Evaluation of energy digestibility and prediction of digestive and metabolisable energy in sunflower seed meal fed to growing pigs

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Abstract

The experiment was conducted to determine the chemical composition, digestible energy (DE), metabolisable energy (ME) and the apparent total tract digestibility (ATTD) in sunflower seed meal (SFSM) and to develop reasonable prediction equations for estimating energy digestibility based on chemical composition of these meals for growing pigs. Ten SFSMs were collected and 66 crossbred barrows (initial body weight=36.43±5.25 kg) were randomly allotted to one of eleven diets. The basal diet was based on corn and soybean meal which contained 82.2% corn, 14.8% de-hulled soybean meal and 3% premix. The test diets contained 30% SFSM at the expense of corn and soybean meals. The experiment comprised a 7-d adaptation period followed by a 5-d collection period of faecal matter and urine. On a dry matter (DM) basis, the content of crude protein, neutral and acid detergent fibre, and gross energy (GE) ranged from 29.33 to 39.09%, 38.15 to 55.40%, 24.59 to 37.34% and 12.47 MJ/kg and 10.26 to 12.16 MJ/kg of DM, respectively. The DE values and ATTD of GE (P<0.05). The ATTD of GE ranged from 52.86 to 63.90%. The best models for predicting DE and ME and apparent total tract digestibility (ATTD) and to develop prediction equations for estimating energy digestibility based on chemical composition of SFSM for growing pigs.

Materials and methods

The Institutional Animal Care and Use Committee at China Agricultural University (Beijing, China) approved the protocol for the experiment. Ten SFSM samples were obtained from five provinces in China. The chemical composition of the samples were analysed (Table 1).

Experiment design

Sixty-six crossbred (Duroc×Landrace×Yorkshire) barrows (initial body weight (BW), 36.43±5.25 kg) were allotted to one of eleven diets according to a completed randomised design. The diet was fed as a mash. All pigs were individually housed in stainless metabolism cages (1.44×0.66×1.22 m²) with a feeder and a nipple drinker. The environmental temperature was controlled at 22±2°C.

Sample collection

Pigs were weighed at the beginning of the experiment and the feed allowance supplied each day was recorded. Two equal meals were fed at 08:00 and 15:30 at a rate of 4% of individual BW (Adela, 2001). The experiment period consists of a seven-day adaption period and five-day total faeces and urine collection period (Song et al., 2003). Faeces were collected in plastic bags and urine was collected in buckets under the metabolism crates which contained 10 mL of 6 N HCl for every 1000 mL of urine. The faeces and urine were stored, thawed and mixed for chemical analysis as described by Zhang et al. (2013).

Chemical analyses

The ten SFSMs were analysed for dry matter (DM), crude protein (CP) (AOAC, 2000), Kjeldahl N (Thiex et al., 2002). Crude protein was calculated as N×6.25. Crude fibre (CF), ash, calcium (Ca), total phosphorus (TP) (AOAC, 2000) and ether extract (EE) (Thiex et
oven and then determined for energy.

The energy lost in faeces and urine was calculated as the experimental unit. CORR procedure, simple and multiple regression analyses (stepwise regression analysis) were conducted to study the relationship among chemical composition and energy content. For selecting the energy prediction equations, the residual standard deviation (RSD) was used as the selection criterion. A smaller RSD was proposed to indicate a better fit. Date were also analysed using the Proc-GLM procedure of SAS. In all analyses, the differences were considered significant if $P<0.05$.

**Results and discussion**

The chemical composition for ten SFSMs is shown in Table 1. Obvious coefficient of variation (CV$>10$%) were almost observed in all chemical compositions (CP, EE, NDF, ADF, CF, crude fibre, Ca, calcium, P, phosphorus, CE, gross energy). Sources of sunflower seed meal; 1, 4 and 8 were from Xinjiang; 2, 7 and 9 were from Hebei; 3 was from Liaoning; 5 was from Shanxi; 6 and 10 were from Inner Mongolia.

| Item                                                                 | SFSM° | Min | Max | Mean | CV |
|---------------------------------------------------------------------|-------|-----|-----|------|----|
| Table 1. Analysed chemical composition of sunflower seed meal.      |       |     |     |      |    |
| DM, %                                                               | 90.91 | 91.37 | 92.51 | 90.76 | 92.15 | 92.91 | 91.27 | 91.85 | 90.79 | 90.31 | 90.31 | 92.91 | 91.48 | 0.92 |
| CP, %DM                                                             | 34.91 | 38.00 | 29.33 | 32.02 | 31.68 | 29.47 | 35.19 | 34.63 | 39.09 | 30.87 | 29.33 | 39.09 | 33.52 | 10.13 |
| EE, %DM                                                             | 2.19  | 2.08  | 5.23  | 0.93  | 1.23  | 3.47  | 2.02  | 0.88  | 1.73  | 0.88  | 0.88  | 1.73  | 1.11  | 10.99 |
| NDF, %DM                                                            | 41.65 | 38.15 | 55.40 | 45.93 | 47.32 | 43.97 | 49.06 | 42.67 | 40.72 | 51.90 | 38.15 | 55.40 | 44.67 | 12.01 |
| ADF, %DM                                                            | 25.85 | 24.59 | 37.34 | 31.31 | 31.42 | 28.04 | 25.89 | 27.99 | 26.07 | 30.52 | 24.59 | 37.34 | 28.90 | 13.28 |
| CF, %DM                                                             | 21.83 | 23.11 | 36.42 | 30.54 | 29.97 | 27.25 | 21.46 | 25.66 | 22.47 | 33.69 | 21.46 | 36.42 | 27.23 | 19.31 |
| Ash, %DM                                                            | 6.86  | 7.15  | 5.45  | 6.32  | 6.82  | 7.75  | 8.30  | 6.40  | 6.76  | 6.71  | 5.45  | 6.30  | 6.85  | 11.37 |
| Ca, %DM                                                             | 0.27  | 0.32  | 0.17  | 0.34  | 0.34  | 0.45  | 0.44  | 0.30  | 0.30  | 0.31  | 0.17  | 0.45  | 0.32  | 25.07 |
| P, %DM                                                              | 1.04  | 1.15  | 0.63  | 0.81  | 0.94  | 0.84  | 1.02  | 0.98  | 1.06  | 0.92  | 0.63  | 1.15  | 0.94  | 15.89 |
| GE, MJ/kg                                                           | 19.17 | 19.52 | 19.88 | 19.08 | 19.00 | 19.51 | 19.02 | 18.65 | 19.36 | 21.50 | 18.65 | 21.50 | 19.47 | 4.07 |

SFSM, sunflower seed meal; CV, coefficient of variation; DM, dry matter; CP, crude protein; EE, ether extract; NDF, neutral detergent fibre; ADF, acid detergent fibre; CF, crude fibre; Ca, calcium; P, phosphorus; GE, gross energy. Sources of sunflower seed meal: 1, 4 and 8 were from Xinjiang; 2, 7 and 9 were from Hebei; 3 was from Liaoning; 5 was from Shanxi; 6 and 10 were from Inner Mongolia.

| Item                                                                 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---------------------------------------------------------------------|---|---|---|---|---|---|---|---|---|----|
| Table 2. Ingredient composition of experimental diets (as-fed basis).|   |   |   |   |   |   |   |   |   |    |
| Calculated composition, %                                           |   |   |   |   |   |   |   |   |   |    |
| Basal diet                                                          |   |   |   |   |   |   |   |   |   |    |
| Corn                                                                | 82.2 |   |   |   |   |   |   |   |   |    |
| Soybean meal                                                        | 14.8 |   |   |   |   |   |   |   |   |    |
| SFSM                                                                | -   |   |   |   |   |   |   |   |   |    |
| Dicalcium phosphate                                                 | 1.1 |   |   |   |   |   |   |   |   |    |
| Limestone                                                           | 0.9 |   |   |   |   |   |   |   |   |    |
| Sodium chloride                                                     | 0.3 |   |   |   |   |   |   |   |   |    |
| Choline chloride                                                    | 0.2 |   |   |   |   |   |   |   |   |    |
| Mineral and vitamin premix°                                          | 0.5 |   |   |   |   |   |   |   |   |    |
| CP                                                                  | 13.88 |   |   |   |   |   |   |   |   | 21.31 |

SFSM, sunflower seed meal; CP, crude protein. °Premix provided the following per kg of complete diets: vitamin A, 5512 μg (vitamin A, 2000 μg; vitamin D3, 2000 μg; vitamin E, 30 μg; vitamin K3, 2.2 μg; vitamin B1, 27 μg; riboflavin, 4 mg; pantothenic acid, 14 mg; niacin, 30 mg; choline chloride, 400 mg; folacin, 0.7 mg; vitamin B6, 1.5 mg; vitamin B12, 3 μg; biotin, 44 μg; Mn, 40 mg (MnO); Fe, 75 mg (FeSO4•H2O); Zn, 75 mg (ZnO); Cu, 10 mg (CuSO4•5H2O); I, 0.3 mg (KI); Se, 0.3 mg (Na2SeO3).

**Calculations**

The energy lost in faeces and urine was determined for each diet, and DE and ME of ten different SFSM diets were calculated. The DE and ME in the basal diet was then divided by 0.97 to calculate the DE and ME in the energy-contributing ingredient according to Gottlob et al. (2006). The DE and ME values provided by each sample were calculated by subtracting the DE and ME values provided by the basal energy-contributing ingredients (Adelola, 2001). The formulae of DE and ME are below:

\[
\text{DE of the diet} = \frac{(\text{GE in feed intake} - \text{GE in faeces}) - \text{WEI of feed intake}}{\text{WEI of feed intake}}
\]

\[
\text{ME of the diet} = \frac{(\text{GE in feed intake} - \text{GE in faeces}) - \text{WEI of feed intake}}{\text{WEI of feed intake}}
\]

\[
\text{Correction (ME)} = \text{DE of the diet} - \text{ME of the diet}
\]

\[
\text{Correction (DE)} = \text{ME of the diet} - \text{DE of the diet}
\]

0.97 means the percentage of energy-contributing ingredient in the diet; %X means the percentage of ingredient aimed to be determined in the energy-contributing ingredient.

**Statistical analyses**

All data were processed using SAS (SAS Inst. Inc., Cary, NC, USA). Individual pig was considered as the experimental unit. CORR procedure, simple and multiple regression analyses (stepwise regression analysis) were conducted to study the relationship among chemical composition and energy content. For selecting the energy prediction equations, the residual standard deviation (RSD) was used as the selection criterion. A smaller RSD was proposed to indicate a better fit. Date were also analysed using the Proc-GLM procedure of SAS. In all analyses, the differences were considered significant if $P<0.05$. The concentration of DE and ME ranged from 10.51 to 12.47 MJ/kg and 10.26 to 12.16 MJ/kg of DM, respectively (Table 3). The DE values and ATTD of GE among the ten SFSM samples significantly differed (P<0.05). The difference between the highest and lowest values of the ten SFSMs for DE and ME was 1.96 MJ/kg and 1.90 MJ/kg of DM, respectively. The ATTD of GE ranged from 52.86 to 63.90%. The concentration of CP had a positive correlation with DE and ME (P<0.05), while ADF content negatively correlated with DE (P<0.05) (Table 4).

Several equations were developed to predict
Table 3. Energy concentration and apparent total tract digestibility of energy of sunflower seed meal.

| Item                        | SFSM1 | Mean  | SEM  | P     |
|-----------------------------|-------|-------|------|-------|
|                             | 1     | 2     | 3     | 4     | 5     | 6     | 7     | 8     | 9     | 10    |
| DE, MJ/kg as-fed basis      | 11.07 | 11.40 | 9.72 | 10.10 | 9.69 | 9.87 | 10.95 | 9.87 | 11.15 | 10.85 |
| ME, MJ/kg as-fed basis      | 10.51 | 11.11 | 9.52 | 9.52  | 9.45 | 9.74 | 10.26 | 9.74 | 10.93 | 10.43 |
| DE, MJ/kg DM                | 12.17 | 12.47 | 10.51 | 11.13 | 10.52 | 10.62 | 11.99 | 10.74 | 12.28 | 11.99 |
| ME, MJ/kg DM                | 11.56 | 12.16 | 10.30 | 10.49 | 10.26 | 10.48 | 11.24 | 10.61 | 12.04 | 11.55 |
| ATTD of GE, %               | 63.52 | 63.90 | 52.86 | 58.32 | 55.36 | 54.44 | 63.04 | 57.60 | 63.45 | 55.78 |
| ATTD of ME, %               | 10.52 | 10.62 | 10.48 | 11.24 | 10.61 | 11.55 | 11.06 | 5.00  | 0.07  |

SFSM, sunflower seed meal; DE, digestible energy; ME, metabolisable energy; ATTD, apparent total tract digestibility; GE, gross energy. *Sources of sunflower seed meal: 1, 4 and 8 were from Xinjiang; 2, 7 and 9 were from Hebei; 3 was from Liaoning, 5 was from Shanxi; 6 and 10 were from Inner Mongolia.* Means within a row without a common superscript letter are significantly different (P<0.05).

Table 4. Correlation coefficients between chemical composition and digestible and metabolisable energy of sunflower seed meal.

| Item       | CP   | EE   | NDF  | ADF  | CF   | Ash  | Ca   | P     | GE    | DE    | ME    |
|------------|------|------|------|------|------|------|------|-------|-------|-------|-------|
|            | 1.00 |      |      |      |      |      |      |       |       |       |       |
| CP         |      | -0.45|      |      |      |      |      |       |       |       |       |
| EE         |      |      | 0.64 | 1.00 |      |      |      |       |       |       |       |
| NDF        | -0.80**| 0.34 | 0.94**| 1.00 |      |      |      |       |       |       |       |
| ADF        | -0.77**|      | 0.95**| 0.93**| 1.00 |      |      |       |       |       |       |
| CF         | -0.81**|      | 0.95**| 0.93**| 1.00 |      |      |       |       |       |       |
| Ash        | 0.26  | -0.15| -0.62| -0.71*| -0.65*| 1.00 |      |       |       |       |       |
| Ca         | 0.03  | -0.19| -0.49| -0.53| -0.43| 0.89**| 1.00 |       |       |       |       |
| P          | 0.85**| -0.29| -0.84**| -0.91**| -0.84**| 0.54| 0.30 | 1.00  |       |       |       |
| GE         | -0.34 | 0.97**| 0.56 | 0.28 | 0.54 | -0.16| -0.19| -0.21| 1.00  |       |       |
| DE         | 0.74* | 0.12 | -0.54| -0.69*| -0.58| 0.36| 0.07| 0.74*| 0.23  | 1.00  |       |
| ME         | 0.78* | 0.14 | -0.55| -0.70*| -0.58| 0.30| <0.01| 0.77**| 0.26  | 0.96**| 1.00  |

Correlation coefficients between chemical composition and digestible and metabolisable energy of sunflower seed meal. CP, crude protein; EE, ether extract; NDF, neutral detergent fibre; ADF, acid detergent fibre; CF, crude fibre; Ca, calcium; P, phosphorus; GE, gross energy; DE, digestible energy; ME, metabolisable energy. *P<0.05; **P<0.01.

Table 5. Linear regression equations for prediction of energy content (MJ/kg DM) based on the chemical composition (% of DM) of sunflower seed meal fed to growing pigs.

| No. | Linear regression equations | R²  | RSD  | P     |
|-----|-----------------------------|-----|------|-------|
| 1   | DE=−4.90+0.14 CP+0.08 CF+0.71 GE | 0.89 | 0.27 | <0.01 |
| 2   | DE=−2.5.15 NDF+0.80 GE | 0.71 | 0.44 | 0.01  |
| 3   | DE=−6.88+0.56 GE+0.22 CP | 0.82 | 0.34 | <0.01 |
| 4   | DE=15.67−0.15 ADF | 0.48 | 0.58 | 0.03  |
| 5   | DE=5.5+0.18 CP | 0.55 | 0.54 | 0.01  |
| 6   | DE=7.28−0.17 ADF+0.47 GE | 0.68 | 0.46 | 0.02  |
| 7   | ME=1.14+0.87 DE | 0.93 | 0.20 | <0.01 |
| 8   | ME=4.59−0.18 NDF+0.35 Ash−0.87 GE | 0.85 | 0.28 | <0.01 |
| 9   | ME=−4.90−0.05 NDF+0.66 GE+0.16 CP | 0.96 | 0.14 | <0.01 |
| 10  | ME=14.93−0.13 ADF | 0.40 | 0.52 | 0.02  |
| 11  | ME=5.43+0.17 CP | 0.62 | 0.45 | <0.01 |
| 12  | ME=2.33−0.14 NDF+0.77 GE | 0.77 | 0.35 | <0.01 |
| 13  | ME=6.81−0.16 ADF+0.46 GE | 0.72 | 0.38 | 0.01  |

RSD, residual standard deviation; DE, digestible energy; CP, crude protein; CF, crude fibre; GE, gross energy; NDF, neutral detergent fibre; ADF, acid detergent fibre; ME, metabolisable energy. Regression equations were developed based on stepwise regression analyses.

The results of CP, EE, NDF, ADF, CF, Ash, Ca and P concentration of SFMS varied greatly (CV>10%), possibly due to the different regions where the sunflower grew. The average concentration of CP (sources 1, 2 and 9) was higher than sources 3, 5 and 6 probably because of the improvement of breeding (Robertson, 1972). The concentrations of GE among the ten SFMSs varied from 18.65 to 21.50 MJ/kg and were related to the extraction process and the amount of residual oil left (Dinuasson, 1990). Although the production process for most SFMSs was similar using pressing extraction method (Fick and Miller, 1997), small differences in temperature, pressure and time might lead to the changes in chemical concentration in SFMS (Clandinin and Robblee, 1950). The NDF content of the ten SFMSs was higher than the data reported by González-Vega and Stein (2012), but the average concentration of ADF was lower than the value reported in National Research Council (2012). The reason was not clear depending on the previous papers, but the different grown places may have a role in these differences in chemical composition.

The range of DE (from 10.51 to 12.47 MJ/kg DM) and ME (from 10.30 to 12.16 MJ/kg DM) content in the ten SFMS sources was related to the differences in CP and cell wall fractions levels among these meals (Noblet and Peres, 1993). The average DE and ME contents of sources 3 and 10 (10.51 and 11.99 MJ/kg DM).
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Conclusions

The energy digestibility of SFSM has great variation resulting from differences in chemical composition. The concentration of CP was the factor mostly affected in the equations established in this experiment. Crude fibre, ADF and GE can significantly improve the accuracy of the prediction equations of DE and ME.

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