Net Energy Values of Different Soybean Meals for Growing Broilers: A Postprint

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Abstract

This experiment was conducted using a poultry open-circuit respiration calorimetry system to determine the net energy values of different soybean meals for growing broiler chickens by indirect calorimetry combined with the substitution method. A modified Latin square experimental design was adopted, consisting of 6 periods. In each period, sixty 1-day-old Ross 308 male broiler chicks from the same hatchery were randomly allocated into 6 groups with 10 birds per group. The basal diet group received a corn-soybean meal basal diet, while the experimental diet groups received experimental diets formulated by substituting 5 types of soybean meals (3 conventional meals with hulls and 2 dehulled meals) into the basal diet at a 25% ratio. Each period lasted 31 days; birds were reared in the chicken house from days 1 to 20. At 21 days of age, after weighing, two healthy birds with body weight close to the group mean were selected from each group and placed in the metabolic chambers of the respiration calorimetry system for 9 days to measure gas exchange and total excreta output, comprising a 3-day adaptation period, 3-day calorimetric measurement period, and 3-day fasting heat production measurement period. Digestion and metabolism trials were conducted concurrently with the calorimetric measurements. The results showed that compared with the basal diet group, the experimental diet groups had significantly lower apparent metabolizable energy, metabolizable energy intake, retained energy, and net energy ($P<0.05$). This experiment concluded that the apparent metabolizable energy values of the 3 conventional soybean meals with hulls for growing broiler chickens were 9.39, 9.70, and 9.71 MJ/kg, respectively, while those of the 2 dehulled soybean meals were 10.35 and 10.47 MJ/kg. The net energy values of the 3 conventional soybean meals with hulls for growing broiler chickens were 5.71, 5.84, and 5.50 MJ/kg, respectively, while those of the 2 dehulled soybean meals were 6.04 and 6.31 MJ/kg.

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Study on Net Energy Values of Different Soybean Meals for Growing Broilers

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Abstract

This experiment utilized an open-circuit respiratory calorimetry apparatus for poultry to conduct energy metabolism tests, determining the net energy values of different soybean meals for growing broilers through indirect calorimetry combined with the substitution method. An approximate Latin square design was employed, with the experiment divided into 6 periods. In each period, sixty 1-day-old Ross 308 male broilers from the same hatchery were randomly allocated into 6 groups of 10 birds each. The basal diet group was fed a corn-soybean meal basal diet, while the test diet groups were fed experimental diets in which five types of soybean meals (3 regular meals with hulls and 2 dehulled meals) replaced 25% of the basal diet. Each period lasted 31 days; birds were housed in chicken coops from 1 to 20 days of age. On day 21, two healthy birds with body weights close to the group average were selected from each group and placed in metabolic chambers of the respiratory calorimetry apparatus for 9 days to measure gas exchange and total excreta collection, comprising a 3-day adaptation period, 3-day respiratory calorimetry measurement, and 3-day fasting heat production measurement, with digestion and metabolism tests conducted simultaneously during respiratory calorimetry. The results showed that compared with the basal diet group, the test diet groups exhibited significantly lower apparent metabolizable energy, metabolizable energy intake, retained energy, and net energy ($P < 0.05$). This experiment concluded that the apparent metabolizable energy values for the three regular soybean meals were 9.39, 9.70, and 9.71 MJ/kg, respectively, while those for the two dehulled soybean meals were 10.35 and 10.47 MJ/kg, respectively. The net energy values for the three regular soybean meals were 5.71, 5.84, and 5.50 MJ/kg, respectively, and those for the two dehulled soybean meals were 6.04 and 6.31 MJ/kg, respectively.

Keywords: broilers; soybean meal; net energy; indirect calorimetry

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Introduction

Currently, the metabolizable energy (ME) system is commonly used to evaluate the effective energy values of feed ingredients for poultry. However, the ME system ignores the heat increment generated during feed digestion and metabolism, overestimates the energy utilization efficiency of protein and fiber-rich ingredients, and underestimates that of ingredients with high fat and starch contents. Compared with the ME system, the net energy (NE) system accounts for differences in the digestive and metabolic utilization of various nutrients, and can most accurately reflect the energy requirements for animal maintenance and production [1-2]. In recent years, numerous studies on net energy have been reported in swine, but research on net energy for poultry remains limited, with a scarcity of net energy data for major feed ingredients in the poultry sector. The establishment and improvement of a net energy system require extensive accumulation of original data. Soybean meal, a byproduct of soybean oil extraction via solvent or pre-press solvent processes, represents the primary source of plant-based protein feed, accounting for over 60% of protein feed ingredient usage in livestock and poultry [3-4]. This experiment aimed to determine the net energy values of different soybean meals for Ross 308 broilers using an open-circuit respiratory calorimetry apparatus, thereby providing scientific basis and technical support for the establishment of a broiler net energy system and the revision of feeding standards.

1.1 Experimental Animals and Design

A total of 360 Ross 308 male broilers were selected for the experiment, with chicks purchased from Yonghong Hatchery in Tieling, Liaoning. An approximate Latin square design was adopted, with the experiment divided into 6 periods, each serving as a replicate to eliminate potential effects of period and different metabolic chambers on experimental results. In each period, sixty 1-day-old Ross 308 male broilers from the same hatchery were randomly allocated into 6 groups of 10 birds each. The basal diet group was fed a corn-soybean meal basal diet ( ), while the test diet groups were fed experimental diets (~) in which five types of soybean meals (3 regular meals with hulls and 2 dehulled meals) replaced 25% of the basal diet. Broilers were fed a commercial diet from days 1 to 14, then switched to experimental diets from day 15 until the end of the experiment. Birds were housed in coops until day 20. On day 21, two healthy birds with body weights close to the group average were selected from each group and placed in metabolic chambers of the respiratory calorimetry apparatus for 9 days: a 3-day adaptation period, 3-day respiratory calorimetry measurement (with the average of initial and final body weights used as body weight data), and 3-day fasting heat production measurement (with the average of initial and final weights used as fasting body weight), with digestion and metabolism tests conducted simultaneously during respiratory calorimetry. Diet and metabolic chamber allocation are shown in Table 1 .

1.2 Experimental Diets

The experiment utilized one basal diet and five test diets, with all diets mechanically extruded and pelleted at 65 ℃. The basal diet was formulated according to Ross 308 broiler nutritional requirements, with its composition and nutrient levels shown in Table 2 . Test diets were prepared by substituting 25% of the basal diet with the soybean meal samples to be tested. A total of five soybean meal samples were used: three regular meals with hulls from COFCO Oils & Fats Co., Ltd., China Grain Reserves Group, and Jiusan Oils & Grains Industries Group Co., Ltd.; and two dehulled meals from Heilongjiang Jiqing Soybean Co., Ltd. and Heilongjiang Yanglin Oils & Fats Group. The commercial diet was a broiler starter feed from Gongzhuling Hefeng Feed Co., Ltd. Conventional nutrient contents of the soybean meal samples are presented in Table 3 , and the composition and nutrient levels of test diets are shown in Table 4.

1.3 Management

From days 1 to 20, experimental birds were housed in partitioned pens in the broiler facility of the Animal Science Branch, Jilin Academy of Agricultural Sciences. The temperature was set at 34 ℃ on day 1 and then reduced by 1 ℃ daily until reaching 24 ℃, which was maintained until the end of the experiment. The temperature for respiratory calorimetry tests was set at (24±1) ℃. Lighting was provided for 23 h at 30–40 lx during days 1–7, and 18 h at 5–10 lx after day 7. Birds had free access to feed and water during the growth and respiratory calorimetry tests, with free access to water only during fasting periods.

1.4 Respiratory Calorimetry Apparatus

The open-circuit respiratory calorimetry apparatus for poultry used in this study was developed by Professor Yang Huaming' s team at Jilin Academy of Agricultural Sciences. The system primarily consists of a gas analyzer, data acquisition controller, metabolic chambers, gas circuit system, vortex blower, and supporting equipment including a refrigeration unit. The gas analyzer integrates oxygen and carbon dioxide sensors, gas path switchers, and supporting components. Oxygen concentration was measured using a zirconia sensor (Model 65-4-20, Advanced Micro Instruments, USA), while carbon dioxide concentration was measured using an infrared sensor (AGM 10, Sensors Europe GmbH, Germany). The apparatus comprises six metabolic chambers constructed with square steel frames and white steel plates, enclosed by transparent glass, with a volume of 0.43 m^3 each. Each chamber is equipped with an automatic drinking device, excreta collection apparatus, and equipment for gas circulation, cooling, heating, and dehumidification. During operation, the data acquisition controller drives the gas analyzer sensors to sequentially sample outdoor air and the metabolic chambers (A, B, C, D, E, F) in a cyclic manner according to the experimental protocol, with automatic switching and adjustable cycle time. The data acquisition controller displays experimental data and equipment status in real time, while remote control software automatically calculates oxygen consumption, carbon dioxide production, and respiratory quotient (RQ) of poultry, and records temperature and humidity data inside and outside the chambers, displaying them on the computer data acquisition interface. The open-circuit respiratory calorimetry apparatus with six parallel chambers for poultry is shown in Figure 1 [Figure 1: see original paper].

1.5 Excreta Collection and Preparation

During respiratory calorimetry tests, feed was added daily at a fixed time (09:00–10:00), spilled feed was collected, and excreta were collected using the total collection method. The total excreta from each metabolic chamber over the 3-day period were pooled, dried in an oven at 65 ℃, ground to pass through a 40-mesh sieve, and stored for analysis.

1.6 Measurement Indicators and Methods

Samples of corn, soybean meal, diets, and excreta were dried in an oven at 105 ℃ to determine dry matter content. Gross energy was determined using an oxygen bomb calorimeter (C2000, IKA) following the method recommended by international standard ISO9831:1998. Contents of crude protein, crude fat, crude ash, and crude fiber were determined according to the methods recommended by the National Standards of the People' s Republic of China GB/T 6432–1994, GB/T 6433–2006, GB/T 6438–2007, and GB/T 6434–2006, respectively.

1.7 Calculation Formulas

Total heat production (HP) or fasting heat production (FHP) (kJ) = 16.1753 × O (L) + 5.0208 × CO (L);
Respiratory quotient (RQ) = CO (L) / O (L);
Apparent metabolizable energy (AME, MJ/kg) = (gross energy intake -gross energy in excreta) / feed intake;
Metabolizable energy intake (MEI, kJ) = AME × feed intake;
Retained energy (RE, kJ) = AME -HP;
Net energy of diet (MJ/kg) = (RE + FHP) / feed intake;
Apparent metabolizable energy of soybean meal samples (MJ/kg) = AME of basal diet -[(AME of basal diet -AME of test diet) / 0.25];
Net energy of soybean meal samples (MJ/kg) = NE of basal diet -[(NE of basal diet -NE of test diet) / 0.25].

1.8 Statistical Analysis

Data were analyzed using SPSS 20.0 software with general linear model multivariate analysis, with diet as a fixed effect and period and respiratory chamber as random effects. Differences among diets were analyzed for significance using Tukey' s method. $P < 0.05$ was considered statistically significant.

2.1 Effects of Different Diets on Growth Performance and GE Intake

As shown in Table 5 , compared with the basal diet group ( ), the test diet groups (~) showed no significant differences in average daily gain, dry matter intake, or gross energy intake ($P > 0.05$). No significant differences were observed among the test diet groups for any of these indicators ($P > 0.05$). The feed-to-gain ratio of the dehulled soybean meal diet groups (,) was significantly higher than that of the basal diet group ($P < 0.05$), but did not differ significantly from the regular soybean meal diet groups (, ,) ($P > 0.05$).

2.2 Effects of Different Diets on Respiratory Metabolism and Fasting Heat Production

As shown in Table 6 , compared with the basal diet group, the test diet groups showed no significant differences in oxygen consumption, carbon dioxide production, respiratory quotient, or total heat production during either growth metabolism or fasting metabolism ($P > 0.05$). Similarly, no significant differences were observed among the test diet groups for any of these indicators ($P > 0.05$).

2.3 Effects of Different Diets on Energy Metabolism

As shown in Table 7 , the basal diet group exhibited significantly higher apparent metabolizable energy, metabolizable energy intake, retained energy, and net energy than the test diet groups ($P < 0.05$). No significant difference was observed in the net energy to metabolizable energy ratio between the basal diet group and test diet groups ($P > 0.05$).

2.4 Energy Values and Conversion Efficiency of Different Soybean Meals

As shown in Table 7, no significant differences were observed among different soybean meals in apparent metabolizable energy, net energy, or net energy to apparent metabolizable energy ratio ($P > 0.05$).

3.1 Effects of Different Diets on Growth Performance of Test Chickens

Diet composition and management are the main factors affecting broiler growth performance. In this study, the test broilers (25–28 days of age) exhibited average daily gains of 82.03–86.87 g/d and feed-to-gain ratios of 1.38–1.53, which align with the Ross 308 broiler feeding standards recommending 83 g/d average daily gain and 1.7 feed-to-gain ratio for male broilers aged 22–28 days. Although differences in weight gain among groups did not reach significance, a trend was observed where dehulled soybean meal diets performed better than regular soybean meal diets, which in turn outperformed the basal diet. Meanwhile, the feed-to-gain ratio of dehulled soybean meal diet groups was significantly lower than that of the basal diet group, likely attributable to the lower fiber and higher crude protein content of dehulled soybean meal diets. Studies by Swick et al. [5] and Barekatain et al. [6] found that feeding high levels of sorghum distillers dried grains with solubles (DDGS) significantly reduced feed conversion efficiency in broilers, but supplementation with exogenous fiberase in sorghum DDGS diets significantly improved feed conversion efficiency, demonstrating that high-fiber diets reduce diet digestibility—a finding similar to our results.

3.2 Effects of Different Diets on Total Heat Production and Fasting Heat Production

The total heat production of test broilers is influenced by multiple factors, including breed, age, feed intake, ambient temperature, and measurement methodology [7-8]. Macleod et al. [9-10] found that at 20 ℃ ambient temperature, heat production increased with dietary energy level and crude protein content, but this phenomenon was not observed at 32 ℃. Compared with a diet containing 13% crude protein, broilers fed a diet with 21% crude protein exhibited an 8% increase in total heat production. In this study, compared with the basal diet, total heat production of test broilers showed an increasing trend with increasing crude protein content in test diets. The basal diet group had higher dry matter intake, gross energy intake, and feed-to-gain ratio than test diet groups, which would increase heat production in the basal diet group. Additionally, the low substitution rate of soybean meal samples in this study resulted in minimal differences in crude protein content between basal and test diets, which may explain why total heat production showed an increasing trend but did not reach significance. Studies by Noblet et al. [11] and Liu et al. [7] indicated that increasing dietary crude protein content in broilers increased heat production, but not significantly, consistent with our findings.

In this study, oxygen consumption of test broilers ranged from 38.05 to 40.04 L/(d · BW ·), carbon dioxide production from 37.58 to 40.27 L/(d · BW ·), and respiratory quotient from 0.99 to 1.02. Barekatain et al. [6] reported oxygen consumption of 40.1–44.3 L/(d · BW ·), carbon dioxide production of 43.4–45.1 L/(d · BW ·), and respiratory quotient of 1.00–1.08 in 25–28-day-old Ross 308 broilers measured using a closed-circuit respiratory calorimetry apparatus, which differ somewhat from our results. Barekatain et al. [6] used sorghum DDGS diets with exogenous enzyme supplementation and found that feeding DDGS diets significantly increased total heat production, while enzyme supplementation significantly increased respiratory quotient. Therefore, these discrepancies may be related to dietary nutrient composition and exogenous enzymes.

Net energy is divided into production net energy and maintenance net energy, with fasting heat production commonly used as the maintenance net energy requirement in net energy studies [12]. In this study, fasting heat production of test broilers at 24 ℃ ranged from 451.3 to 452.0 kJ/(kg BW・ ・d), with no significant differences among groups, indicating that different diet types did not affect fasting heat production. Sakomura et al. [13] reported maintenance net energy of 456.10 kJ/(kg BW・ ・d) for 4-week-old broilers at 22 ℃ ambient temperature. Noblet et al. [14] reported fasting heat production ranging from 418.40 to 447.70 kJ/(kg BW・ ・d) for broilers weighing 0.5–3.0 kg. Gao Yali et al. [15] determined maintenance net energy of 439.3 kJ/(kg BW・ ・d) for 8–15-day-old Avian broilers using the comparative slaughter method combined with regression analysis, all consistent with our results. Ning et al. [16] found fasting heat production of 295.2 kJ/(kg BW・ ・d) in Hy-Line Brown hens. Sakomura et al. [13] reported maintenance net energy values of 493.7 and 384.9 kJ/(kg BW・ ・d) for 4-week-old broilers at 15 ℃ and 30 ℃, respectively. These findings demonstrate that fasting heat production measurement is significantly influenced by poultry breed, sex, body weight, and environmental factors. Noblet et al. [17] noted that the 0.75 power of body weight lacks precision for growing animals, and the 0.70 power is more appropriate for growing broilers. The 0.75 power is generally used for body weight indices of adult breeding roosters in current research [7]. Therefore, the metabolic body weight of test broilers in this experiment used the 0.70 power of body weight.

3.3 Effects of Different Diets on Energy Utilization Efficiency

The higher metabolizable energy and net energy values of the basal diet compared with test diets can be attributed to differences in dietary ingredient composition. Test diets were formulated by substituting 25% of the basal diet with soybean meal. Although the gross energy value of soybean meal is approximately 10% higher than that of corn, its metabolizable energy value is only 72% of corn' s [18], resulting in lower metabolizable energy values for test diets than the basal diet. Consequently, with similar feed intake, metabolizable energy intake and retained energy were lower in test diet groups than in the basal diet group. The efficiency of converting metabolizable energy to net energy was higher in the basal diet than in test diets because test diets contained higher levels of soybean meal, and the higher crude protein and crude fiber contents in soybean meal reduce the efficiency of metabolizable energy conversion to net energy [5]. The apparent metabolizable energy values of soybean meal diets determined in this study were 12.02–12.10 MJ/kg DM (regular soybean meal diets) and 12.26–12.29 MJ/kg DM (dehulled soybean meal diets). Muztar et al. [19] reported apparent metabolizable energy values of 11.42–11.90 MJ/kg DM for soybean meal diets determined using White Leghorn roosters, which are similar to our results.

Currently, diet formulation in broiler production primarily employs the metabolizable energy system, with limited reports on dietary net energy values. Dietary net energy values are influenced by multiple factors including diet type, nutrient composition, measurement methodology, broiler breed, and age, resulting in substantial variation in reported net energy values across studies. In this study, net energy values of soybean meal diets were 8.57-8.66 MJ/kg (regular soybean meal diets) and 8.71-8.78 MJ/kg (dehulled soybean meal diets). The net energy to metabolizable energy ratio was 0.70-0.71. Dehulled soybean meal diets had higher net energy values than regular soybean meal diets. Liu et al. [7] determined net energy values of 10.53 and 10.61 MJ/kg for regular and dehulled soybean meal diets, respectively, using adult Arbor Acres (AA) broiler breeding roosters with the same equipment, methodology, and soybean meal substitution rate as our study. These values differ from our results, indicating that broiler breed and age can significantly affect dietary net energy values.

3.4 Metabolizable and Net Energy Values of Different Soybean Meal Samples

The metabolizable energy values determined in this experiment were 9.71, 9.70, and 9.39 MJ/kg for the three regular soybean meals, and 10.35 and 10.47 MJ/kg for the two dehulled meals, respectively. The corresponding net energy values were 5.72, 5.84, and 5.50 MJ/kg for regular meals, and 6.04 and 6.31 MJ/kg for dehulled meals, respectively, with an average metabolizable energy to net energy ratio of 0.59. Ravindran et al. [20] reported apparent metabolizable energy values of 6.56-10.61 MJ/kg DM for soybean meals from the USA (dehulled), Argentina (dehulled), Brazil (dehulled), and India (regular) in broilers. Muztar et al. [19] reported apparent metabolizable energy values of 9.40 and 11.60 MJ/kg DM for regular and dehulled soybean meals, respectively. These results are similar to our findings. Zhang Zhengfan et al. [21] determined net energy values of 5.63-7.82 MJ/kg for 21 soybean meal samples in 1-21-day-old yellow-feathered broilers, with net energy to metabolizable energy ratios of 55.24%-62.78%. The net energy values and net energy to metabolizable energy ratios determined in our study fall within this range. Hill et al. [22] reported that the presence or absence of hulls determines the metabolizable energy values of regular versus dehulled soybean meals. In our experiment, dehulled soybean meals showed increased trends in both metabolizable and net energy values. Dilger et al. [23] reported that hulls are the primary cause of energy value differences between regular and dehulled soybean meals, as hulls increase crude fiber and non-starch polysaccharide contents in soybean meal, which not only dilutes nutrients but also causes energy waste during animal digestion. Additionally, when using the substitution method to determine feed ingredient energy values, factors such as basal diet, substitution rate, animal breed, age, and dietary nutrient composition can all affect the measured energy values [24-25].

Conclusion

In this experiment, using a corn-soybean meal diet as the basal diet and Ross 308 broilers as experimental animals, the substitution method yielded apparent metabolizable energy values of 9.39, 9.70, and 9.71 MJ/kg and net energy values of 5.71, 5.84, and 5.50 MJ/kg for the three regular soybean meals, and apparent metabolizable energy values of 10.35 and 10.47 MJ/kg and net energy values of 6.04 and 6.31 MJ/kg for the two dehulled soybean meals.

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