

Effects of Dietary Palm Oil Fat Powder Supplementation Levels on Growth Performance and Nutrient Digestion and Metabolism in Finishing Hu Sheep (Postprint)

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Abstract

This experiment investigated the effects of dietary palm oil fat powder supplementation levels on growth performance and nutrient digestion and metabolism of Hu sheep during the fattening period, aiming to determine the appropriate supplementation level of palm oil fat powder in the diet. Eighty 4-month-old Hu sheep rams in good body condition with body weight of (30 ± 1) kg were randomly divided into 4 groups, with 4 replicates per group and 5 sheep per replicate. Four experimental diets were formulated with palm oil fat powder supplementation levels of 1%, 3%, 5%, and 7%, respectively. The feeding trial consisted of a 10-day preliminary period and a 60-day formal experimental period. When the average body weight of the experimental sheep reached 40 kg, 6 sheep close to the average body weight were selected from each group for a digestion and metabolism trial using the total collection of feces and urine method. The digestion and metabolism trial consisted of a 5-day preliminary period and a 5-day formal experimental period. The results showed: 1) The average daily gain (ADG) during the entire period (1-60 d) in the 1% and 3% groups was significantly higher than that in the 5% and 7% groups ($P < 0.05$); the dry matter intake (DMI) during the entire period decreased linearly with increasing palm oil fat powder supplementation level ($P < 0.05$); the feed conversion ratio (FCR) during the entire period in the 3% group was significantly lower than that in the other groups ($P < 0.05$). 2) There were no significant differences among groups in the apparent digestibility of dry matter, organic matter, ether extract, and neutral detergent fiber ($P > 0.05$). 3) No significant differences were observed among groups in any of the energy metabolism indices ($P > 0.05$). 4) The apparent nitrogen digestibility increased linearly with increasing palm oil fat powder supplementation level ($P < 0.05$), while there were no significant differences in retained nitrogen among groups ($P > 0.05$). Under the conditions of this experi-

ment, and considering the growth performance, apparent nutrient digestibility, energy metabolism, and nitrogen metabolism indices of Hu sheep during the fattening period, the appropriate supplementation level of palm oil fat powder in the diet for fattening Hu sheep was 3%.

Full Text

Effects of Palm Oil Powder Supplemental Level on Growth Performance and Nutrient Digestion and Metabolism of Finishing Hu Sheep

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Abstract: This experiment investigated the effects of palm oil powder supplemental level on growth performance and nutrient digestion and metabolism in finishing Hu sheep to determine the appropriate supplemental level. Eighty 4-month-old male Hu sheep with good body condition and initial body weight of (30±1) kg were randomly allocated into 4 groups with 4 replicates per group and 5 sheep per replicate. Four experimental diets were formulated with palm oil powder supplemental levels of 1%, 3%, 5%, and 7%, respectively. The feeding trial consisted of a 10-day adaptation period followed by a 60-day experimental period. When the average body weight reached 40 kg, six sheep per group with body weight close to the group mean were selected for a digestion and metabolism trial using total fecal and urine collection. The digestion and metabolism trial included a 5-day adaptation period and a 5-day collection period. The results showed: (1) The average daily gain during the entire period (days 1-60) in the 1% and 3% groups was significantly higher than that in the 5% and 7% groups ($P<0.05$). Dry matter intake during the entire period decreased linearly with increasing palm oil powder level ($P<0.05$). The feed-to-gain ratio in the 3% group was significantly lower than in other groups ($P<0.05$). (2) No significant differences were observed among groups in apparent digestibility of dry matter, organic matter, ether extract, or neutral detergent fiber ($P>0.05$). (3) No significant differences were found among groups in any energy metabolism indices ($P>0.05$). (4) Nitrogen apparent digestibility increased linearly with increasing palm oil powder level ($P<0.05$), while retained nitrogen did not differ significantly among groups ($P>0.05$). Under the conditions of this experiment, considering growth performance, nutrient apparent digestibility, energy metabolism, and nitrogen metabolism indices, the appropriate supplemental level of palm oil powder in finishing Hu sheep diets is 3%.

Keywords: palm oil powder; finishing period; Hu sheep; growth performance;

digestion and metabolism

Introduction

China is the world's largest sheep producer, with mutton production accounting for approximately 30% of global output [1-2]. As intensification increases, sheep production performance can be further enhanced, making adequate energy supply increasingly critical for finishing. In practice, dietary energy levels are typically increased through carbohydrates and fats. However, carbohydrate addition is limited due to risks of rumen acidosis from rapid fermentation [3]. Traditional fat supplementation also negatively affects rumen function, as fats may coat fiber particles, preventing microbial digestion [4], and high concentrations of unsaturated fatty acids in plant oils can be toxic to rumen microorganisms [5]. Additionally, fat-mineral complexes may impair microbial utilization and rumen function [6-7].

Recent research has focused on modifying lipid physicochemical properties in the rumen to improve animal performance. Palm oil powder, produced by hydrogenating palm oil to convert unsaturated fatty acids to saturated forms, has a melting point above rumen temperature, allowing it to bypass rumen fermentation and be digested directly in the abomasum and duodenum for absorption in the small intestine. Due to its high utilization efficiency and minimal impact on rumen microbial activity, it has become a widely used feed fat source [8]. Studies on rumen-protected fats in ruminants are abundant. Research indicates that adding rumen-protected fat to dairy cow diets increases milk yield and fat content [9], with a recommended supplemental level of 3% of dry matter intake. For meat animals, numerous studies show that rumen-protected fat supplementation increases meat production and feed efficiency [10-12]. However, limited reports exist on the effects of different palm oil powder levels on nutrient digestion and metabolism in finishing sheep, and the optimal supplemental level requires further investigation. Therefore, this experiment was conducted to evaluate the effects of varying palm oil powder levels on growth performance and nutrient digestion and metabolism in finishing Hu sheep, providing a theoretical basis for scientifically formulated diets.

Materials and Methods

Experimental Time and Location

The experiment was conducted from September to November 2017 at Xilaiyuan Ecological Agriculture Co., Ltd. in Taizhou, Jiangsu Province.

Experimental Diets

Palm oil powder (sourced from Tianjin Zhengchi International Trade Co., Ltd.; fatty acid composition: C14:0, 1.5%; C16:0, 71.2%; C18:0, 7.5%; C18:1, 9.6%; C18:2, 1.7%; others, 8.5%) served as the primary fat source. Four isonitrogenous

but varying energy diets were formulated with palm oil powder supplemental levels of 1%, 3%, 5%, and 7%. Diets were pelleted (6 mm diameter, 4-6 cm length). Premix was provided by Beijing Precision Animal Research Center, and other ingredients were supplied by the sheep farm. Diet composition and nutrient levels are presented in Table 1 .

Experimental Design

A single-factor design was employed. Eighty 4-month-old non-castrated male Hu sheep weighing (30 ± 1) kg were randomly divided into 4 groups (4 replicates per group, 5 sheep per replicate) and fed diets containing 1%, 3%, 5%, or 7% palm oil powder. The feeding trial lasted 70 days (10-day adaptation, 60-day experimental period). Daily feed intake was recorded, and body weight was measured every 15 days. When average body weight reached 40 kg, six sheep per group with body weight close to the mean were selected for a digestion and metabolism trial using total fecal and urine collection, following methods described by Jia et al. [13]. The digestion and metabolism trial consisted of a 5-day adaptation period and a 5-day collection period.

Feeding Management

Sheep were housed in semi-open pens. All animals were ear-tagged and followed the farm's standard vaccination program. Pens were disinfected every 15 days using 0.5% Baidusha and 0.1% Xinjiermie. Sheep were fed twice daily at 07:00 and 16:00 with ad libitum access to pelleted feed and water. Orts were collected daily during the experimental period to calculate daily dry matter intake.

Measurements

Dietary Nutrient Content Analysis Total energy was determined using a Parr-6400 oxygen bomb calorimeter. Crude protein content was measured with a KDY-9830 automatic Kjeldahl nitrogen analyzer. Dry matter, ether extract, neutral detergent fiber, ash, calcium, and phosphorus were analyzed according to *Feed Analysis and Feed Quality Detection Technology* [14].

Growth Performance Daily feed offered and previous-day ors were recorded accurately to adjust feeding amounts and ensure ad libitum intake. Body weight was recorded every 15 days per replicate. Dry matter intake, average daily gain, and feed-to-gain ratio were calculated from these data.

Digestion and Metabolism Indices During the collection period, feed offered was weighed before feeding, and ors were weighed the following morning to calculate intake. Total feces were collected and weighed before morning feeding; 10% of total fecal weight was stored in self-sealing bags with 10 mL of 10% sulfuric acid per 100 g fresh feces for nitrogen fixation. Daily fecal samples were mixed per sheep and stored at -20°C for analysis. Total urine was collected

daily with 100 mL of 10% sulfuric acid added to collection buckets for nitrogen fixation. Urine samples were diluted to 5 L with tap water, and 20 mL aliquots were stored in collection bottles, mixed daily per sheep, and stored at -20°C. At the end of the trial, diets and orts were ground through a 40-mesh screen for nutrient analysis. Fecal samples were oven-dried at 65°C for 48 h, equilibrated for 48 h under ambient conditions, weighed to calculate initial moisture, ground through a 40-mesh screen, and analyzed for nutrients. Urine samples were analyzed for energy and nitrogen content.

Data Processing and Analysis

Data were organized using Excel 2003. One-way ANOVA was performed using SPSS 22.0. Duncan's multiple comparison test was applied when significant differences were detected ($P < 0.05$). Trends were considered at $0.05 < P < 0.10$. Linear and quadratic trend analyses were conducted for indices significantly affected by palm oil powder level.

Results

Effects of Palm Oil Powder Level on Average Daily Gain

As shown in Table 2, average daily gain exceeded 200 g throughout the trial (days 1-60). The 1% and 3% groups exhibited significantly higher average daily gain than the 5% and 7% groups ($P < 0.05$), indicating negative effects when palm oil powder exceeded 3%. The beneficial effect of 3% supplementation became apparent after day 15 of the trial.

Effects of Palm Oil Powder Level on Dry Matter Intake

Table 4 shows that dry matter intake decreased linearly with increasing palm oil powder level during the entire trial ($P < 0.05$). The 1% group had significantly higher intake than other groups ($P < 0.05$), while the 3% and 5% groups had significantly higher intake than the 7% group ($P < 0.05$).

Effects of Palm Oil Powder Level on Feed-to-Gain Ratio

As shown in Table 4, feed-to-gain ratio exhibited a quadratic trend with increasing palm oil powder level ($0.05 < P < 0.10$). The 3% group achieved the highest feed efficiency, with a significantly lower feed-to-gain ratio than other groups ($P < 0.05$). Elevating palm oil powder to 5% or 7% significantly increased the feed-to-gain ratio ($P < 0.05$). During the first 15 days, the 5% group had a significantly higher feed-to-gain ratio than other groups ($P < 0.05$), while no significant differences were observed among the 1%, 3%, and 7% groups ($P > 0.05$). The 3% group maintained superior feed efficiency throughout the remainder of the trial.

Effects of Palm Oil Powder Level on Nutrient Apparent Digestibility

Table 5 demonstrates that palm oil powder level primarily affected nutrient intake and excretion rather than apparent digestibility ($P>0.05$). Dry matter, organic matter, and neutral detergent fiber intake decreased linearly with increasing palm oil powder level ($P<0.05$), while dry matter excretion showed a linear decreasing trend ($0.05 P<0.10$). Ether extract intake and excretion increased linearly ($P<0.05$). The 3% group exhibited the highest apparent digestibility for dry matter (65.20%), organic matter (69.05%), and ether extract (82.33%), though differences among groups were not significant ($P>0.05$).

Effects of Palm Oil Powder Level on Energy Metabolism

Table 6 shows that palm oil powder level did not significantly affect energy metabolism in finishing Hu sheep ($P>0.05$). No significant differences were observed among groups in gross energy intake, fecal energy, urinary energy, digestible energy, metabolizable energy, gross energy apparent digestibility, gross energy metabolizability, or digestible energy metabolizability ($P>0.05$). Methane energy was estimated as 8% of gross energy intake [15].

Effects of Palm Oil Powder Level on Nitrogen Metabolism

Table 7 reveals that nitrogen intake, fecal nitrogen, and total nitrogen excretion decreased linearly with increasing palm oil powder level ($P<0.05$), while urinary nitrogen showed a linear decreasing trend ($0.05 P<0.10$). Nitrogen apparent digestibility increased linearly ($P<0.05$), with the 1% group significantly lower than the 7% group ($P<0.05$), though no significant differences were observed among the 3%, 5%, and 7% groups ($P>0.05$). Retained nitrogen, nitrogen utilization efficiency, and biological value of nitrogen did not differ significantly among groups ($P>0.05$).

Discussion

Effects on Growth Performance

Growth performance is a key indicator reflecting animal status. In this trial, dry matter intake decreased linearly with increasing palm oil powder level, consistent with Liu et al. [16]. This may occur because animals regulate dry matter intake to maintain stable digestible energy intake; higher dietary energy density from palm oil powder allows animals to meet energy requirements with less feed [17]. However, some studies reported no significant effect of rumen-protected fat on dry matter intake [18-20]. Allen [21] analyzed data from multiple studies and found that calcium fatty acid salts significantly reduced dry matter intake in lactating dairy cows, while effects of hydrogenated fats were inconsistent, suggesting that results vary by fat type and animal species.

Average daily gain is directly related to dry matter intake. This trial demonstrated that palm oil powder level significantly affected average daily gain, with

moderate levels promoting weight gain while excessive or insufficient levels were less effective. This may be because higher palm oil powder levels reduced dry matter intake without improving feed efficiency. Lai et al. [12] reported similar results in 3-month-old fattening ewe lambs fed calcium fatty acid salts at 10, 20, or 30 g/(d · head), where daily gain and feed efficiency initially increased then decreased. However, Zeedan et al. [22] found that increasing protected fat levels (0, 3%, and 5%) in 3-4-year-old Damascus goat diets improved daily gain and feed efficiency, possibly due to negative energy balance during lactation. These findings collectively suggest that optimal palm oil powder levels should be adjusted based on animal species, physiological stage, and dietary energy composition.

Effects on Nutrient Apparent Digestibility

Dry matter and organic matter digestibility are important indicators of animal performance and reflect dietary digestion characteristics [23]. This trial found no significant effect of palm oil powder level on apparent digestibility of dry matter or organic matter. Franulic et al. [24] reported that hydrogenated fat and calcium fatty acid salts at 1.5%, 3.0%, and 6.0% levels did not significantly affect nutrient apparent digestibility in 3-4-month-old Holstein calves. Wang [25] and Xing et al. [26] also found that rumen-protected fat levels did not significantly affect apparent digestibility of dry matter or neutral detergent fiber, consistent with our results. The superior daily gain and feed efficiency observed at 3% palm oil powder may be directly related to higher apparent digestibility of dry matter, organic matter, and ether extract at this level.

Regarding effects on ether extract digestibility, most studies indicate that rumen-protected fat supplementation increases fat digestibility, though results vary. Jenkins et al. [27] found lower fatty acid digestibility in beef cattle fed hydrogenated fat, while Chan et al. [28] reported no significant effect of fat supplementation on whole-tract fatty acid digestibility in dairy cows. This trial showed that increasing palm oil powder level linearly increased ether extract intake and excretion but did not significantly affect apparent digestibility, consistent with Xing et al. [26]. Yang et al. [29] reported linear increases in ether extract apparent digestibility with increasing rumen-protected fat in Jinan cattle, suggesting that differences may be due to animal species and fat type. Limited literature exists on fat powder supplementation in finishing sheep, necessitating reference to cattle studies.

Effects on Energy Metabolism

Energy is fundamental to animal nutrition, as all activities require energy. Dietary energy primarily derives from carbohydrates, fats, and proteins [30]. After gastrointestinal digestion and absorption, nutrients are metabolized to release ATP for energy needs [31]. However, not all dietary energy is utilized; available energy includes digestible energy, metabolizable energy, and net energy [32]. This trial demonstrated that increasing palm oil powder level did not alter

energy intake or utilization efficiency in sheep. Weiss and Wyatt [33] compared different levels of calcium fatty acids and hydrogenated fats, finding that calcium fatty acid salts increased gross energy intake, while hydrogenated fats had no significant effect, consistent with our results. The lack of significant differences in digestible energy among groups supports the hypothesis that reduced dry matter intake at higher palm oil powder levels may represent an adaptive mechanism to maintain stable digestible energy intake. The metabolizable energy to digestible energy ratio (0.85-0.86) in this trial was similar to the empirical formula in NRC (1996) [34] (metabolizable energy = digestible energy \times 0.82). Limited research exists on palm oil powder effects on energy metabolism in finishing sheep, requiring further investigation.

Effects on Nitrogen Metabolism

Nitrogen is an essential nutrient for ruminants, and nitrogen metabolism represents protein metabolism [35]. During digestion, undigested dietary nitrogen, endogenous secretions, microbial nitrogen, and urea are excreted in feces and urine, while the remainder constitutes retained nitrogen, which directly reflects nitrogen utilization efficiency and is more important than apparent digestibility [36]. This trial found that nitrogen apparent digestibility increased linearly with palm oil powder level, but nitrogen intake decreased linearly due to reduced dry matter intake, resulting in no significant improvement in nitrogen retention. Studies show that increased nitrogen intake tends to increase fecal nitrogen excretion [37-38], while excess rumen-degradable protein is primarily excreted as urinary nitrogen, causing linear increases in urinary nitrogen [39-40], consistent with our results.

Literature on fat effects on nitrogen metabolism is inconsistent. Wang [25] and Chan et al. [28] reported no significant differences in whole-tract nitrogen apparent digestibility with fat supplementation. Xing et al. [26] found that increasing rumen-protected fat significantly reduced fecal nitrogen, nitrogen retention, and crude protein apparent digestibility. Yang et al. [29] reported that nitrogen apparent digestibility decreased with increasing rumen-protected fat, while nitrogen retention rate was unaffected. These discrepancies may arise from feeding conditions and animal species differences. In this trial, low-level fat groups consumed more protein, potentially exceeding maximum nitrogen retention requirements and leading to increased nitrogen excretion and reduced utilization efficiency. Additionally, rumen-protected fat may affect small intestine nitrogen digestibility [41].

Conclusions

1. Under these experimental conditions, the optimal supplemental level of palm oil powder in finishing Hu sheep diets is 3%, based on comprehensive evaluation of growth performance, nutrient apparent digestibility, energy metabolism, and nitrogen metabolism indices.

2. Supplementing finishing Hu sheep diets with 3% palm oil powder tends to improve apparent digestibility of dry matter, organic matter, and ether extract.
3. Increasing palm oil powder level in finishing Hu sheep diets linearly increases nitrogen apparent digestibility without significantly affecting nitrogen retention.
4. Palm oil powder supplemental level does not significantly affect energy metabolism in finishing Hu sheep.

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