Determination and Estimation of the Effective Energy Value of Peanut Vines as a Sole Roughage for Meat Sheep (Postprint)

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Abstract

This experiment aimed to determine and estimate the effective energy value of peanut vine for meat sheep using the substitution method and interpolation method, determine the appropriate substitution proportion of peanut vine in diets for the substitution method, and provide a methodological reference for the determination and estimation of effective energy values of single-straw forages. Fifty-four healthy adult Dorper × Small-tailed Han sheep F1 wethers with good body condition and body weight of (45.00$±$1.96) kg were selected and randomly assigned to 9 groups using a randomized block design. The diets consisted of a basal diet, a whole peanut vine diet, and experimental diets with 10%, 20%, 30%, 40%, 50%, 60%, and 70% peanut vine substituting the basal diet, respectively, with 6 replicates per group and 1 sheep per replicate. The preliminary period lasted for 10 days; the experimental period lasted for 9 days, including 3 days of gas metabolism trial and 6 days of digestion and metabolism trial. The results showed: 1) The apparent digestibility of peanut vine dry matter (DM) in the whole peanut vine diet group was not significantly different from the 20%, 30%, and 40% groups ($P>0.05$), but was significantly higher than the other groups ($P<0.05$). The apparent digestibility of peanut vine organic matter (OM) in the whole peanut vine diet group was not significantly different from the 20% group ($P>0.05$), but was significantly higher than the other groups ($P<0.05$). The apparent digestibility of peanut vine gross energy (GE), neutral detergent fiber (NDF), acid detergent fiber (ADF), and ether extract (EE) in the whole peanut vine diet group was significantly higher than the 10% group ($P<0.05$), while the apparent digestibility of crude protein (CP) was significantly lower than the 10% group ($P<0.05$), with no significant differences from the other groups ($P>0.05$). 2) The digestible energy (DE) and metabolizable energy (ME) of peanut vine showed the same trend, that is, the DE and ME of the whole peanut vine diet group (8.57, 6.69 MJ/kg DM) were not significantly different from the 20% (8.22, 6.58 MJ/kg DM), 30% (8.02, 6.50 MJ/kg DM), and 40% groups (8.10, 6.52 MJ/kg DM) ($P>0.05$), but were significantly higher than the other groups ($P<0.05$). 3) The "true value" of peanut vine ME obtained by the interpolation method was 6.62 MJ/kg DM, which was close to the peanut vine ME obtained by the substitution method. In conclusion, the substitution method can be used to estimate the DE and ME of peanut vine (a single roughage) for meat sheep; when using the substitution method to determine the effective energy value of peanut vine straw roughage, the appropriate substitution proportion in the diet is 20%~40%.

Full Text

Determination and Estimation of Available Energy Value of Peanut Vine as a Single Roughage for Mutton Sheep

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Abstract

This study aimed to determine and estimate the available energy value of peanut vine for mutton sheep using both substitution and extrapolation methods, and to identify the appropriate substitution proportion of peanut vine in diets when using the substitution method, thereby providing a methodological reference for determining and estimating the available energy value of single straw feedstuffs.

Fifty-four healthy adult crossbred wethers (Dorper × Small-tailed Han F1) with a body weight of (45.00 ± 1.96) kg were used in a randomized block design. The sheep were divided into nine groups (six replicates per group, one sheep per replicate) and fed either a basal diet, a full peanut vine diet, or experimental diets in which peanut vine replaced 10%, 20%, 30%, 40%, 50%, 60%, or 70% of the basal diet. The adaptation period lasted 10 days, followed by a 9-day experimental period comprising 3 days of gas metabolism testing and 6 days of digestion and metabolism testing.

The results showed: (1) The dry matter (DM) apparent digestibility of peanut vine in the full peanut vine diet group was not significantly different from the 20%, 30%, and 40% groups ($P > 0.05$), but was significantly higher than all other groups ($P < 0.05$). The organic matter (OM) apparent digestibility of peanut vine in the full peanut vine diet group did not differ significantly from the 20% group ($P > 0.05$), but was significantly higher than all other groups (P

< 0.05). The gross energy (GE), neutral detergent fiber (NDF), acid detergent fiber (ADF), and ether extract (EE) apparent digestibility values in the full peanut vine diet group were significantly higher than those in the 10% group ($P < 0.05$), while crude protein (CP) apparent digestibility was significantly lower than in the 10% group ($P < 0.05$), with no significant differences observed among the remaining groups ($P > 0.05$). (2) Both digestible energy (DE) and metabolizable energy (ME) of peanut vine followed the same pattern: the full peanut vine diet group (8.57 and 6.69 MJ/kg DM) showed no significant differences from the 20% (8.22 and 6.58 MJ/kg DM), 30% (8.02 and 6.50 MJ/kg DM), and 40% groups (8.10 and 6.52 MJ/kg DM) ($P > 0.05$), but these values were significantly higher than those of other groups ($P < 0.05$). (3) The "true" ME value of peanut vine obtained by extrapolation was 6.62 MJ/kg DM, which closely approximated the ME value derived from the substitution method. In conclusion, the substitution method can be used to estimate the DE and ME of peanut vine as a single roughage for mutton sheep, with an appropriate substitution proportion of 20%-40% in the diet when determining the available energy value of straw feedstuffs.

Keywords: mutton sheep; energy determination; metabolizable energy; substitution method; peanut vine; available energy value

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Introduction

China has a long history of sheep production and ranks first globally in sheep inventory, slaughter volume, and mutton output. From 2003 to 2014, the national sheep inventory remained stable at 280-300 million head. With the expansion of sheep inventory and the mutton industry, production systems have transitioned from small-scale household operations to intensive, standardized farming. The scientific and efficient development of the mutton sheep industry relies on a complete nutritional requirement system, precise feed nutritional parameter database, and appropriate feeding standards. In practical production, to formulate appropriate rations for ruminants, meet their nutritional requirements, optimize dietary formulations, and improve overall production efficiency, feed nutritional parameters matching feeding standards must be determined, such as metabolizable energy (ME) and metabolizable protein values. International standards including the U.S. NRC and UK AFRC predominantly adopt the ME system, and Chinese standards for mutton sheep also use ME. However, accurately obtaining ME values from feedstuffs remains a significant challenge; currently available reference values are mostly derived from in vitro methods or estimated using mathematical formulas [1-3].

The substitution method has been widely applied and yielded satisfactory results in reports on energy value determination and prediction models for single feedstuffs in monogastric animals [4-8]. Determining feed energy values for mutton sheep using in vivo methods presents numerous difficulties. Liu et al. [9]

established prediction equations for effective energy values of compound diets, but few reports exist on evaluating single roughage effective energy values. Zhao et al. [10] found that the substitution method could accurately determine the ME of Leymus chinensis (a roughage) when using an appropriate substitution proportion. ME is an indispensable nutritional parameter for diet formulation, yet the database currently lacks accurate and reliable ME values for roughage ingredients. Therefore, exploring an accurate determination method is urgently needed. Straw is a widely utilized roughage resource, among which peanut vine is nutritionally rich and palatable, representing a typical straw-based roughage. This study selected peanut vine as the test material to investigate the application of the substitution method for evaluating the energy value of single roughage feedstuffs for mutton sheep and to determine the appropriate substitution proportion of peanut vine, providing a methodological basis and relevant parameters for accurate ME determination of straw-based feedstuffs such as peanut vine.

1.1 Experimental Animals and Design

Fifty-four healthy adult crossbred wethers (Dorper × Small-tailed Han F1) with a body weight of (45.00 ± 1.96) kg were divided into nine groups, with six replicates per group and one sheep per replicate. Each sheep was individually housed in stainless steel pens (3.2 m × 0.8 m). Digestion and metabolism trials and gas metabolism trials were conducted at the pilot base of the Chinese Academy of Agricultural Sciences, while sample analysis was performed at the Feed Research Institute of the Chinese Academy of Agricultural Sciences.

1.2.1 Peanut Vine Material

The peanut vine variety was Yuhua 9326. Experimental samples were collected in Jiaxiang County, Jining City, Shandong Province in October 2014, with a stubble height of approximately 3 cm at harvest.

1.2.2 Experimental Diets and Preparation

Experimental diets were formulated according to NRC (2007) [11] for 40–50 kg adult mutton rams at 1.3 times maintenance requirements. Diets included a basal diet, a full peanut vine diet, and seven experimental diets in which peanut vine replaced 10%, 20%, 30%, 40%, 50%, 60%, or 70% of the basal diet. All experimental diets were processed into pelleted feed (diameter 4.5 mm, length 10 mm). Diet composition and nutrient levels are shown in Table 1 .

Table 1 Composition and nutrient levels of experimental diets (dry matter basis)

Item	Basal Diet	Substitution Proportion (%)	Full Peanut Vine Diet
Ingredients			
Peanut vine	-	10–70	100
Corn	-	-	-
Soybean meal	-	-	-
Leymus chinensis	-	-	-
$CaHPO_4$	-	-	-
$CaCO_3$	-	-	-
NaCl	-	-	-
Premix[1]	-	-	-
Total	100	100	100
Nutrient Levels[2]			
GE (MJ/kg)	-	-	-
DM	-	-	-
OM	-	-	-
CP	-	-	-
NDF	-	-	-
ADF	-	-	-
EE	-	-	-

[1]The premix provided per kg of diet: Cu 16.0 mg, Fe 60.0 mg, Mn 40.0 mg, Zn 70.0 mg, I 0.80 mg, Se 0.30 mg, Co 0.30 mg, VA 12,000 IU, VD 5,000 IU, VE 50.0 mg.
[2]Measured values.

1.3 Experimental Methods and Operations

The experimental period lasted 19 days, comprising a 10-day adaptation period and a 9-day experimental period (3 days for gas metabolism testing and 6 days for digestion and metabolism testing). At the end of the trial, feces collected from each sheep were mixed and placed in a 65°C oven for 48 hours, then reweighed after 48 hours of moisture equilibration to calculate initial moisture content. Fecal samples were then ground through a 40-mesh sieve to prepare analytical samples.

1.3.1 Digestion and Metabolism Trial Prior to the trial, maintenance feed intake for zero daily weight gain was determined by feeding the basal diet.

During the experimental period, sheep were limit-fed (1,200 g/d, 600 g at 08:00 and 18:00) with free access to water. The digestion and metabolism trial employed the total collection method using specialized metabolic cages designed by the Feed Research Institute of the Chinese Academy of Agricultural Sciences, which automatically separate feces and urine. Daily fecal output was weighed and recorded, with 10% sampled. Fecal samples from each sheep over 6 days were mixed and stored frozen. Urine was collected in plastic buckets containing 100 mL of 10% H_2SO_4, diluted to 5 L (to prevent uric acid precipitation during storage), thoroughly mixed, filtered through gauze, and 20 mL of daily urine sample was taken. Urine samples from each sheep over 6 days were mixed and stored at -20°C.

1.3.2 Gas Metabolism (Respiratory Calorimetry) Trial Gas metabolism was measured using a closed-circuit respiratory chamber system (Sable) with an LGR gas analyzer to determine methane production, carbon dioxide production, and oxygen consumption. The system connected six sealed respiratory chambers, enabling continuous measurement and recording of respiratory status for six animals simultaneously. Experimental sheep were moved into the chambers in nine batches, with six sheep from the same group measured per batch. Sheep were adapted to the chambers for 24 hours, followed by 48 hours of methane production measurement (including methane from both respiratory and digestive tracts) for dietary ME calculation.

1.3.3 Extrapolation Method for ME Determination The extrapolation method is commonly used to estimate feed ME values [12]. The test feed ingredient is combined with a basal diet at different ratios to create graded mixed diets, and the ME of each mixed diet is determined through digestion and metabolism trials. Using the proportion of test ingredient in the diet (%) as the independent variable (X) and the measured ME values of mixed diets as the dependent variable (Y), a regression equation is established. Setting X = 100 yields the extrapolated "true" ME value of the test ingredient.

1.4.1 Nutrient Determination Methods

Diet, ingredient, and fecal samples were analyzed for dry matter (DM), crude protein (CP), ether extract (EE), neutral detergent fiber (NDF), acid detergent fiber (ADF), crude ash content, and gross energy (GE), while ingredient samples were also analyzed for calcium (Ca) and phosphorus (P) content, according to *Feed Analysis and Feed Quality Detection Technology* [13].

1.4.2 ME Determination

Urine Energy (UE) Determination: Three quantitative filter papers were weighed (m_1) and their energy value determined using a Parr 6400 bomb calorimeter in triplicate to calculate filter paper GE. Another three filter papers were weighed (m_2), then 10 mL of urine was applied dropwise to each paper, dried at 65°C, cooled, and reweighed (m_3). The GE of filter paper plus urine was then determined in the Parr 6400 bomb calorimeter.

UE = (GE of filter paper and urine) × m_3 - GE of filter paper × m_2
ME = GE - Fecal Energy (FE) - UE - Methane Energy
Methane Energy (kJ) = Methane production (L) × 39.54 (kJ/L) [14]

1.5 Calculation Formulas

Diet and ingredient nutrient apparent digestibility calculations followed Adeola et al. [15]:

Diet nutrient apparent digestibility (%) = (Nutrient intake - Nutrient in feces) / Nutrient intake × 100

Ingredient nutrient apparent digestibility (%) = [Diet nutrient apparent digestibility - (100 - X) × Basal diet nutrient apparent digestibility] / X

Where: X is the substitution proportion of test ingredient for basal diet (%).

Substitution method ingredient energy value calculation followed Liu [7] and Tao [16]:

Energy value = [Test diet energy value - (100 - X) × Basal diet energy value] / X

Where: X is the substitution proportion of test ingredient for basal diet (%). Energy values include digestible energy (DE) and metabolizable energy (ME), expressed in MJ/kg.

1.6 Statistical Analysis

Experimental data were analyzed using the ANOVA procedure in SAS 9.2 statistical software for one-way analysis of variance, with Duncan' s multiple comparison test used for intergroup comparisons. Differences were considered significant at $P < 0.05$.

2.1 Nutrient Composition of Peanut Vine

The measured nutrient levels of peanut vine are shown in Table 2 .

Table 2 Nutrient levels of peanut vine (dry matter basis)

Item	Content
Gross energy (GE, MJ/kg DM)	-
Dry matter (DM)	-
Organic matter (OM)	-
Crude protein (CP)	-

Item	Content
Ether extract (EE)	-
Neutral detergent fiber (NDF)	-
Acid detergent fiber (ADF)	-
Calcium (Ca)	-
Phosphorus (P)	-

2.2 Effects of Different Peanut Vine Substitution Proportions on Diet Nutrient Apparent Digestibility

Table 3 presents the effects of different peanut vine substitution proportions on diet nutrient apparent digestibility. Peanut vine substitution proportion significantly affected the apparent digestibility of all dietary nutrients ($P < 0.05$). With increasing peanut vine substitution proportion, apparent digestibility of dietary DM, OM, CP, GE, and EE decreased, while NDF and ADF apparent digestibility fluctuated within a certain range.

Table 3 Effects of different peanut vine substitution proportions on nutrient apparent digestibility of diets (%)

Item	Basal Diet	Substitution Proportion (%)	Full Peanut Vine Diet	P-value
DM	63.10a	65.13a	62.60a	66.21a
OM	-	-	-	-

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

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