

Postprint: Prediction of Metabolizable Energy of Wheat for Meat Ducks Using Near-Infrared Spectroscopy

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Abstract

This experiment aimed to determine the apparent metabolizable energy (AME) of wheat from different sources for meat ducks and construct a prediction model using near-infrared spectroscopy (NIRS). A total of 410 one-week-old Cherry Valley meat ducks were randomly assigned to 41 treatments, with 5 replicates per treatment and 2 ducks per replicate. Ducks in each treatment were fed either a corn-soybean meal basal diet or one of 40 wheat substitution diets (containing 20% wheat). The substitution method was used to calculate the AME of wheat, and NIRS was then employed to establish a prediction model for wheat AME. The results showed that the AME of wheat for meat ducks from different sources ranged from 11.03 to 14.34 MJ/kg, with a coefficient of variation of 5.58%. Wheat AME was significantly negatively correlated with crude fiber (CF), neutral detergent fiber (NDF), and acid detergent fiber (ADF) ($P < 0.01$), and significantly positively correlated with ether extract (EE) ($P < 0.01$). The calibration coefficient of determination, calibration standard error, and cross-validation relative standard deviation of the wheat AME prediction model were 0.85, 0.187 MJ/kg, and 1.70%, respectively. The external validation coefficient of determination, external validation relative standard deviation, and external validation relative prediction error were 0.89, 1.46%, and 3.23%, respectively. It can be concluded that differences existed in the AME and chemical composition of wheat from different sources for meat ducks, and the variation in AME was correlated with its chemical composition. The results of using NIRS to predict wheat AME for meat ducks were “good” .

Full Text

Study on Estimating Metabolizable Energy of Wheat for Meat Ducks by Near Infrared Reflectance Spectroscopy

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Abstract

This experiment was conducted to measure the apparent metabolizable energy (AME) of wheat from different sources for meat ducks and to construct a predictive model using near infrared reflectance spectroscopy (NIRS). A total of 410 one-week-old Cherry Valley meat ducks were randomly assigned to 41 treatments, with 5 replicates per treatment and 2 ducks per replicate. Ducks in each treatment were fed either a corn-soybean meal basal diet or one of 40 wheat substitution diets (containing 20% wheat). The AME of wheat was calculated using the substitution method, and a NIRS prediction model for wheat AME was subsequently established. The results showed that the AME of wheat for meat ducks ranged from 11.03 to 14.34 MJ/kg, with a coefficient of variation of 5.58%. Wheat AME was extremely significantly negatively correlated with crude fiber (CF), neutral detergent fiber (NDF), and acid detergent fiber (ADF) ($P < 0.01$), and extremely significantly positively correlated with ether extract (EE) ($P < 0.01$). The calibration coefficient of determination, calibration standard deviation, and cross-validation relative standard deviation for the wheat AME prediction model were 0.85, 0.187 MJ/kg, and 1.70%, respectively. The external validation coefficient of determination, external validation relative standard deviation, and external validation relative analysis error were 0.89, 1.46%, and 3.23%, respectively. These results indicate that both chemical composition and AME vary among wheat from different sources, and that wheat AME variation is correlated with its chemical composition. The application of NIRS to predict wheat AME for meat ducks yielded “good” predictive performance.

Keywords: wheat; meat ducks; apparent metabolizable energy; near infrared reflectance spectroscopy; prediction model

Wheat has attracted increasing attention as a common energy feed in the poultry industry. Although the apparent metabolizable energy (AME) of wheat for meat ducks has been reported, chemical composition varies considerably among wheat from different sources due to factors such as variety, origin, and storage methods, leading to substantial differences in AME for poultry. Using average metabolizable energy values for diet formulation in production affects accuracy and precision nutrition implementation. To efficiently utilize wheat

resources in production, it is essential to accurately evaluate the energy value of each wheat source to achieve precise diet formulation. Near infrared reflectance spectroscopy (NIRS) has been widely applied for rapid prediction of chemical composition and available energy in animal feed due to its advantages of being fast (requiring only about 2 minutes), non-destructive, and pollution-free. Research on using NIRS for rapid prediction of wheat nutritional value has primarily focused on conventional nutrients. Notably, Owens et al. established a NIRS prediction model for measuring gross energy in wheat, and Li Juntao developed NIRS prediction models for gross energy, digestible energy, and metabolizable energy of wheat for growing pigs, where the gross energy model showed good calibration, while the digestible and metabolizable energy models were only suitable for rough screening and classification of samples. Currently, no literature reports exist on NIRS prediction models for wheat AME for meat ducks. Therefore, this experiment aimed to measure the AME of wheat from different sources for meat ducks and establish a NIRS prediction model to provide a reference for rapid and accurate evaluation of wheat AME.

1.1 Sample Collection and Preparation

Based on the regional distribution of wheat production areas in China and the bulk density grading index in the national standard *Wheat* (GB 1351–2008), 40 wheat samples were collected from Henan, Shandong, Hebei, Shanxi, Shaanxi, Sichuan, Anhui, Jiangsu, Hubei, Ningxia, Jiangxi, and Zhejiang provinces. Each wheat sample was collected using the quartering method, ground with a high-speed grinder, passed through a 40-mesh sieve (0.42 mm), and stored at -20°C .

1.2 Experimental Design and Methods

A total of 410 one-week-old Cherry Valley meat ducks with a body weight of (67.43 ± 1.66) g were randomly divided into 41 treatments, with 5 replicates per treatment and 2 ducks per replicate. Ducks were fed either the basal diet (corn-soybean meal type) or one of 40 wheat substitution diets (containing 20% wheat). The total collection method was used to determine dietary AME. Fecal collection trays lined with clean plastic sheets were placed under metabolic cages. Collected excreta were weighed, and 10 mL of 10% dilute hydrochloric acid was added per 100 g of fresh sample for nitrogen fixation. Excreta were collected twice daily for 7 days. Daily excreta samples were stored at -20°C . After the experimental period, excreta samples from each replicate were mixed uniformly, dried in thin layers in a 65°C oven, equilibrated for 24 hours to constant weight, ground through a 40-mesh sieve, and bagged for analysis.

1.3 Diet Formulation

Basal and experimental diets were formulated according to the *Feeding Standard of Meat Ducks* (NY/T 2122-2012). The basal diet was a corn-soybean meal type, while experimental diets substituted 20% wheat for 部分 corn and soybean meal in the basal diet, with unchanged mineral and vitamin supplementation levels.

1.4 Animal Management

The experiment was conducted at the teaching and research experimental base of the Institute of Animal Nutrition, Sichuan Agricultural University. Houses were disinfected according to routine procedures before the experiment. Ducks were housed in metabolic cages (1 m × 1 m × 1 m) by replicate and fed three times daily (08:00, 13:00, 18:00). Ducks had ad libitum access to feed and water throughout the experiment. Room temperature was maintained at (28±2)°C with relative humidity at 60%-70%.

1.5 Measurements and Methods

Wheat dry matter (DM), crude protein (CP), ether extract (EE), crude fiber (CF), neutral detergent fiber (NDF), and acid detergent fiber (ADF) contents were determined according to GB/T 6435–2014, GB/T 6432–1994, GB/T 6433–2006, GB/T 6434–2006, GB/T 20806–2006, and NY/T 1459–2007, respectively. Average daily feed intake (ADFI), average daily gain (ADG), and feed-to-gain ratio (F/G) were measured for each treatment group. Gross energy of feed and excreta samples was determined using an oxygen bomb calorimeter (Parr 6400 calorimeter, Moline, IL, USA).

Dietary AME (MJ/kg) = (Gross energy of feed consumed - Gross energy of excreta) / Feed intake.

The substitution method formula for calculating wheat AME was:

$$\text{Wheat AME} = \frac{\text{Experimental diet AME} - (100 - X) \times \text{Basal diet AME}}{X}$$

where X is the wheat substitution ratio (%), which was 20% in this experiment.

1.6 NIRS Analysis

1.6.1 Wheat NIRS Scanning Wheat samples were scanned using a BRUKER MPA Fourier transform near infrared spectrometer with the following parameters: spectral range 4,000-12,500 cm⁻¹; resolution 8 cm⁻¹; 64 scans per sample. Indoor scanning temperature was 25°C. Samples were equilibrated at room temperature for at least 24 hours before scanning, and each sample was scanned three times with repacking.

1.6.2 Calibration and Validation of NIRS Prediction Model for AME

Using AME values of 40 samples as reference values, samples were randomly divided into a calibration set (n =30) and validation set (n =10) at a 3:1 ratio for model development and external validation, respectively. Original spectra were collected using BRUKER OPUS/QUENTS5.5 commercial spectroscopy quantitative analysis software. Wheat AME measured values were correlated

with spectral data, and a calibration model was established using partial least squares regression (PLS). Internal cross-validation was performed using leave-one-out cross-validation to evaluate model prediction performance. The optimal number of principal components, spectral region, and spectral preprocessing method were determined based on root mean square error of cross-validation (RMSECV). The validation set was used for external validation.

Model quality was assessed using coefficient of determination (R^2), standard deviation (SD), relative standard deviation (RSD), and ratio of performance to deviation (RPD), calculated as follows:

$$R^2 = 1 - \frac{\sum_{i=1}^n (y_i - \hat{y}_i)^2}{\sum_{i=1}^n (y_i - \bar{y})^2}$$

where n is the number of samples, y is the predicted value of the i -th sample, \hat{y} is the measured value of the i -th sample, and \bar{y} is the mean measured value. An R^2 close to 100% indicates predicted values are close to measured values.

$$SD = \sqrt{\frac{\sum_{i=1}^n (y_i - \hat{y}_i)^2}{n - p}}$$

where n is the number of samples, y is the reference value of the i -th sample, \hat{y} is the predicted value of the i -th sample, and p is the number of wavelengths or principal components.

$$RSD (\%) = \frac{SD}{\bar{y}} \times 100$$

$$RPD (\%) = \frac{100 \times SD}{RMSEP}$$

where \bar{y} is the mean of all measured values. RSD reflects the overall prediction effect of the model, with smaller values being better. RPD indicates model prediction ability, with larger values being better.

1.7 Statistical Analysis

Experimental results are expressed as “mean \pm standard deviation.” Correlations between AME and chemical composition were analyzed using SPSS 22.0 software. Paired t-tests were conducted between measured AME values and NIRS predicted values, with $P < 0.05$ considered statistically significant.

2.1 Chemical Composition of Wheat from Different Sources and Its AME for Meat Ducks

The chemical composition of 40 wheat samples is presented in Table 2 , growth performance of meat ducks and AME of different diets and wheat are shown in Table 3 , and correlation coefficients between wheat AME and chemical composition are presented in Table 4 . The results showed that average NDF, ADF, EE, and crude ash contents were $(9.56\pm 1.10)\%$, $(2.58\pm 0.69)\%$, $(1.90\pm 0.25)\%$, and $(1.76\pm 0.31)\%$, respectively, with coefficients of variation greater than 10%, indicating substantial variation. The AME of wheat for meat ducks determined by the substitution method ranged from 11.03 to 14.34 MJ/kg, with a mean value of (13.15 ± 0.70) MJ/kg. Correlation analysis revealed that wheat AME was extremely significantly negatively correlated with CF, NDF, and ADF contents ($P<0.01$), and extremely significantly positively correlated with EE content ($P<0.01$), indicating that wheat AME is related to its chemical composition.

2.2 Development of NIRS Prediction Model for Wheat AME in Cherry Valley Meat Ducks

NIRS scanning spectra of different wheat samples are shown in Figure 1 [Figure 1: see original paper] and Figure 2 [Figure 2: see original paper], with wavenumber (cm^{-1}) on the x-axis and absorbance ($\lg R^{-1}$) on the y-axis. Figure 1 shows that spectral distributions differed among wheat samples. Figure 2 demonstrates distinct characteristic peaks. Combined analysis of Figure 1 and the average spectrum in Figure 2 indicates that the 40 wheat samples showed similar spectral trends but different maximum absorption peak heights, suggesting similarity in composition but variation in content, which indicates good sample representativeness.

[Figure 1: see original paper]

[Figure 2: see original paper]

The software's automatic optimization function determined the optimal spectral analysis region as $7,502.1-4,597.7 \text{ cm}^{-1}$, with spectral preprocessing using first derivative + vector normalization, and 5 principal components. A calibration model was established using the software's built-in partial least squares regression. Leave-one-out cross-validation was applied to construct the NIRS prediction model for AME of wheat from different sources for Cherry Valley meat ducks. Model parameters are presented in Table 5 . The calibration coefficient of determination (R^2_{cal}) was 0.85, with a calibration standard error (RMSEE) of 0.187 MJ/kg. The cross-validation coefficient of determination (R^2_{cv}) was 0.73, cross-validation relative standard deviation (RSD_{cv}) was 1.70%, and cross-validation relative analysis error (RPD_{cv}) was 2.24%, indicating excellent model fit. External validation coefficient of determination (R^2_{v}), external validation relative standard deviation (RSD_{v}), and external validation relative analysis error (RPD_{v}) were 0.89, 1.46%, and 3.23%, respectively, demonstrating good

predictive capability of the NIRS model.

As shown in Table 6, paired t-tests between measured and NIRS-predicted AME values showed no significant differences ($P>0.05$), indicating that predicted values did not differ significantly from measured values and the model can be used for rapid detection of wheat AME for Cherry Valley meat ducks.

3 Discussion

This experiment found substantial variation in chemical composition and AME of wheat from different sources. Correlation analysis showed that AME values were related to wheat chemical composition. The 40 wheat samples from different regions showed large differences in chemical composition, with NDF and ADF contents ranging from 6.80% to 12.15% and 1.69% to 3.92%, respectively, which were extremely significantly negatively correlated with wheat AME. This indicates that NDF and ADF contents vary among wheat from different regions and affect nutrient utilization value. These findings are consistent with Ball et al., who reported that different regions and varieties affect wheat chemical composition and broiler utilization efficiency of wheat-based diets. Kim et al. collected 18 wheat samples from different regions and harvest times, finding CP content ranged from 9.8% to 19.1% (mean 13.4%), and NDF and ADF contents ranged from 12.99% to 18.93% and 2.99% to 4.42%, respectively. Zijlstra et al. collected 16 wheat samples with CP and CF contents of 13.0%-18.1% and 2.6%-4.1%, respectively, and NDF and ADF contents of 12.9%-25.0% and 3.1%-5.1%, respectively, with digestible energy for growing pigs significantly negatively correlated with CF, NDF, and ADF contents. Zhao et al. found that for Cherry Valley meat ducks, corn AME, nitrogen-corrected AME (AMEn), true metabolizable energy (TME), and nitrogen-corrected TME (TMEn) were significantly negatively correlated with CF, NDF, and ADF contents. Wan et al. studied TME of wheat processing by-products in Cherry Valley meat ducks and reported that CF, NDF, and ADF contents were significantly negatively correlated with TME, with NDF showing the highest correlation coefficient.

The average AME of wheat for meat ducks in this study was (13.15 ± 0.70) MJ/kg, which is lower than the wheat AME value in China's *Feeding Standard of Meat Ducks* (NY/T 2122-2012) and lower than the 13.64 MJ/kg reported by King et al. for Pekin ducks, but higher than the 12.62 MJ/kg reported by Fan et al. for Beijing Z-strain male ducks. These differences may be related to wheat sample selection, duck breed, physiological stage, and evaluation methods. Although these methods can estimate feed metabolizable energy values, they are relatively time-consuming (over 24 hours) and cannot meet production needs. Therefore, whether NIRS can rapidly predict feed effective energy values has become an important research focus.

The quality of NIRS calibration models is evaluated from two main aspects: first, the model's own correlation performance and measurement bias; second, the model's actual analytical prediction capability (robustness, reliability, and

dynamic adaptability). In model development, the number of samples in the set and the range of reference values play critical roles. Therefore, sample representativeness and AME accuracy directly affect model prediction precision and are crucial for model establishment. In this experiment, samples were collected from major wheat-producing regions across China and different bulk density grades according to the regional distribution and *Wheat* (GB 1351-2008) standard. Table 2 shows that the chemical composition of the 40 wheat samples had a wide range, while Figure 1 shows that the spectra had similar trends with multiple absorption peaks at different heights, indicating good sample representativeness. The total collection method for AME determination is also a traditional metabolic experiment based on animal nutrition with reliable results.

Organic matter in feed samples contains hydrogen-containing groups such as C-H, O-H, N-H, and S-H. Variations in these components affect near-infrared absorption peak magnitudes, and spectra do not completely overlap among samples. Spectral differences can be used to judge changes in chemical composition. Since AME is determined by the interaction of various conventional nutrients, its spectral information is more complex, which forms the important basis for NIRS analysis of feed AME. Losada et al. used NIRS to evaluate nitrogen-corrected apparent metabolizable energy of rooster feed and concluded that NIRS could be used for feed metabolizable energy evaluation. Deaville et al. established NIRS prediction models for metabolizable energy of wheat and barley samples for sheep that could be used for routine analysis. Haba et al. suggested that when relative standard deviation is 1.1%-2.0%, 2.1%-3.0%, 3.1%-4.0%, and 4.1%-5.0%, calibration models achieve “very good,” “good,” “fair,” and “poor” results, respectively; when relative standard deviation exceeds 5%, calibration is unsatisfactory. In this experiment, cross-validation and external validation relative standard deviations were 1.70% and 1.46%, respectively, indicating “good” performance of the wheat AME NIRS prediction model for feed analysis and prediction. External validation relative analysis error is an important parameter for evaluating model prediction capability. When external validation relative analysis error is 3.0%, the model has good prediction capability and can accurately predict unknown samples; when it is 2.0%-3.0%, the model has fair prediction capability and can be used for rough sample screening; when 2.0%, prediction capability is poor. The external validation relative analysis error for wheat AME in meat ducks was 3.23%, achieving “good” predictive performance. These results demonstrate that the calibration model has good prediction capability, and NIRS can accurately predict wheat AME for practical detection applications.

4 Conclusion

Chemical composition and meat duck AME vary among wheat from different sources, and wheat AME for meat ducks is related to its chemical composition. NIRS can be used to “well” establish a prediction model for wheat AME for meat ducks and achieve “good” prediction performance.

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