intake [**?**], prevention of nutritional imbalances from selective feeding, and reduced feed waste [**?**]. Holter et al. [**?**] reported that pelleting total mixed rations significantly improved apparent digestibility of dietary nutrients in dairy cows while maintaining consistent concentrate-to-forage ratios. Reddy et al. [**?**] demonstrated that pelleted total mixed rations enhanced nitrogen retention compared to loose diets in sheep.

Mertens [**?**] introduced the concept of physically effective neutral detergent fiber (peNDF) in 1997, defined as the portion of dietary fiber that influences chewing activity and rumen stratification, which is related to feed particle length. Since NDF is an essential nutrient for ruminants, peNDF more accurately reflects rumen environment stability. Diets with varying peNDF levels affect ruminant feed intake [**?**], saliva secretion, rumen environment [**?**], and nutrient apparent digestibility. Fiber deficiency reduces saliva secretion, altering rumen environment by decreasing pH, shifting microbial populations and fermentation patterns, and ultimately compromising animal health and performance [**?**]. However, pelleting reduces peNDF levels, and the effects of pelleting diets with different peNDF levels on nutrient utilization, particularly fiber digestion, remain inconclusive. Therefore, this study examined how pelleting affects nutrient apparent digestibility in goats fed diets with different peNDF levels, providing guidance for appropriate feed processing technologies in total mixed rations with varying peNDF levels.

Materials and Methods

Experimental Design

Four 8-month-old male hybrid goats (Boer × Xuhuai) weighing (25.0$±0.5)*kgwereusedina*4×$4 Latin square design. The experiment comprised four periods, each lasting 15 days, with four dietary treatments: Diet A (low peNDF powder, 22.69% peNDF), Diet B (low peNDF pelleted, 22.69% peNDF), Diet C (high peNDF powder, 31.69% peNDF), and Diet D (high peNDF pelleted, 31.69% peNDF).

Experimental Diets

Diets were formulated according to NRC (1985) [**?**] nutritional requirements for goats, targeting a daily gain of 150 g. Diet composition and nutrient levels are presented in Table 1 .

Table 1. Composition and nutrient levels of experimental diets (air-dry basis), %

Item	Diets A/B	Diets C/D
Ingredients		
Maize		
Soybean meal		
Wheat		
Wheat bran		
Straw		
Soybean hull		
Limestone		
$CaHPO_4$		
NaCl		
Premix		
Bentonite		
Total		
Nutrient levels		
DE/(MJ/kg)		
CP		
Ca		
NDF		
peNDF		

Notes: 1) Diets A and B had the same formula, and diets C and D had the same formula. The same applies below. 2) The premix provided per kg of diet: VA 4,000 IU, VD_3 400 IU, VE 20,000 IU, $FeSO_4$ 69.03 mg, $CuSO_4$ 17.6 mg, K_2SO_4 31.70 mg, $ZnSO_4$ 57.14 mg, $MnSO_4$ 44.03 mg, $CoCl_2$ 0.25 mg, Na_2SeO_3 8.95 mg, monensin 6.00 mg, $NaHCO_3$ 3,740.91 mg. 3) Nutrient levels were calculated values.

Feeding Management

The feeding trial was conducted at the Jiangsu Academy of Agricultural Sciences experimental sheep farm from May 20 to June 9, 2016. Goats were dewormed before the experiment. Each period included a 10-day preliminary phase followed by a 5-day collection phase, during which goats were fed quantitatively based on the lowest intake group from the preliminary period. All animals were housed individually in metabolic cages with free access to water, and total feces and urine were collected.

Sample Collection

Diet Samples: Diet samples were collected daily (100 g) for 10 days using the quartering method, ground through a 40-mesh sieve, and stored at -20°C for analysis.

Fecal Samples: Fresh feces were collected continuously for 5 days using the

total collection method, with daily fecal output weighed and recorded. Each day, 10% of fresh feces were placed in aluminum boxes, treated with 20% HCl for nitrogen fixation, dried at 75°C to constant weight, equilibrated at room temperature for 24 hours, weighed, ground through a 40-mesh sieve, and stored at -20°C.

Urine Samples: Urine was collected continuously for 5 days using the total collection method, with daily urine output weighed and recorded. Samples were stored in sealed buckets with a few drops of 30% HCl for nitrogen fixation. After 5 days, urine samples were mixed, filtered through gauze, and 200 mL aliquots were stored at -20°C.

Detection Indicators and Methods

Dry matter (DM), crude ash, NDF, ADF, OM, CP, and GE in diets and feces were determined according to AOAC (1995) [**?**] methods. Calcium content was measured by acetylene-air flame atomic absorption spectrometry (GB/T 13885-2003), and phosphorus content by vanadium molybdate yellow colorimetry (GB/T 6437-2002).

The peNDF level was determined using the Penn State Particle Separator (PSPS) developed by Heinrichs et al. [**?**]. The PSPS consists of four layers (three sieve screens with 19.00, 8.00, and 1.18 mm apertures, and a bottom pan). Approximately 200 g of fresh sample was placed on the top sieve (19.00 mm) and oscillated horizontally 40 times (5 times per direction for 2 sets) at 1 oscillation/second with horizontal displacement >17 cm, without vertical vibration. After oscillation, each fraction was weighed, DM content determined, and the proportion of DM retained on each sieve calculated. The physical effectiveness factor ($pef_{1 \cdot 18}$) equals the sum of DM retained on all sieves. peNDF (%) = $pef_{1 \cdot 18}$ × NDF(%). Particle size distribution and $pef_{1 \cdot 18}$ values for the four diets are shown in Table 2 .

Table 2. Particle size distribution and $pef_{1 \cdot 18}$ of four diets

Item	Diets
Proportion of DM retained on sieves (% of total DM)	
>19.00 mm	
>8.00–19.00 mm	
1.18–8.00 mm	
<1.18 mm	
$pef_{1 \cdot 18}$	

Calculations

Nutrient Apparent Digestibility:
Apparent digestibility of a nutrient (%) = 100 × (nutrient intake - fecal nutrient excretion) / nutrient intake.

Nitrogen Retention, Retention Rate, and Biological Value:
Nitrogen retention [g/(head • d)] = N intake - fecal N - urinary N
Nitrogen retention rate (%) = 100 × (N intake - fecal N - urinary N) / N intake
Nitrogen biological value (%) = 100 × N retention / N intake

Statistical Analysis

Data were analyzed using the multivariate procedure in the general linear model of SPSS 20.0 for Latin square design. Multiple comparisons among groups were performed using Duncan' s method. Results are expressed as mean ± standard deviation. P<0.05 was considered statistically significant.

Results

Effects of Pelleting on NDF and ADF Apparent Digestibility

As shown in Table 3 , NDF and ADF intake did not differ significantly among the four diets (P>0.05). At the low peNDF level, NDF apparent digestibility was not significantly different between diets A and B (P>0.05), though diet A was 0.83% lower than diet B, while ADF apparent digestibility was significantly lower in diet A than diet B (P<0.05). At the high peNDF level, both NDF and ADF apparent digestibility were significantly lower in diet C than diet D (P<0.05). These results indicate that pelleting improved NDF and ADF digestibility. In powder form, diet A showed significantly higher NDF and ADF digestibility than diet C (P<0.05), while in pelleted form, diet B exhibited significantly higher NDF and ADF digestibility than diet D (P<0.05), suggesting that low peNDF levels enhanced fiber digestibility.

Table 3. Effects of pelleted diets with different peNDF levels on NDF and ADF apparent digestibility in goats (n=4)

Item	Diet A	Diet B	Diet C	Diet D
NDF				
Intake [g/(head • d)]	353.12$±0.00\|359.93±0.00\|344.91±0.00\|357.54±0.00\|\|*Output*[*g*/(*head*· *d*)]\|121.10±0.53^{c}\|110.22±3.43^{d}\|164.91±2.73^{a}\|143.03±6.21^{b}\|\|*Retention*[*g*/(*head*· *d*)]\|232.02±0.53^{b}\|249.70±3.43^{a}\|180.01±2.73^{d}\|214.23±6.21^{c}\|\|*Apparentdigestibility*(±3.46^{a}|64.24±			
	∗*ADF* ∗ ∗||||||*Intake*[*g*/(*head*· *d*)]|201.94±0.00|198.06±0.00|211.65±0.00|188.29±0.00||*Output*[*g*/(*head*· *d*)]|90.60±4.39^{b}|75.83±0.97^{c}|112.30±3.88^{a}|89.85±1.15^{b}||*Retention*[*g*/(*head*· *d*)]|111.34±4.39^{b}|122.23±0.97^{a}|99.35±3.88^{c}|98.43±1.15^{c}||*Apparentdigestibility*(±2.18^{b}|61.71±0.4			

In the same row, values with the same or no superscript letters indicate no significant difference (P>0.05), while different letters indicate significant difference (P<0.05). The same applies below.

Effects of Pelleting on CP, OM, and DM Apparent Digestibility

As shown in Table 4 , at the low peNDF level, diet A exhibited significantly lower CP, OM, and DM apparent digestibility than diet B (P<0.05), with reductions of 27.71%, 9.17%, and 14.15%, respectively. At the high peNDF level, diet C showed significantly lower CP, OM, and DM apparent digestibility than diet D (P<0.05), with reductions of 19.52%, 8.04%, and 15.60%, respectively. These results demonstrate that pelleting enhanced CP, OM, and DM digestibility. In powder form, diet A had significantly higher CP, OM, and DM digestibility than diet C (P<0.05), with improvements of 7.38%, 11.76%, and 18.74%, respectively. In pelleted form, diet B showed significantly higher CP, OM, and DM digestibility than diet D (P<0.05), with improvements of 13.32%, 12.68%, and 17.71%, respectively, indicating that low peNDF levels improved nutrient digestibility.

Table 4. Effects of pelleted diets with different peNDF levels on CP, OM, and DM apparent digestibility in goats (n=4), %

Item	Diet A	Diet B	Diet C	Diet D
CP	52.55$±1.78^{c}	67.11±1.31^{a}	48.67±1.13^{d}	58.17±0.16^{b}
OM	70.09±1.04^{b}	76.52±0.98^{a}	61.85±1.31^{d}	6

Effects of Pelleting on Nitrogen Metabolism

As shown in Table 5 , nitrogen intake did not differ significantly among diets (P>0.05). At the low peNDF level, diet A exhibited significantly lower nitrogen retention, retention rate, and biological value than diet B (P<0.05). At the high peNDF level, while nitrogen retention and biological value did not differ significantly between diets C and D (P>0.05), diet C showed 24.34% and 18.98% reductions in these parameters compared to diet D, and nitrogen retention rate was significantly lower (P<0.05). These findings indicate that pelleting promotes nitrogen deposition and utilization. In powder form, nitrogen retention, retention rate, and biological value did not differ significantly between diets A and C (P>0.05), though diet A showed 10.99% higher biological value. In pelleted form, all nitrogen metabolism parameters were significantly higher in diet B than diet D (P<0.05), suggesting that low peNDF levels favor nitrogen utilization.

Table 5. Effects of pelleted diets with different peNDF levels on nitrogen metabolism in goats (n=4)

Item	Diet A	Diet B	Diet C	Diet D
N intake [g/(head · d)]	14.37$±0.00	14.38±0.00	14.62±6.91	14.32±6.43
$FecalN$[$g/(head\cdot d)$]	6.30±0.73^{a}	5.14±0.46^{b}	6.91±0.71^{a}	6.43±0.60^{a}
$UrinaryN$[$g/(head\cdot d)$]	4.39±0.25^{a}	2.62±0.18^{c}	3.52±0.36^{b}	2.68±0.41^{c}
$Nretention$[$g/(head\cdot d)$]	3.68±0.72^{c}	6.62±1.27^{a}	4.19±0.48^{bc}	5.21±0.94^{b}
$Nretentionrate$(%	±2.17^{c}	46.04±7.55^{a}	28.66±1	

Effects of Pelleting on Calcium and Phosphorus Apparent Digestibility

As shown in Table 6 , Ca and P intake did not differ significantly among diets (P>0.05). At the low peNDF level, diet A showed significantly lower Ca and P apparent digestibility than diet B (P<0.05). At the high peNDF level, P digestibility did not differ significantly between diets C and D (P>0.05), but Ca digestibility was significantly lower in diet C than diet D (P<0.05), with a 6.93% reduction. These results indicate that pelleting enhances Ca and P absorption. In powder form, diet A exhibited significantly higher P digestibility than diet C (P<0.05), and while Ca digestibility did not differ significantly, diet A showed 4.25% higher Ca digestibility. In pelleted form, diet B had significantly higher P digestibility than diet D (P<0.05), and while Ca digestibility did not differ significantly, diet B showed 7.80% higher Ca digestibility, suggesting that low peNDF levels improve mineral utilization.

Table 6. Effects of pelleted diets with different peNDF levels on Ca and P apparent digestibility in goats

Item	Diet A	Diet B	Diet C	Diet D
Ca				
Intake [g/(head · d)]	5.52$±0.00\|5.42±0.00\|5.66±0.00\|5.85±0.00\|\|*Output*[*g*/(*head*· *d*)]\|3.82±0.25^{b}\|3.50±0.19^{b}\|3.93±0.13^{a}\|3.94±0.10^{a}\|\|*Apparentdigestibility*(±4.43^{bc}\|35.27±3.45^{a}|30			
	$*P*			
	*||||||*Intake*[*g*/(*head*· *d*)]|4.58±0.00|4.62±0.00|4.62±0.00|4.61±0.00||*Output*[*g*/(*head*· *d*)]|3.01±0.07^{b}|2.87±0.09^{b}|3.27±0.10^{a}|3.28±0.07^{a}||*Apparentdigestibility*(±1.63^{b}|37.71±2.04^{a}|29.		

Effects of Pelleting on Gross Energy Apparent Digestibility

As shown in Table 7 , GE intake did not differ significantly among diets (P>0.05). At the low peNDF level, GE apparent digestibility did not differ significantly between diets A and B (P>0.05), though diet A was 1.65% lower. At the high peNDF level, diet C exhibited significantly lower GE apparent digestibility than diet D (P<0.05). These results indicate that pelleting improves energy utilization efficiency. In powder form, diet A showed significantly higher GE digestibility than diet C (P<0.05). In pelleted form, diet B had significantly higher GE digestibility than diet D (P<0.05), suggesting that low peNDF levels enhance energy utilization.

Table 7. Effects of pelleted diets with different peNDF levels on GE apparent digestibility in goats (n=4)

Item	Diet A	Diet B	Diet C	Diet D
GE intake (kJ/d)	135.81$±0.00\|138.05±0.00\|132.71±0.00\|141.12±0.00\|\|$Fecalenergy(kJ/d)$\|47.43±1.16^{c}|46.26±0.8			

Discussion

Effects on NDF and ADF Apparent Digestibility

Pelleted diets influence rumen retention time and nutrient digestibility in ruminants. The complex three-dimensional structure of rice straw cell walls resists microbial degradation, resulting in low digestibility when fed directly. This study improved the nutritional value of rice straw physically through pelleting complete diets. The results showed that pelleting significantly enhanced fiber apparent digestibility, substantially improving dietary nutritional value. The primary mechanism involves saponification of ester bonds between lignin and carbohydrates or within phenolic acid-carbohydrate complexes, making carbohydrates more digestible. Under identical formulations, pelleting increased NDF and ADF apparent digestibility. Low peNDF levels improved NDF and ADF digestibility by reducing forage particle size and increasing microbial contact area. Moreover, low peNDF pelleted diets showed more pronounced improvements in fiber digestibility than high peNDF pelleted diets. However, further research is needed to determine whether low peNDF pelleted diets affect rumen wall development in fattening goats.

Effects on CP, DM, and OM Apparent Digestibility

Pelleting significantly improved CP, DM, and OM apparent digestibility under our experimental conditions. Shi et al. [**?**] reported that pelleted total mixed rations increased CP digestibility but decreased DM and OM digestibility in young sheep compared to powder diets. Sun et al. [**?**] found that pelleted diets improved nutrient apparent digestibility compared to powder diets, likely due to reduced forage particle size increasing effective contact with digestive enzymes. Few studies have examined peNDF effects on nutrient digestibility in sheep. Our results showed that low peNDF diets significantly increased CP, DM, and OM apparent digestibility compared to high peNDF diets, consistent with findings by Yang et al. [**?**] and Zhao et al. [**?**].

Effects on Nitrogen Metabolism

For ruminants, nitrogen retention is more practically significant than apparent digestibility. Our results demonstrate that pelleting increased nitrogen retention and biological value at both peNDF levels, suggesting improved nitrogen absorption and utilization. This may result from reduced rumen protein degradation rates and increased microbial protein synthesis flowing to the small intestine.

Dong et al. [?] reported significantly increased nitrogen retention in pregnant ewes fed pelleted diets. Dietary peNDF levels affect rumen digesta passage rate and microbial protein synthesis. Yang et al. [?] found that low peNDF diets increased the proportion of microbial nitrogen in duodenal nitrogen and improved nitrogen biological value in the small intestine. Our finding that low peNDF diets enhanced nitrogen retention and biological value aligns with these results.

Effects on Calcium and Phosphorus Apparent Digestibility

Ruminants excrete approximately 95–98% of phosphorus through feces, with minimal urinary excretion. Calcium digestibility depends on dietary calcium content, inorganic calcium availability, and small intestinal absorption capacity. When adequate available calcium is provided, dietary calcium absorption generally meets requirements. Pelleting improved calcium and phosphorus digestibility in our study. Limited research exists on peNDF effects on mineral digestibility. Our results showed that low peNDF diets improved calcium and phosphorus apparent digestibility, indicating higher absorption and utilization efficiency in hybrid goats under these conditions.

Effects on Gross Energy Apparent Digestibility

Few studies have examined peNDF effects on energy digestibility in ruminants. Digestible energy directly reflects digestible dry matter content. After ingestion, cellulose, protein, carbohydrates, and fats are digested and metabolized to produce energy, which is converted to ATP—the ultimate energy form utilized by animals. Volatile fatty acids (VFA) are the primary energy source for ruminants. Fecal energy typically accounts for about one-third of ingested GE [?], representing the main energy loss. Our results showed increased GE apparent digestibility after pelleting, suggesting improved energy metabolism. The increased energy digestibility may result from faster digesta passage reducing energy expenditure on eating, rumination, and rumen motility, thereby increasing net energy value, improving metabolizable energy utilization, and enhancing energy intake and conversion efficiency [?]. Low peNDF diets (A and B) showed higher GE apparent digestibility than high peNDF diets (C and D), indicating that low peNDF levels facilitate energy utilization in goats.

Conclusion

At both high and low peNDF levels, pelleting significantly improved apparent digestibility of NDF, ADF, CP, DM, OM, GE, calcium, and phosphorus, as well as nitrogen retention rate and biological value in goats.

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