Postprint: Net Energy Evaluation of Rapeseed Meal for Meat Ducks

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Abstract

This experiment was conducted to determine the net energy (NE) of rapeseed meal for meat ducks and establish regression models between rapeseed meal NE and its routine components through correlation and regression analysis. The factorial method was employed to partition rapeseed meal NE into net energy for maintenance (NEm) and net energy for production (NEp) provided to meat ducks, with NEm estimated using fasting heat production (FHP) of meat ducks and NEp determined by the comparative slaughter method. A total of 760 Cherry Valley meat ducks at 7 days of age with an average body weight of (130.48$±3.01)*gwereselectedfortheexperiment* : *first*, 100*meatduckswereselectedfortheNEmevaluationtrial*, *withfivetreatmentsincludingadlibitumfeeding*
3) Rapeseed meal NE was highly correlated with its routine components, and the regression model established by multiple linear stepwise regression was as follows: NE=0.416AME+0.041CP-0.020NDF+0.110CF-1.093 (R2=0.901, RSD=0.06 MJ/kg, P<0.01), where: CP is crude protein, NDF is neutral detergent fiber, CF is crude fiber. In conclusion, there were substantial differences in routine components and meat duck NE among rapeseed meals from different sources, and rapeseed meal NE was highly correlated with its routine components and exhibited a regression relationship.

Full Text

Study on Evaluating Net Energy of Rapeseed Meal for Meat Ducks

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Abstract

This experiment was conducted to measure the net energy (NE) of rapeseed meal for meat ducks and establish prediction models for NE based on its conventional composition through correlation and regression analysis. A factorial approach was employed to partition the NE of rapeseed meal into net energy for maintenance (NEm) and net energy for production (NEp). NEm was estimated using fasting heat production (FHP) of meat ducks, while NEp was determined using the comparative slaughter technique.

A total of 760 seven-day-old Cherry Valley ducks with an average body weight of (130.48$±$3.01) g were used in the study. First, 100 ducks were selected for the NEm evaluation trial with five treatments: ad libitum feeding and feed restriction at 15%, 25%, 35%, and 45% levels. The regression relationship between heat production (HP) and metabolizable energy intake (MEI) was established and extrapolated to MEI = 0 to determine FHP. Subsequently, 640 ducks were used for the NEp evaluation trial, where 20 ducks were slaughtered before the trial to determine initial body energy as a baseline control. Thirty-one treatments were established, consisting of a basal diet group and groups where basal diet 2 was replaced by 15% of each rapeseed meal sample. All treatments had five replicates with four ducks per replicate, and all ducks were slaughtered at 15 days of age to determine final body energy. Finally, correlation and regression analyses were performed between the NE of rapeseed meal and its conventional components to develop prediction models.

The results showed that: 1) The NEm of Cherry Valley ducks was 0.557 MJ/(kg W0.75 · d). 2) The NE values of the 31 different rapeseed meals varied considerably, ranging from 4.18 to 6.05 MJ/kg DM using the substitution method, with a NE to apparent metabolizable energy (AME) ratio of 0.56$±$0.06. 3) The NE of rapeseed meal was highly correlated with its conventional components, and a multiple linear stepwise regression model was established as follows: NE = 0.416AME + 0.041CP - 0.020NDF + 0.110CF - 1.093 (R2 = 0.901, RSD = 0.06 MJ/kg, P < 0.01), where CP is crude protein, NDF is neutral detergent fiber, and CF is crude fiber. In conclusion, both the conventional composition and the NE of rapeseed meal from different sources showed substantial variation, and the NE of rapeseed meal was highly correlated with its conventional components, exhibiting a significant regression relationship.

Key words: rapeseed meal; Cherry Valley ducks; net energy; conventional composition

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Introduction

Accurate estimation of the true energy value of feedstuffs is crucial for reducing feed formulation costs while meeting the actual energy requirements of animals

[?]. When evaluating the energy value of diets rich in fiber and protein, metabolizable energy (ME) and digestible energy (DE) systems tend to overestimate their energy content, whereas they underestimate the energy value of starch-rich diets [?]. When feed ingredients differ substantially in nitrogenous nutrients and fiber content, the heat production (HP) during intestinal digestion and utilization varies accordingly [?]. Therefore, the net energy (NE) system provides a more accurate estimation of the true energy value of feeds compared to the ME system [?], as it is the only energy system that expresses both animal energy requirements and feed energy values on the same plane and is unaffected by feed differences. Moreover, using the NE system for diet formulation can reduce production costs [?].

Currently, NE values have been reported for corn and soybean meal in ducks, but no studies have investigated the NE of rapeseed meal for meat ducks or developed prediction models. Furthermore, direct measurement of NE through animal experiments is technically challenging, time-consuming, and expensive, making mathematical modeling an alternative approach for evaluating nutrient availability [?]. Therefore, this study selected Cherry Valley ducks as experimental animals to measure the NE of different rapeseed meals through animal trials and explore the correlation and regression relationships between rapeseed meal NE and its conventional components, aiming to develop an ideal prediction model for rapid determination of rapeseed meal NE in meat ducks.

Materials and Methods

1.1 Sample Collection and Experimental Diets

Based on the regional distribution of rapeseed meal production areas in China and the grading indicators specified in the national standard "Feed Rapeseed Meal" (GB/T 23736–2009), 31 rapeseed meal samples were collected from various regions across the country. Referring to the nutrient requirements for meat ducks from NRC (1994), basal diet 1 was formulated to determine the NEm of rapeseed meal for meat ducks, while basal diet 2 was formulated to determine NEp. Each rapeseed meal sample was incorporated at 15% to replace basal diet 2, creating 31 test diets. The composition and nutrient levels of the basal diets are presented in Table 1 , and all diets were manufactured as pellets.

1.2 Experimental Design

One thousand one-day-old Cherry Valley ducklings were purchased from the Institute of Animal Genetics, Sichuan Agricultural University, and raised under normal management until six days of age, during which all ducks were fed basal diet 1. At seven days of age, after 24 hours of fasting, 760 ducks with an average body weight of (130.48$±$3.01) g were selected for the formal experiment, which lasted from 8 to 14 days of age. Twenty ducks with similar body weight were randomly selected and slaughtered to determine initial body composition, while the remaining 740 ducks were divided into two groups for determining NEm and

NEp of rapeseed meal.

The NEm of rapeseed meal was determined using the regression method with 100 Cherry Valley ducks, with feeding levels set at ad libitum and restricted feeding at 15%, 25%, 35%, and 45%. Fasting heat production (FHP) was obtained by extrapolating the HP measured at different energy intake levels to zero MEI. The NEp of rapeseed meal was determined using the comparative slaughter method with 640 ducks, including 20 ducks for determining the NEp of basal diet 2 and 620 ducks for determining the NEp of the 31 rapeseed meal diets. Both NEm and NEp trials consisted of five replicates per treatment with four ducks per replicate.

1.3 Sample Collection and Laboratory Analysis

Metabolizable energy was determined using the total collection method as described by Cao et al. [?]. Fecal collection trays covered with clean plastic sheets were placed under each metabolic cage, and excreta were collected every 12 hours with feathers and feed debris promptly removed. All excreta collected from each cage during the experimental period were pooled and stored at -20°C, and subsequently analyzed for dry matter (DM) content and energy [?]. Ducks were weighed at the beginning (8 days) and end (15 days) of the trial on a replicate basis, and feed intake was recorded throughout the experimental period to calculate average daily gain, average daily feed intake, and feed-to-gain ratio.

At 15 days of age, ducks were euthanized by cervical dislocation, and carcasses were immediately stored at -20°C. Frozen carcasses were thawed, dissected, coarsely ground, thoroughly mixed in a blender to obtain homogeneous samples, and then dried and finely ground for further analysis. The energy values of experimental diets, rapeseed meals, meat samples, and excreta were determined using an oxygen bomb calorimeter (PARR-6400 model). The conventional components of rapeseed meal were analyzed according to national standards: DM (GB/T 6435–2006), crude protein (CP) (GB/T 6432–1994), crude fiber (CF) (GB/T 6434–2006), neutral detergent fiber (NDF) (GB/T 20806–2006), acid detergent fiber (ADF) (NY/T 1459–2007), ether extract (EE) (GB/T 6433–2006), and crude ash (GB/T 6438–2007).

1.4 Calculation of Net Energy for Meat Ducks

Metabolizable energy intake was calculated as: MEI (MJ/kg) = (gross energy intake - gross energy of excreta) / feed intake. The NE of rapeseed meal was calculated by partitioning it into NEp and NEm and summing the two components [?]. The NEm of rapeseed meal for meat ducks was determined using the method of NRC (1981) and Souza et al. [?]:

$$HP = MEI - RE$$
$$\log HP = a + b \times MEI$$

where RE is recovered energy, and a and b are constants. Fasting heat production was calculated by regressing HP against MEI and extrapolating to zero MEI. The NEp of rapeseed meal was calculated as the difference between final and initial body energy deposition.

Diet NE = (NEm × W0.75 × 7 d + NEp) / 7 d (W0.75: average metabolic body weight during the trial period) [?].
Rapeseed meal NE = (NE of basal diet 2 - NE of basal diet 1 × 0.85) / 0.15 [?].

1.5 Data Processing

Experimental data were organized using Excel and analyzed using SPSS 22.0 software. Results are expressed as mean ± standard deviation. One-way ANOVA was performed on MEI, RE, and HP obtained from different treatments, with $P < 0.05$ considered statistically significant. Correlation analysis was conducted between rapeseed meal NE and its conventional components, followed by stepwise regression analysis of NE against conventional components and apparent metabolizable energy (AME) for the 31 rapeseed meal samples to develop prediction models.

Results

2.1 Conventional Composition of Rapeseed Meals

Laboratory analysis of the 31 rapeseed meal samples revealed gross energy values ranging from 16.09 to 19.02 MJ/kg, with CP, DM, EE, CF, NDF, and ADF contents of 35.05%-46.33%, 88.39%-91.97%, 0.42%-3.03%, 11.72%-17.82%, 25.02%-50.32%, and 14.46%-19.38%, respectively. The composition of conventional components is illustrated in Figure 1 [Figure 1: see original paper], which shows that all 31 rapeseed meals met the "Feed Rapeseed Meal" (GB/T 23736—2009) standard, with considerable variation observed among the conventional components.

2.2 Fasting Heat Production of Cherry Valley Ducks

The MEI, RE, and HP for the five feeding levels in the FHP trial are presented in Table 2 . No significant differences were observed in HP among the groups ($P > 0.05$). However, significant differences in RE were detected between most groups ($P < 0.05$), except between the ad libitum and 15% restriction groups, and between the 15% and 25% restriction groups ($P > 0.05$).

Linear regression was performed with MEI as the independent variable and log-transformed HP (logHP) as the dependent variable, yielding the following equation: logHP = 0.001X + 2.124 (R2 = 0.984, RSD = 0.000, P = 0.000). Based on this relationship, FHP was determined to be 0.557 MJ/kg W0.75 · d when MEI = 0.

2.2 Net Energy for Maintenance, Production, and Total NE of Rapeseed Meal

As shown in Table 3 , the NEp provided by rapeseed meal substituting the basal diet for Cherry Valley ducks was (3.24 $\pm$ 1.54) MJ/kg, while NEm was (2.11 $\pm$ 0.07) MJ/kg. The NE values obtained by the substitution method ranged from 4.18 to 6.05 MJ/kg DM, with a NE/AME ratio of (0.56 $\pm$ 0.06).

2.3 Relationship Between Rapeseed Meal NE and Conventional Components

Correlation analysis between rapeseed meal NE, AME, and conventional components revealed significant relationships, as shown in Table 4 . Net energy exhibited extremely significant correlations with AME, NDF, EE, and ADF ($P < 0.01$). Further stepwise regression analysis of NE against AME and conventional components yielded the results presented in Table 5 . When NE was regressed against conventional components alone, only NDF, ADF, and EE entered the model as significant variables, while other variables were excluded due to low correlation. The prediction model incorporating AME showed improved accuracy, with R2 increasing to 0.901 and residual standard deviation (RSD) decreasing to 0.06 MJ/kg.

Discussion

3.1 Evaluation of Fasting Heat Production in Cherry Valley Ducks

Net energy for maintenance is a critical parameter for estimating feed ingredient NE [?]. The measurement of NEm involves extrapolating HP measured at different energy intake levels to determine FHP. Currently, FHP is primarily measured using respiratory chambers or derived from regression equations proposed by NRC (1981) and Souza et al. [?]. In this study, the regression equation logHP = 0.001MEI + 2.115 (R2 = 0.984) demonstrated high reliability. The NEm obtained for Cherry Valley ducks at 26–28°C was 545.5 kJ/(kg W0.75 · d). This value is comparable to previous reports: Li et al. [?] determined NEm of Tianfu meat ducks as 598.251 kJ/(kgW0.75 · d) using regression, Yu et al. [?] reported 577.03 kJ/(kgW0.75 · d) for 2-3-week-old Tianfu meat ducks, and Zheng [?] measured FHP of 410.3 kJ/(kgW0.75 · d) for 1–21-day-old Cherry Valley ducks at 28–32°C. These findings indicate that NEm values for meat ducks range from 410.3 to 598.3 kJ/(kg W0.75 · d), with our results aligning closely with most literature values except for Zheng [?].

Kil et al. [?] reported that NEm in pigs is substantially influenced by sex, age, environment, genetics, physiological status, and feeding level. Palander et al. [?], Knap [?], and Verstegen [?] found that NEm is affected by thermoregulation, immune system activation, disease, and stress conditions. Longo et al. [?] measured NEm values of 667.06, 486.27, and 538.55 kJ/(kg W0.75 · d) for broilers at 13°C, 23°C, and 32°C, respectively, while Sakomura et al. [?] observed decreasing NEm in laying hens with increasing temperature. These results demonstrate that temperature significantly affects animal NEm. The temperature in our trial (26-28°C) was lower than that in Zheng' s study [?] (28-32°C). Additionally, NEm measurements are influenced by animal activity during the experiment. Filho et al. [?] reported lower NEm in caged quails compared to floor-reared quails due to reduced activity and lower HP in caged birds. Buskirk et al. [?] found that specific experimental conditions limiting animal activity could reduce NEm, while NRC (1998) recommended increasing NEm by 10% for cattle on high-quality pasture and 20% for those on poor-quality pasture compared to experimental conditions. In our study, individual caging and fecal collection procedures may have caused stress and increased activity, thereby affecting HP. In conclusion, FHP is influenced by environmental temperature, animal activity, and other factors, resulting in dynamic variations in measured NEm, which validates the accuracy of our NEm determination.

3.2 Net Energy and NE/AME Ratio of Rapeseed Meal for Cherry Valley Ducks

Limited data are available on the NE of feedstuffs for meat ducks [?, ?]. Regarding rapeseed meal NE values across species, Nair et al. [?] reported 12.64 MJ/kg for feedlot steers, the French energy system provided values of 8.6 and 9.1 MJ/kg DM for growing and finishing pigs, respectively, and Gan et al. [?] determined 6.55 MJ/kg DM for growing pigs. These results indicate that rapeseed meal NE values range from 6.55 to 12.8 MJ/kg DM across animal species. Our study obtained rapeseed meal NE values of 4.18-6.05 MJ/kg DM for Cherry Valley ducks, which differ from values reported for pigs and cattle, possibly due to differences in utilization efficiency and conventional composition of the rapeseed meals. No previous reports exist on rapeseed meal NE for meat ducks; however, our results are comparable to Zhang et al. [?], who reported 5.22 MJ/kg DM for 1-3-week-old yellow-feathered broilers, and Li et al. [?], who reported 4.72-7.22 MJ/kg DM for Avian broilers.

The AME of rapeseed meal measured in this study ranged from 8.31 to 10.44 MJ/kg DM, which is consistent with literature values of 11.7-13.4 MJ/kg for ruminants, 10.41-16.06 MJ/kg for pigs, 7.50-9.35 MJ/kg for laying hens, 8.31-10.06 MJ/kg for turkeys, and 7.41-10.09 MJ/kg for broilers [?]. The NE/AME ratio reflects the true utilization efficiency of feed energy. Our study obtained a NE/AME ratio of 0.56 ± 0.06, which is slightly lower than the 0.59-0.62 reported by Li et al. [?] for Avian broilers and the 0.61-0.64 reported by Sauvant et al. [?] and NRC (1998) for growing pigs. Sarmiento-Franco et al. [?] found that poultry diet composition can affect the NE/AME ratio of feed ingredients. De Lange et al. [?] noted that minimal variation in digestible nutrients in poultry diets reduces the variability in the efficiency of converting AME to NE. Swick et al. [?] reported that increased dietary fat content elevates NE/AME, whereas increased fiber and CP content decreases NE/AME, a finding supported by Noblet et al. [?]. In our study, the relatively high inclusion level of rapeseed meal

(15%) and its high CP and NDF contents likely influenced the results. Following the methodology of Enami et al. [?] and De Goey et al. [?], we used a 15% substitution rate to formulate test diets and applied the substitution method to determine rapeseed meal NE. This approach can be affected by substitution level, leading to variations in NE values. Our experimental design and measurement methods followed those of Dietz et al. [?], Souza et al. [?], and Li et al. [?], and our results are consistent with their findings, demonstrating that the combination of comparative slaughter and substitution methods is feasible for determining NE of high-protein, high-fiber feedstuffs like rapeseed meal.

3.3 Relationship Between Rapeseed Meal NE and Conventional Components

This study explored the relationship between rapeseed meal NE and its conventional components. Noblet et al. [?] reported that conventional components can accurately predict digestible energy (DE) and ME in growing pigs, with NDF being the best predictor. Our study found that rapeseed meal NE was highly correlated with NDF, EE, and ADF contents, exhibiting significant regression relationships. Stepwise regression analysis revealed that the most reliable and accurate prediction of rapeseed meal NE was achieved using AME combined with NDF, ADF, and CP (R2 = 0.985, RSD = 0.088 MJ/kg). Noblet et al. [?] suggested that the ME system can adequately evaluate energy values of protein- and fiber-rich feed ingredients. Zhang et al. [?] found that ADF was the best predictor for ME prediction models of duck meal feeds. Sun et al. [?] also reported that NDF and ADF provided better prediction accuracy than CF when establishing models for estimating feed energy values in pigs. Atkinson et al. [?] noted that ducks can only digest a small portion of dietary fiber, which acts as an anti-nutritional factor impeding nutrient absorption. Therefore, the poor fiber digestibility in ducks may explain why fiber components serve as excellent predictors in energy prediction models for duck feeds. Our study found that NDF content in rapeseed meal was high and variable, which may also contribute to its status as the best single predictor. These findings indicate that the prediction factors in our equations are consistent with those reported in the literature, confirming that developing NE prediction models for Cherry Valley duck rapeseed meal using conventional components is feasible.

Conclusions

The conventional composition of rapeseed meals from different sources varied considerably. For Cherry Valley ducks, the NE of rapeseed meal ranged from 4.18 to 6.05 MJ/kg DM, with a NE/AME ratio of 0.56 ± 0.06. The NE of rapeseed meal was significantly correlated with its conventional components, and a regression equation was established: NE = 0.416AME + 0.041CP - 0.020NDF + 0.110CF - 1.093 (R2 = 0.901, RSD = 0.06 MJ/kg, $P < 0.01$).

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