Evaluation of the Available Energy Value of Soybean Lecithin Oil and Its Application Effects in Piglet Diets: Post-Print

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Abstract

This study comprised two experiments. Experiment 1 aimed to evaluate the effective energy value of soybean lecithin oil, while Experiment 2 investigated the effects of soybean lecithin oil on growth performance, serum lipid metabolism, and rectal microbial counts in weaned piglets. Experiment 1 (metabolism trial): Sixteen "Duroc × Landrace × Large White" barrows with an average body weight of (27.54$±$1.20) kg were selected and randomly allocated into two groups, with eight replicates per group and one pig per replicate. The pigs were fed either a basal diet or a test diet in which 4% soybean lecithin oil replaced the basal diet, with a 5-day preliminary period and a 4-day formal collection period. Experiment 2 (feeding trial): Fifty-four "Duroc × Landrace × Large White" piglets weaned at 23 days of age with an initial body weight of (6.50$±$0.48) kg were randomly divided into three groups according to the principle of similar body weight, with six replicates per group and three pigs per replicate. The groups were fed a basal diet (containing 2% soybean oil, control group), a 1.0% lecithin oil diet (soybean lecithin oil isocalorically replaced 50% of the soybean oil in the basal diet, i.e., containing 1.0% soybean oil + 1.0% lecithin oil), or a 1.5% lecithin oil diet (soybean lecithin oil isocalorically replaced 50% of the soybean oil in the basal diet, i.e., containing 1.0% soybean oil + 1.5% lecithin oil) for a 35-day experimental period. The metabolism trial results showed that the apparent digestible energy of soybean lecithin oil was 31.32 MJ/kg, and the apparent metabolizable energy was 30.07 MJ/kg. The feeding trial results indicated that, compared with the control group: 1) On days 15-35, the average daily feed intake (ADFI) of piglets in the 1.0% and 1.5% lecithin oil diet groups increased by 6.23% and 3.13%, respectively, and the average daily gain (ADG) increased by 6.66% and 5.28%, respectively (P>0.05); on days 1-35, the ADFI and ADG of piglets in the 1.0% lecithin oil diet group increased by 5.34% and 5.64%, respectively (P>0.05). 2) The diarrhea rate and

diarrhea index of piglets in the 1.0% lecithin oil diet group decreased by 5.81% and 13.41%, respectively (P>0.05). 3) The serum triglyceride and free fatty acid concentrations in piglets of the 1.0% lecithin oil diet group decreased by 10.91% and 12.80%, respectively (P>0.05); in the 1.5% lecithin oil diet group, serum triglyceride, total cholesterol, and high-density lipoprotein cholesterol concentrations decreased by 7.27%, 5.33%, and 10.53%, respectively (P>0.05). 4) On day 15, the rectal fecal Escherichia coli count in piglets of the 1.0% and 1.5% lecithin oil diet groups decreased by 4.88% and 4.12%, respectively (P>0.05); on day 36, the rectal fecal Escherichia coli count in piglets of the 1.0% lecithin oil diet group decreased by 4.88% (P>0.05). In conclusion, the apparent digestible energy of soybean lecithin oil was 31.32 MJ/kg, and the apparent metabolizable energy was 30.07 MJ/kg; dietary supplementation with 1.0% soybean lecithin oil to isocalorically replace soybean oil in the basal diet could improve ADFI and ADG to a certain extent and reduce the diarrhea rate and rectal fecal Escherichia coli count in piglets.

Full Text

Evaluation of Effective Energy Value and Application Effects of Soybean-Lecithin Oil in Weaned Piglet Diets

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Abstract

This study comprised two experiments. Experiment 1 aimed to evaluate the effective energy value of soybean-lecithin oil, while Experiment 2 investigated its effects on growth performance, serum lipid metabolism, and rectal microflora populations in weaned piglets. In Experiment 1 (metabolism trial), sixteen emasculated "Duroc × Landrace × Large White" crossbred barrows with an average body weight of $(27.54\$\pm1.20)kgwererandomlyallocatedto2groups, eachconsistingof8replicateswith1pigperreplicate.Thepigs$ kg were randomly assigned to 3 groups based on similar body weight, with 6 replicates per group and 3 pigs per replicate. The dietary treatments consisted of: (1) a basal diet containing 2% soybean oil (control group), (2) a 1.0% soybean-lecithin oil diet (in which soybean-lecithin oil replaced 50% of the soybean oil in the basal diet on an equal weight basis, resulting in 1.0% soybean oil + 1.0% soybean-lecithin oil), and (3) a 1.5% soybean-lecithin oil diet (in which soybean-lecithin oil replaced 50% of the soybean oil in the basal diet on

an equal energy basis, resulting in 1.0% soybean oil + 1.5% soybean-lecithin oil). The experimental period lasted 35 days.

The metabolism trial results indicated that soybean-lecithin oil contained 31.32 MJ/kg apparent digestible energy and 30.07 MJ/kg apparent metabolizable energy. The feeding trial results showed that, compared with the control group: (1) During days 15–35, the average daily feed intake (ADFI) of piglets in the 1.0% and 1.5% soybean-lecithin oil groups increased by 6.23% and 3.13%, respectively, while their average daily gain (ADG) increased by 6.66% and 5.28% ($P>0.05$). Over the entire experimental period (days 1–35), the ADFI and ADG of piglets in the 1.0% soybean-lecithin oil group increased by 5.34% and 5.64%, respectively ($P>0.05$). (2) The diarrhea rate and diarrhea index in the 1.0% soybean-lecithin oil group decreased by 5.81% and 13.41%, respectively ($P>0.05$). (3) Serum triglyceride and free fatty acid concentrations in the 1.0% soybean-lecithin oil group decreased by 10.91% and 12.80%, respectively ($P>0.05$), while serum triglyceride, total cholesterol, and high-density lipoprotein cholesterol concentrations in the 1.5% soybean-lecithin oil group decreased by 7.27%, 5.33%, and 10.53%, respectively ($P>0.05$). (4) On day 15, the rectal fecal *Escherichia coli* counts in the 1.0% and 1.5% soybean-lecithin oil groups decreased by 4.88% and 4.12%, respectively ($P>0.05$); on day 36, the rectal fecal *E. coli* count in the 1.0% soybean-lecithin oil group decreased by 4.88% ($P>0.05$). In conclusion, the apparent digestible energy and apparent metabolizable energy values of soybean-lecithin oil were 31.32 MJ/kg and 30.07 MJ/kg, respectively. Dietary supplementation with 1.0% soybean-lecithin oil to replace soybean oil in the basal diet can improve ADFI and ADG, and reduce diarrhea incidence and rectal fecal *E. coli* populations in weaned piglets.

Keywords: soybean-lecithin oil; effective energy value; weaned piglets; application effects

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Introduction

With the rapid development of the feed industry and modern animal husbandry in China, the shortage of high-quality protein feed ingredients has become increasingly prominent, and the scarcity of energy feed ingredients is also worsening. The supply of high-quality energy sources such as soybean oil is insufficient, and prices continue to rise [1]. Therefore, developing new feed energy ingredients and seeking high-quality, stable alternatives to soybean oil is of great production value and economic significance. Soybean-lecithin oil, also known as liquid lecithin or crude lecithin, is a yellowish viscous byproduct obtained from the degumming process of soybean oil production through vacuum drying and decolorization. Its main components include lecithin, cephalin, inositol phospholipids, unsaturated fatty acids, and soybean oil, which are biologically active substances related to animal growth, development, and immunity [2], and it contains relatively high effective energy. Due to its abundant bioactive

substances and biological functions such as growth promotion [3], antioxidant activity, lipid metabolism enhancement [4], immune system strengthening [5], and biological membrane formation [6], soybean lecithin has extensive applications in the pharmaceutical and food industries [7-8]. Recent studies have shown that soybean lecithin can partially replace vegetable oils in feed, promote animal growth, enhance disease resistance, and reduce equipment wear, and it is gradually being applied in aquaculture and livestock feed with favorable economic results [9-10].

Although numerous studies have reported on soybean-lecithin oil in livestock and poultry production, most have focused on growth performance and nutrient utilization [11-12]. However, reports on the nutritional value of soybean-lecithin oil and its effects on lipid metabolism and intestinal microflora in livestock and poultry are scarce. Meanwhile, due to compositional differences, the nutritional and feed values of soybean-lecithin oil from various sources also differ. Therefore, this study aimed to assess the digestible and metabolizable energy content of a feed-grade soybean-lecithin oil in pigs and examine its effects on piglet growth performance, serum lipid metabolism, and rectal microflora populations, thereby providing experimental evidence for the application of soybean-lecithin oil in pig production.

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1. Materials and Methods

1.1 Experimental Material Soybean-lecithin oil was provided by Guangzhou Yide Biological Technology Co., Ltd. as a viscous, yellowish-brown liquid. Its active components and contents were: phosphatidylcholine 18%, phosphatidylethanolamine 12%, phosphatidylinositol 9%, phosphatidic acid 5%, phosphatidylserine 6%, soybean oil 40%, and other phospholipids, sterols, and compounds 10%.

1.2 Metabolism Experiment

1.2.1 Experimental Design Sixteen emasculated "Duroc × Landrace × Large White" (DLY) crossbred barrows with an average body weight of (27.54$±$1.20) kg were randomly divided into 2 groups based on body weight, with 8 replicates per group and 1 pig per replicate. The pigs were fed either a basal diet or a soybean-lecithin oil test diet. The trial consisted of a 5-day adaptation period followed by a 4-day total collection period.

1.2.2 Experimental Diets The basal diet was formulated as a corn-soybean meal diet according to the NRC (2012) nutrient requirements for 20–50 kg pigs. The composition and nutrient levels of the basal diet are shown in Table 1 . The soybean-lecithin oil test diet was formulated by replacing 4% of the basal diet with soybean-lecithin oil on an equal weight basis.

1.2.3 Animal Management The metabolism trial was conducted at the metabolism laboratory of the research base of the Institute of Animal Nutrition, Sichuan Agricultural University. All experimental pigs were housed individually in metabolism crates under conventional management. Pigs were fed three times daily (08:00, 14:00, and 20:00) with free access to water. After 3 days of observation in the metabolism crates, pigs were weighed and grouped. The total trial period was 9 days, with the first 5 days as the adaptation period during which pigs were allowed ad libitum feed intake to determine consumption levels, and the last 4 days as the total fecal and urine collection period during which feed was provided at 90% of the ad libitum intake level.

1.2.4 Sample Collection and Processing Feed samples were collected according to the national standard GB/T 14699.1-2005 (Feed Sampling Method) using the quartering method. One kilogram of feed samples from each group was ground to pass through a 40-mesh sieve, mixed thoroughly, placed in clean sealed plastic bags, labeled, and stored at -20 °C until analysis.

Fecal and urine samples were collected completely from each pig during the 4-day collection period. Daily fecal output from each pig was collected individually in sample bags, and 10 mL of 10% sulfuric acid was added per 100 g of feces, along with a few drops of toluene as a preservative. Each morning, feces collected from the previous day were mixed, weighed, and subsampled at 15% of the total weight, then stored at -20 °C. Urine was collected in urine containers, with 5 mL of 10% sulfuric acid added per 100 mL of urine. Each morning, urine collected from the previous day was mixed, measured, and subsampled at 3% of the total volume, then stored in sealed containers at -20 °C. After the collection period, all fecal samples from each pig were pooled and mixed thoroughly, then dried at 60–65 °C for 48 hours, rehydrated for 24 hours, weighed, dried again for 24 hours, and rehydrated for another 24 hours. This process was repeated until constant weight was achieved. The dried samples were ground to pass through a 40-mesh sieve and stored at -20 °C until analysis. All urine samples from each pig were pooled and mixed before subsampling and stored at -20 °C.

1.2.5 Measurement Indicators and Methods 1.2.5.1 Dietary Energy Apparent Digestibility and Utilization

Gross energy in feed, fecal, and urine samples was determined using an automatic oxygen bomb calorimeter (PARR-1281, USA) to calculate dietary apparent digestible energy, apparent metabolizable energy, and energy utilization rates. The apparent digestible energy of pig diets was determined according to the national standard GB/T 26438-2010. Energy apparent digestibility and utilization rates were calculated using the total collection method as described by Zhang Liying [13]. The formulas were as follows:

Dietary energy apparent digestibility (%) = [(Total energy intake - Total energy in feces) / Total energy intake] × 100

Dietary energy apparent utilization (%) = [(Total energy intake - Total energy in feces - Total energy in urine) / Total energy intake] × 100

1.2.5.2 Effective Energy Content of Soybean-Lecithin Oil

When using a corn-soybean meal diet as the basal diet, the apparent energy digestibility of soybean-lecithin oil was calculated using the substitution method with the following formula:

D (%) = [(A - B) / F] × 100 + B
Apparent digestible energy of soybean-lecithin oil = Gross energy of soybean-lecithin oil × Apparent digestibility of soybean-lecithin oil

Where: D is the apparent digestibility of the test soybean-lecithin oil (%); A is the apparent energy digestibility of the substituted mixed diet (%); B is the apparent energy digestibility of the basal diet (%); and F is the proportion of energy provided by the test soybean-lecithin oil in the substituted mixed diet (%).

1.3 Feeding Experiment

1.3.1 Experimental Design Fifty-four DLY piglets weaned at 23 days of age with an initial body weight of (6.50$±$0.48) kg were used in a feeding trial. The piglets were randomly divided into 3 groups based on body weight: (1) control group fed the basal diet (containing 2% soybean oil), (2) 1.0% soybean-lecithin oil diet group (in which soybean-lecithin oil replaced 50% of the soybean oil in the basal diet on an equal weight basis, resulting in 1.0% soybean oil + 1.0% soybean-lecithin oil), and (3) 1.5% soybean-lecithin oil diet group (in which soybean-lecithin oil replaced 50% of the soybean oil in the basal diet on an equal energy basis, resulting in 1.0% soybean oil + 1.5% soybean-lecithin oil). Each group consisted of 6 replicates with 3 pigs per replicate. The experimental period lasted 35 days.

1.3.2 Experimental Diets The basal diet was formulated as a corn-soybean meal diet according to the NRC (2012) nutrient requirements for weaned piglets. The composition and nutrient levels of the basal diet are shown in Table 2 .

1.3.3 Animal Management The feeding trial was conducted in the piglet facility at the research base of the Institute of Animal Nutrition, Sichuan Agricultural University. The room temperature was maintained at approximately 25 °C. Pigs were fed four times daily (08:00, 12:00, 16:00, and 20:00) to ensure slight feed remaining in the trough after satiation, with free access to water. Pens were cleaned daily with attention to ventilation. Daily records were kept for feed intake, temperature, relative humidity, and diarrhea incidence. Regular disinfection was performed.

1.3.4 Sample Collection and Processing Serum samples: At the end of the experiment, one piglet with body weight close to the average of each replicate was selected, fasted, and 15 mL of blood was collected from the anterior vena cava. After standing for 30 minutes, the blood was centrifuged at 3,000 r/min for 15 minutes to prepare serum, which was aliquoted into EP tubes and stored at -20 °C.

Rectal fecal samples: On the morning of day 15 and day 36 of the experiment, one piglet with body weight close to the average of each replicate was selected. A sterile cotton swab was inserted 4–5 cm into the rectum, rotated gently, and the feces were quickly placed into sterile cryovials, snap-frozen in liquid nitrogen, and stored for subsequent microbial analysis.

1.3.5 Measurement Indicators and Methods 1.3.5.1 Growth Performance

During the experimental period, daily feed intake for each replicate was recorded accurately. Pigs were weighed at the start of the experiment, on day 15, and on day 36 at 08:00 after fasting, to calculate average daily gain (ADG), average daily feed intake (ADFI), and feed/gain ratio (F/G).

1.3.5.2 Diarrhea Scoring

Throughout the experimental period, the same observer recorded daily the number of piglets with diarrhea and the severity of diarrhea in each replicate, and assigned diarrhea scores according to the criteria shown in Table 3 . The diarrhea rate was calculated according to Yuan et al. [14], and the average diarrhea index was calculated according to Liao [15] using the following formulas:

Diarrhea rate (%) = (Number of piglets with diarrhea during the experimental period) / (Number of pigs per replicate × Number of experimental days) × 100
Average diarrhea index = Diarrhea score / (Number of pigs per replicate × Number of experimental days)

1.3.5.3 Serum Lipid Metabolism

Serum total cholesterol (TC), high-density lipoprotein cholesterol (HDL-C), low-density lipoprotein cholesterol (LDL-C), and triglyceride (TG) concentrations were determined using an automatic biochemical analyzer (HITACHI-7020, Hitachi Ltd., Japan). Free fatty acid (FFA) concentration was measured using a Shanghai Mepda UV-1100 UV-Vis spectrophotometer. All assay kits were purchased from Nanjing Jiancheng Bioengineering Institute.

1.3.5.4 Rectal Fecal Microorganisms

Total bacteria, *Escherichia coli*, *Lactobacillus*, *Bifidobacterium*, and *Bacillus* populations in feces were detected using real-time fluorescence quantitative PCR according to the method of Diao [16]. Total DNA was extracted from digesta using the DNA extraction kit from Omega Company and stored at -20 °C. Real-time quantitative PCR was performed using the ABI7900HT Real-Time

PCR System (ABI, USA). Specific primers were designed based on bacterial 16S rRNA gene sequences, and Taqman probes were used for real-time fluorescence quantitative PCR reactions. RealMaster Mix from Tiangen Company was used for detection. Results were expressed as the number of copies per gram of content, calculated from Ct values and standard curves, and presented as the common logarithm of bacterial count per gram [lg(CFU/g)]. The reaction system for *Lactobacillus* and *E. coli* was 20 L: 20× Probe Enhance Solution 1 L, RealMaster Mix 8 L, 1 L each of forward and reverse primers, 1 L DNA, 0.3 L probe, and 7.7 L ddH_2O. The reaction system for *Bifidobacterium* was 20 L: 20× Probe Enhance Solution 1 L, RealMaster Mix 8 L, 1 L each of forward and reverse primers, 1 L DNA, 0.8 L probe, and 7.2 L ddH_2O. The three-step PCR amplification program was: pre-denaturation at 95 °C for 10 s, followed by 50 cycles of 95 °C for 5 s, 50–60 °C for 25 s, and 95 °C for 10 s. Primer and probe sequences were referenced from Qi et al. [17]. The reaction system for total bacteria was 25 L: SYBR Premix Ex Taq™ II 12.5 L, 1 L each of forward and reverse primers, 1 L DNA, and 9.5 L ddH_2O. The three-step PCR amplification program was: pre-denaturation at 95 °C for 10 s, followed by 40 cycles of 95 °C for 5 s, 50–60 °C for 25 s, and 95 °C for 10 s, with a melting curve analysis at 95 °C for 39 s, 55 °C for 1 min, and 95 °C for 1 min. Primer design was referenced from Fierer et al. [18]. PCR primer and probe sequences are shown in Table 4 .

1.4 Data Processing and Statistical Analysis All experimental data were initially organized using Excel 2010. Data from Experiment 1 were analyzed using independent samples t-test in SPSS 19.0 software. Data from Experiment 2 were analyzed using one-way ANOVA combined with Duncan' s multiple comparison test in SPSS 19.0 software. Results were expressed as mean ± standard error, with $P<0.05$ considered statistically significant.

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2. Results

2.1 Effects of Soybean-Lecithin Oil on Dietary Energy Digestibility and Effective Energy Content As shown in Table 5 , there was no significant difference in gross energy apparent digestibility between the two diets ($P>0.05$). However, the digestible energy and metabolizable energy values of the soybean-lecithin oil diet were significantly higher than those of the basal diet ($P<0.05$). Using the substitution method calculation formula, the apparent digestible energy of soybean-lecithin oil was determined to be 31.32 MJ/kg, and the apparent metabolizable energy was 30.07 MJ/kg.

2.2 Effects of Soybean-Lecithin Oil on Growth Performance of Weaned Piglets As shown in Table 6 , there were no significant differences in ADFI, ADG, or F/G between the 1.0% and 1.5% soybean-lecithin oil groups and the control group at any experimental stage ($P>0.05$). However,

compared with the control group, during days 15–35, ADFI increased by 6.23% and 3.13%, and ADG increased by 6.66% and 5.28% in the 1.0% and 1.5% soybean-lecithin oil groups, respectively. Over the entire experimental period (days 1–35), ADFI and ADG in the 1.0% soybean-lecithin oil group increased by 5.34% and 5.64%, respectively.

2.3 Effects of Soybean-Lecithin Oil on Diarrhea in Weaned Piglets As shown in Table 7 , there were no significant differences in diarrhea rate or diarrhea index among groups (P>0.05). However, compared with the control group, the diarrhea rate and diarrhea index in the 1.0% soybean-lecithin oil group decreased by 5.81% and 13.41%, respectively, while those in the 1.5% soybean-lecithin oil group increased by 27.56% and 10.98%, respectively.

2.4 Effects of Soybean-Lecithin Oil on Serum Lipid Metabolism in Weaned Piglets As shown in Table 8 , there were no significant differences in serum triglyceride, total cholesterol, low-density lipoprotein cholesterol, high-density lipoprotein cholesterol, or free fatty acid concentrations among groups (P>0.05). However, compared with the control group, serum triglyceride and free fatty acid concentrations in the 1.0% soybean-lecithin oil group decreased by 10.91% and 12.80%, respectively, while serum low-density lipoprotein cholesterol concentration increased by 7.03%. In the 1.5% soybean-lecithin oil group, serum triglyceride, total cholesterol, high-density lipoprotein cholesterol, and free fatty acid concentrations decreased by 7.27%, 5.33%, 10.53%, and 7.69%, respectively.

2.5 Effects of Soybean-Lecithin Oil on Rectal Fecal Microorganism Populations in Weaned Piglets As shown in Table 9 , there were no significant differences in total bacteria, *Bacillus*, *E. coli*, *Lactobacillus*, or *Bifidobacterium* counts in rectal feces among groups on either day 15 or day 36 (P>0.05). However, compared with the control group, on day 15, *Lactobacillus* counts in the 1.0% and 1.5% soybean-lecithin oil groups increased by 5.40% and 4.52%, respectively, while *E. coli* counts decreased by 4.88% and 4.12%, respectively. On day 36, *E. coli* counts in the 1.0% soybean-lecithin oil group decreased by 4.88%, and *Lactobacillus* counts in the 1.5% soybean-lecithin oil group increased by 3.92%.

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3. Discussion

3.1 Effects of Soybean-Lecithin Oil on Dietary Energy Digestibility and Effective Energy Content As an energy ingredient that can replace vegetable oils and reduce feed costs, soybean-lecithin oil has been applied in animal and aquaculture feeds [19]. Research indicates that dietary fat supplementation is an effective method to increase weight gain [20]. Different types of fats vary in their digestibility in animals due to differences in fatty acid chain length and saturation level; shorter fatty acid chains and higher unsaturation

levels result in higher digestibility [21-23]. Additionally, the digestible energy value of fats is related to storage time, oxidation level, and free fatty acid content [24]. This study demonstrated that soybean-lecithin oil had an apparent digestible energy of 31.32 MJ/kg and an apparent metabolizable energy of 30.07 MJ/kg. The possible reasons are: first, soybean-lecithin oil is rich in short-chain unsaturated fatty acids such as linoleic acid and linolenic acid, which promote fat digestion and absorption, as higher unsaturation leads to higher digestible and metabolizable energy values [25]; second, soybean-lecithin oil is rich in phospholipids, which act as excellent emulsifiers that can enhance the digestive and absorptive capacity of nutrients in the small intestine [26-27].

3.2 Effects of Soybean-Lecithin Oil on Growth Performance of Weaned Piglets Studies have shown that soybean-lecithin oil supplementation can promote animal growth, improve feed efficiency, and reduce mortality [28]. Wang et al. [29] reported that adding 5% soybean lecithin to weaned piglet diets significantly increased ADG and reduced F/G by 12.66%. Zhang et al. [30] found that dietary soybean lecithin supplementation was positively correlated with ADG and ADFI in weaned piglets, and suggested that the optimal ratio of soybean lecithin to animal fat in diets was 1:10, similar to the ratio of (0.5–1.0):10 proposed by Jones et al. [31]. However, Overland et al. [32] reported that adding soybean-lecithin oil to diets for piglets with extended weaning age (35 days) or ultra-early weaning (before 21 days) tended to reduce growth performance and fat utilization. These discrepancies may be related to animal age, composition and supplementation level of soybean lecithin, and experimental duration. In this study, during days 15–35, piglets in the groups with equal weight and equal energy replacement of 50% soybean oil showed ADFI increases of 6.23% and 3.13%, and ADG increases of 6.66% and 5.28%, respectively. Over the entire 35-day period, piglets in the equal weight replacement group showed ADFI and ADG increases of 5.34% and 5.64%, respectively, though these differences were not statistically significant. Research suggests that soybean lecithin, with its pleasant fatty aroma, can improve feed palatability [19] and promote feed intake. Additionally, the hydrophobic fatty acid chains and hydrophilic groups in soybean lecithin molecules act as surfactants and emulsifiers, dispersing fat entering the small intestine and increasing the contact area between fat and lipophilic substances with the intestinal mucosa, thereby enhancing fat digestion, absorption, and transport, and improving nutrient utilization. Furthermore, the high content of unsaturated fatty acids in soybean-lecithin oil plays an important role in promoting organ development and body growth in young animals [31-33]. The soybean-lecithin oil product used in this study contained not only a large proportion of soybean lecithin but also 40% soybean oil, thus not only partially replacing soybean oil in the diet but also providing additional biological activity.

3.3 Effects of Soybean-Lecithin Oil on Diarrhea in Weaned Piglets Soybean-lecithin oil is extracted from soybean oil foots and is rich in lecithin and cephalin [34]. Studies both domestically and internationally have shown that adding lecithin to piglet diets can improve dietary protein and energy digestibility, reduce diarrhea caused by indigestion, and promote metabolism [35]. This study also found that equal weight replacement of 50% soybean oil with soybean-lecithin oil reduced diarrhea rate and diarrhea index by 5.81% and 13.41%, respectively. The likely reason is that the abundant phospholipids in soybean-lecithin oil have emulsifying properties that can compensate for the immature digestive function and insufficient bile secretion in weaned piglets, thereby facilitating nutrient digestion and absorption and reducing diarrhea. However, equal energy replacement of 50% soybean oil with soybean-lecithin oil increased diarrhea rate and diarrhea index by 27.56% and 10.98%, respectively, possibly due to inappropriate fat combination ratios in the diet, though the specific mechanism requires further investigation.

3.4 Effects of Soybean-Lecithin Oil on Serum Lipid Metabolism in Weaned Piglets Research indicates that soybean-lecithin oil can regulate lipid metabolism because phospholipids, as components of membrane structures and surface constituents of lipid transport particles, play important regulatory roles in the cardiovascular system. On one hand, soybean lecithin products contain large amounts of unsaturated fatty acids [such as eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA)] and phospholipids, which increase unsaturated fatty acid levels in the body after ingestion, thereby protecting cell membrane integrity. On the other hand, phospholipids can reduce blood lipids by increasing triglyceride transport and emulsifying and clearing cholesterol [36-37]. Polyunsaturated fatty acids in soybean-lecithin oil can esterify with cholesterol to form cholesterol esters. When blood cholesterol is converted to cholesterol esters, it is further converted to bile acids and excreted through the intestine, thereby reducing serum total cholesterol and preventing lipid deposition in the liver and arterial walls. Chi et al. [38] reported that soybean lecithin significantly reduced serum cholesterol, triglyceride, and low-density lipoprotein cholesterol concentrations in rats. Lough et al. [39] also found that appropriate soybean lecithin supplementation reduced serum total cholesterol and low-density lipoprotein cholesterol while increasing high-density lipoprotein cholesterol. Spilburg et al. [40] reported that soybean lecithin reduced cholesterol absorption and plasma low-density lipoprotein cholesterol while increasing high-density lipoprotein cholesterol, likely due to activation of lipoprotein lipase and lecithin cholesterol acyltransferase activities and inhibition of hepatic endothelial lipase activity. Wang et al. [41] demonstrated that soybean lecithin could completely replace soybean oil in broiler diets, reducing abdominal fat and improving meat quality. This study found that equal energy replacement of 50% soybean oil with soybean-lecithin oil reduced serum triglyceride, total cholesterol, and high-density lipoprotein cholesterol concentrations by 7.27%, 5.33%, and 10.53%, respectively, indicating that dietary supplementation with

appropriate amounts of soybean-lecithin oil can indeed regulate animal lipid metabolism.

3.5 Effects of Soybean-Lecithin Oil on Rectal Fecal Microorganism Populations in Weaned Piglets Intestinal microflora constitutes the microbial barrier of the animal gut, and its dynamic balance plays a crucial role in intestinal health. Current research on soybean-lecithin oil has mainly focused on growth performance and lipid metabolism, with limited studies on intestinal microflora. This study found that dietary supplementation with soybean-lecithin oil had no significant effects on rectal fecal microorganism indicators in piglets at either the mid-point or end of the experiment, though it showed a trend toward reducing *E. coli*. On day 15, compared with the control group, equal weight and equal energy replacement of 50% soybean oil reduced rectal fecal *E. coli* counts by 4.88% and 4.12%, respectively. On day 36, equal weight replacement reduced *E. coli* counts by 4.88%. These effects may be related to the regulatory role of medium- and short-chain unsaturated fatty acids such as linolenic acid and linoleic acid in soybean-lecithin oil on intestinal microflora.

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4. Conclusion

This study demonstrated that the apparent digestible energy and apparent metabolizable energy values of soybean-lecithin oil were 31.32 MJ/kg and 30.07 MJ/kg, respectively. Dietary supplementation with 1.0% soybean-lecithin oil to replace soybean oil in the basal diet had positive effects on increasing ADFI and ADG, and reducing diarrhea incidence and rectal fecal *E. coli* populations in weaned piglets.

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