Validation of metabolisable energy prediction equation for de-oiled corn distillers dried grains with solubles fed to finishing pigs

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ABSTRACT
This experiment was conducted to determine the accuracy of a prediction equation for metabolisable energy (ME) content generated from the chemical composition of de-oiled corn distillers dried grains with solubles (DDGS) in finishing pigs. A total of 72 pigs (average initial body weight 85.7 kg), with four pigs per pen and six pens per treatment, were fed one of the three experimental diets. The experimental diets were a corn-soybean meal basal diet or two diets containing 30% de-oiled DDGS diets. The experimental diets were formulated using ME values obtained from a prediction equation or NRC. ME prediction equation for the de-oiled DDGS was ME (kcal/kg DM) = 4066 – (46.3 \times \%NDF) + (45.8 \times \%CP) – (106.2 \times \%ash) (R^2 = 0.94, SE = 86.20).

In conclusion, the prediction equation of ME content in de-oiled DDGS was more accurate than the value and its use resulted in improved pig performance.

Introduction

Many studies have been conducted recently to evaluate corn distillers dried grains with solubles (DDGS) as an ingredient in swine diets (Stein 2007; Stein & Shurson 2009). Historically, corn DDGS contains approximately 10% oil with an ME content similar to corn (Stein and Shurson 2009). However, over the past several years, the extraction of oil from corn has led to more variation in corn DDGS ether extract (EE) content ranging from 2.1 (Ganesan et al. 2009) to 14.3% (Pedersen et al. 2007).

Some researchers have evaluated the DE and metabolisable energy (ME) content of corn DDGS (Pedersen et al. 2007; Stein et al. 2009; Mendoza & Ellis 2010; Ren et al. 2011; Anderson et al. 2012; Kerr et al. 2013), but the number of samples (especially for the de-oiled DDGS) was usually limited. Li et al. (2015) determined the ME content of 25 DDGS samples; 10 of them were de-oiled. From these data, prediction equations were generated. The best de-oiled DDGS ME prediction equation (DM basis) was ME (kcal/kg DM) = 4066 – (46.3 \times \%NDF) + (45.8 \times \%CP) – (106.2 \times \%ash) (R^2 = 0.94, SE = 86.20).

Many energy prediction equations for different feedstuffs have been reported (Noblet & Perez 1993; Stein et al. 2006; Pedersen et al. 2007; Jacela et al. 2011; Anderson et al. 2012; Urriola et al. 2013; Li et al. 2015). However, few reports ever verified the accuracy of these prediction equations. We hypothesised that the accuracy of an ME calculated by a prediction equation based on the actual chemical analysis of the DDGS may be superior to a book value for a generic DDGS obtained from NRC (2012). Therefore, the objective of this study was to compare the accuracy of energy values determined using the prediction equation of Li et al. (2015) and NRC (2012) value in de-oiled DDGS in diets fed to finishing pigs.

Materials and methods

All experimental procedures and animal care were approved by the China Agricultural University Animal Care and Use Committee (Beijing, China).
Animals and housing

A total of 72 crossbred pigs (Duroc × Landrace × Yorkshire) with an initial body weight of 85.70 ± 7.33 kg were selected from a commercial herd (Fengning, China). The experiment was set up as a completely randomised design with three dietary treatments, and six replicates of four pigs (two barrows and two gilts) per treatment. All pens were equipped with a nipple type drinker and a feeder. Feed was given twice daily (07:30 and 16:30 h) and water was available ad libitum throughout the 4-week study. Pigs and feeders were weighed at the beginning and end of the experiments in order to calculate ADG, ADFI and feed efficiency.

Experimental diets

A typical sample of de-oiled corn DDGS was selected. The chemical composition was analysed and put into a prediction equation to calculate the ME of DDGS (Tables 1 and 2). The best de-oiled DDGS ME (kcal/kg DM) prediction equation was

$$\text{ME} = 4066 - (46.3 \times \% \text{NDF}) + (45.8 \times \% \text{CP}) - (106.2 \times \% \text{ash})$$

($R^2 = 0.94$, SE = 86.20), with NDF, CP and ash expressed on DM (Li et al. 2015). The experimental diets were formulated using the ME of DDGS obtained from the prediction equation or NRC (2012) value and the ME of other ingredients were obtained from NRC (2012). The SID AA values were according to the NRC (2012). The three treatments were a corn-soybean meal as a control, de-oiled DDGS prediction equation value and de-oiled DDGS NRC (2012) value. All diets were formulated according to the nutrient requirements suggested by NRC (2012) for finishing pigs. The ingredient composition of the experimental diets is shown in Table 3. The diets were equal in ME (3.30 Mcal/kg) and SID Lys level (0.69%). Samples of feed were collected and stored at 4°C until chemical analysis.

Sample collection

On the 28th d of the trial, six pigs were randomly selected from each treatment (one pig per pen) and an 8 ml sample of blood was obtained by vena cava puncture using a 9 ml clot activator tube (Greiner Bio-One GmbH, Kremsmünster, Austria). Blood samples were centrifuged for 15 min (3000 rpm) and stored at −20°C for further analysis. After blood sample collection, pigs were slaughtered by exsanguination.

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**Table 1. Analysed nutrient composition and metabolisable energy level of de-oiled DDGS (% of DM, except otherwise stated)**

| Item                      | De-oiled DDGS |
|---------------------------|---------------|
| Dry matter, %             | 91.29         |
| Crude protein             | 32.79         |
| Calcium                   | 0.09          |
| Total phosphorus          | 0.64          |
| Ash                       | 4.80          |
| Ether extract             | 3.98          |
| Neutral detergent fibre   | 39.09         |
| Acid detergent fibre      | 13.59         |
| Gross energy, kcal/kg DM  | 4892          |
| Essential amino acids     |               |
| Arginine                  | 0.87          |
| Histidine                 | 0.74          |
| Isoleucine                | 0.94          |
| Leucine                   | 3.43          |
| Lysine                    | 0.79          |
| Methionine                | 0.46          |
| Phenylalanine             | 1.36          |
| Threonine                 | 0.97          |
| Tryptophan                | 0.16          |
| Valine                    | 1.29          |
| Non-essential amino acids |               |
| Alanine                   | 2.32          |
| Asparagine                | 1.73          |
| Cystine                   | 0.41          |
| Glutamine                 | 2.97          |
| Glycerine                 | 0.89          |
| Proline                   | 2.44          |
| Serine                    | 4.11          |
| Tyrosine                  | 0.62          |
| ME from prediction equations, kcal/kg DMb | 3238          |
| ME from NRC (2012), kcal/kg DM | 3476          |

*All analysis were conducted in duplicates. The de-oiled DDGS ME (kcal/kg DM) prediction equation was $\text{ME} = 4066 - (46.3 \times \% \text{NDF}) + (45.8 \times \% \text{CP}) - (106.2 \times \% \text{ash})$, with NDF, CP and ash expressed on DM.

**Table 2. Analysed fatty acid profile of de-oiled DDGS (% of oil)**

| Item       | De-oiled DDGS |
|------------|---------------|
| C8:0       | 0.02          |
| C10:0      | 0.02          |
| C12:0      | 0.02          |
| C14:0      | 0.08          |
| C15:0      | 0.03          |
| C16:0      | 18.73         |
| C16:1n-7   | 0.20          |
| C17:0      | 0.11          |
| C18:0      | 2.65          |
| C18:1n-9   | 20.27         |
| C18:2n-6   | 53.76         |
| C18:3n-6   | 0.07          |
| C18:3n-3   | 2.23          |
| C20:0      | 0.43          |
| C20:1n-9   | 0.03          |
| C21:0      | 0.09          |
| C20:2n-6   | 0.08          |
| C22:0      | 0.52          |
| C22:1n-9   | 0.16          |
| C22:2      | 0.06          |
| C23:0      | 0.08          |
| C24:0      | 0.37          |
| Total MUFA | 20.66         |
| Total PUFA | 56.20         |
| Total SFA  | 23.14         |
| UFA:SFA ratio | 3.32        |
| PUFA:SFA ratio | 2.43        |
| Iodine value | 116.89       |

*aAll analysis were conducted in duplicates.*
Table 3. Ingredient composition of the experimental diets (% as-fed).

| Ingredient                  | Control   | Prediction equation | NRC (2012) |
|-----------------------------|-----------|---------------------|------------|
| Corn                        | 74.98     | 54.62               | 55.81      |
| Soybean                     | 21.48     | 9.58                | 9.57       |
| Low-oil DDGS                | –         | 30.00               | 30.00      |
| Soybean oil                 | 1.19      | 3.33                | 2.15       |
| Dicalcium phosphate         | 0.72      | 0.14                | 0.14       |
| Limestone                   | 0.78      | 1.19                | 1.19       |
| Salt                        | 0.35      | 0.35                | 0.35       |
| i-Lysine HCl                | –         | 0.29                | 0.29       |
| Vitamin and mineral premixa | 0.50      | 0.50                | 0.50       |

Composition (calculated value)

- SID Lys, %: 0.69
- ME, kcal/kg: 3300
- SID Lys, %: 2.09
- SID Met, %: 32.25
- SID Met and CysLys, %: 67.27
- SID Thr, %: 70.86
- SID Trp, %: 24.35
- Total Lys, %: 0.80
- CP, %: 14.72
- Ca, %: 0.51
- P, %: 0.46
- Dig P, %: 0.21

*Premix provided the following per kg of complete diet for finishing pigs: vitamin A, 5512 U; vitamin D3, 2200 U; vitamin E, 30 mg; vitamin K3, 2.2 mg; vitamin B12, 0.3 mg; I, 0.3 mg; Se, 0.3 mg.

From the left half of each carcass, meet samples between the 10th and 11th ribs of *Longissimus dorsi* muscle were obtained for the determinations of pH value, water-holding capacity and intramuscular fat (IMF) content.

**Carcass and meat quality measurements**

At slaughter, the carcass was split longitudinally and the head, hair, feet, viscera and leaf fat were removed. Hot carcass weight (HCW) was recorded before chilling. The dressing percentage for an individual animal was defined as HCW divided by the live weight. Measurements of backfat depth at the midline were conducted with a vernier caliper at the 10th and the last rib, respectively. Measurements of the height and width of *Longissimus dorsi* muscle were conducted on the cut surface at the intercostal space between the 10th and 11th ribs (Huff-Lonergan et al. 2002; Jia et al. 2010). After slaughter, 45 min-pH (pH 45) and 24 h-pH (pH 24) were measured with a glass penetration pH electrode (pH-star, Mattheus, Germany). Measurement of loin colour (including L*, a* and b* values) was conducted with a Chroma Meter (CR-410, Konica Minolta, Tokyo, Japan). Drip loss was measured as described previously (Aaslyng et al. 2003; Straadt et al. 2007).

*Longissimus* muscle area (LMA) was determined by the equation \( \text{LMA} = \text{height} \times \text{width} \times 0.7 \) (Huang et al. 2008).

Twenty-four hours after carcasses were chilled at 1.7–4.4 °C, 2.54-cm cores from the belly and jowl were collected. The belly tissue cores were collected at the midline opposite the last rib, and the jowl fat cores were collected from the right side at the same position. Core samples of belly and jowl fat were stored at −20 °C after collection and analysed for a fatty acid profile using gas chromatography according to the American Oil Chemists’ Society (AOCS 1998) method (Ce 1062). The iodine value (IV) of fat was calculated using the following equation (AOCS 1998): \( \text{IV} = (\text{C16:1} \times 0.95) + (\text{C18:1} \times 0.86) + (\text{C18:2} \times 1.732) + (\text{C18:3} \times 2.616) + (\text{C20:1} \times 0.785) + (\text{C22:1} \times 0.723) \). IMF percentage was determined in the *Longissimus dorsi* by ether extraction without previous acid hydrolysis (Serra et al. 1998).

**Sample preparation and chemical analysis**

The ingredients and diet samples were analysed for Kjeldahl N (Thiex et al. 2002) and EE (Thiex et al. 2003). DM (Association of Official Analytical Chemists (AOAC) method 930.15), ash (AOAC method 942.05), calcium (AOAC method 927.02) and phosphorus (AOAC method 965.17) were determined using the methods of the AOAC (AOAC 2000). NDF and acid detergent fibre concentrations were determined using the methods of Van Soest et al. (1991). GE was determined with an isoperibol oxygen bomb calorimeter (Parr Instruments, Moline, IL).

Before analysis of AA, the de-oiled corn DDGS sample was hydrolysed with 6 N HCl for 24 h at 110 °C (AOAC method 999.13) and analysed for AA using an Amino Acid Analyzer (Hitachi L-8900, Tokyo, Japan). Methionine and cystine were determined as methionine sulphone and cystic acid after cold performic acid oxidation overnight and hydrolysed with 7.5 N HCl for 24 h at 110 °C (AOAC method 994.12) using an Amino Acid Analyzer (Hitachi L-8800). Tryptophan was determined after LiOH hydrolysis for 22 h at 110 °C (AOAC method 998.15) using high-performance liquid chromatography (Agilent 1200 Series, Santa Clara, CA).

**Estimation, calculation and statistical analysis**

All data were analysed using the MIXED procedure of SAS (Statistical Analysis System, version 6.12, 2001). The pen was used as the experimental unit for all responses. All results are reported as least square mean. Multiple comparisons among treatments were
performed using PDIFF and adjusted by the Tukey option for multiple comparisons of means. An alpha level of \( p < 0.05 \) was the criterion for statistical significance.

**Results**

**Performance**

The effect of the method of ME calculation in the diets on the performance of finishing pigs is shown in Table 4. The pigs fed the diet calculated by NRC (2012) had significantly lower ADG and feed efficiency compared with pigs fed the diet calculated by prediction equation \( (p < 0.05) \).

**Carcass traits and meat quality**

The effects of the method of ME calculation in the diets on carcass traits and meat quality of finishing pigs is shown in Table 5. The pigs fed the diet calculated by NRC (2012) had significantly lower HCW and LMA compared with pigs fed the diet calculated by prediction equations \( (p < 0.05) \). The \( b^* \) yellowness in pigs fed the control diet was lower compared with the other treatments \( (p < 0.05) \). However, dressing percentage, carcass length, muscle \( pH \), \( L^* \) lightness, \( a^* \) redness, drip loss and IMF content in pigs did not differ among treatments \( (p > 0.05) \).

**Fatty acid composition and iodine value of jowl and belly fat**

Fatty acid composition and IV of jowl and belly fat in pigs are shown in Tables 6 and 7. There was no difference in fatty acid composition and IV due to treatment \( (p > 0.05) \).

**Discussion**

**Performance**

ADG in pigs fed diet calculated by NRC (2012) was lower compared with the other treatments. The reason for the decreased ADG may be a deficiency of energy. Because the ADFI in pigs fed the two diets was not different, the poor ADG is likely a result of the fact that the ME values in NRC (2012) of de-oiled DDGS were overestimated. There were 10 samples of de-oiled DDGS selected in the prediction equation (Li et al. 2015). However, the 10 samples consisted of nine samples of low-oil DDGS and only

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**Table 4. Effects of method of metabolisable energy calculation in the diets on the performance of finishing pigs.**

| Item            | Control | Prediction equation | NRC (2012) | SEM | \( p \) value |
|-----------------|---------|---------------------|------------|-----|---------------|
| ADFI, kg        | 2.86    | 2.79                | 2.84       | 0.08| 0.585         |
| ADG, kg         | 0.91\( ^a \) | 0.90\( ^a \) | 0.84\( ^b \) | 0.02| 0.027         |
| Feed efficiency | 0.32\( ^a \) | 0.32\( ^a \) | 0.29\( ^b \) | 0.01| 0.034         |

\( ^a,b \)Means with the same row without common superscripts differ significantly \( (p < 0.05) \).

**Table 5. Effects of method of metabolisable energy calculation in the diets on the carcass traits of finishing pigs.**

| Item                          | Control | Prediction equation | NRC (2012) | SEM | \( p \) value |
|-------------------------------|---------|---------------------|------------|-----|---------------|
| Hot carcass weight, kg        | 85.87\( ^a \) | 86.93\( ^a \) | 83.83\( ^b \) | 1.60| 0.018         |
| Dressing percentage, %        | 75.33   | 77.75               | 76.96      | 1.35| 0.643         |
| Carcass length, cm            | 94.75   | 91.13               | 92.00      | 0.96| 0.265         |
| Tenth rib fat depth, mm       | 26.67   | 32.38               | 28.63      | 2.73| 0.384         |
| Longissimus muscle area, cm\(^2\) | 68.03\( ^a \) | 62.35\( ^a \) | 54.26\( ^b \) | 2.19| 0.005         |
| \( pH_{45 min} \)             | 6.35    | 6.23                | 6.16       | 0.08| 0.424         |
| \( pH_{45 min} \)             | 5.44    | 5.48                | 5.56       | 0.05| 0.260         |
| \( L^* \) Light              | 50.76   | 47.94               | 50.37      | 2.49| 0.825         |
| \( a^* \) Redness             | 6.66    | 6.94                | 6.43       | 0.64| 0.754         |
| \( b^* \) Yellowness          | 3.44\( ^b \) | 5.76\( ^b \) | 6.36\( ^a \) | 0.56| 0.019         |
| Drip loss, %                  | 4.90    | 4.70                | 6.54       | 1.32| 0.745         |
| Intramuscular fat content, %   | 7.96    | 8.28                | 7.19       | 1.52| 0.837         |

\( ^a,b \)Means with the same row without common superscripts differ significantly \( (p < 0.05) \).
one medium-oil DDGS. Furthermore, the de-oiled DDGS prediction equation did not contain the factor of EE which indicated that the equation cannot predict variable oil content of DDGS. Therefore, the prediction equation can be used in de-oiled DDGS because the EE content in de-oiled DDGS did not vary much. As the development of DDGS processing techniques improved, the energy and AA digestibility increased (Urriola & Stein 2009; Anderson et al. 2012). However, the energy and SID AA content in de-oiled DDGS were also varied considerably and using a fixed value of ME may be not appropriate which may be the reason why the NRC (2012) value of low-oil DDGS is overestimated in this experiment. Because of the decreased ADG in pigs fed the diet calculated by NRC (2012), the feed efficiency was poor in this treatment.

Table 7. Effects of method of metabolisable energy calculation in the diets on the fatty acid composition in belly fat of finishing pigs.

| Item                        | Control | Prediction equation | NRC (2012) | SEM  | p value |
|-----------------------------|---------|---------------------|------------|------|---------|
| Fatty acid, % of total fat  |         |                     |            |      |         |
| C14:0                       | 1.13    | 1.17                | 1.15       | 0.05 | 0.665   |
| C16:0                       | 23.05   | 23.21               | 23.35      | 0.66 | 0.663   |
| C18:1n-9                    | 1.07    | 1.28                | 1.38       | 0.11 | 0.358   |
| C18:2n-6                    | 16.84   | 16.51               | 16.73      | 0.74 | 0.674   |
| C18:3n-9                    | 32.65   | 33.63               | 36.87      | 1.33 | 0.341   |
| C18:2n-6                    | 20.89   | 19.95               | 16.44      | 1.77 | 0.467   |
| C18:3n-3                    | 1.20    | 1.07                | 1.02       | 0.11 | 0.338   |
| C20:0                       | 0.23    | 0.25                | 0.26       | 0.02 | 0.746   |
| C20:1n-9                    | 0.55    | 0.64                | 0.72       | 0.05 | 0.433   |
| C20:2n-6                    | 0.10    | 0.09                | 0.08       | 0.01 | 0.607   |
| C20:3n-6                    | 0.30    | 0.26                | 0.22       | 0.03 | 0.386   |
| Total SFA                   | 42.83   | 42.65               | 42.83      | 1.07 | 0.655   |
| Total MUFA                  | 34.31   | 35.58               | 39.01      | 1.39 | 0.379   |
| Total PUFA                  | 22.78   | 21.69               | 18.06      | 1.88 | 0.467   |
|PUFA:SFA ratio              | 1.34    | 1.35                | 1.34       | 0.06 | 0.658   |
|PUFA:SFA ratio              | 0.54    | 0.51                | 0.42       | 0.05 | 0.603   |
| Iodine value                | 69.01   | 68.12               | 64.84      | 2.36 | 0.512   |

Table 8. Effects of method of metabolisable energy calculation in the diets on the plasma indexes of finishing pigs.

| Item                        | Control | Prediction equation | NRC (2012) | SEM  | p value |
|-----------------------------|---------|---------------------|------------|------|---------|
| Plasma urea nitrogen, mmol/l| 4.22    | 3.81                | 3.76       | 0.39 | 0.501   |
| Total protein, g/l          | 55.98   | 60.00               | 63.76      | 1.98 | 0.242   |
| Glucose, mmol/l             | 5.97    | 5.06                | 4.10       | 0.39 | 0.014   |
| Triglycerides, mmol/l       | 0.38    | 0.44                | 0.40       | 0.08 | 0.715   |
| Total cholesterol, mmol/l   | 2.30    | 2.16                | 1.93       | 0.23 | 0.256   |
| High-density lipoprotein, mmol/l | 0.69  | 0.70                | 0.63       | 0.07 | 0.543   |
| Low-density lipoprotein, mmol/l | 2.65  | 2.16                | 1.92       | 0.22 | 0.003   |
| Very low-density lipoprotein, mmol/l | 0.24 | 0.26                | 0.21       | 0.01 | 0.265   |
| Lipase, U/ml                | 7.85    | 9.53                | 6.53       | 0.42 | 0.004   |
| Insulin, uIU/ml             | 14.59   | 15.75               | 15.52      | 0.87 | 0.557   |
| Growth hormone, ng/ml       | 4.02    | 4.34                | 4.40       | 0.37 | 0.585   |
| Leptin, ng/ml               | 8.35    | 8.37                | 4.39       | 0.43 | <0.001  |

Carcass traits and meat quality

The carcass traits of pigs fed the diet calculated by prediction equation did not differ compared with pigs fed the control diet which is in agreement with previous research (Widmer et al. 2008). The pigs fed the diet calculated by NRC (2012) had lower HCW compared with pigs fed the other diets which are in agreement with the lower ADG in this experiment. Pigs fed the diet calculated by NRC (2012) had decreased Longissimus dorsi muscle area compared with pigs fed the other two diets. The reason may be that the decreased energy intake affected the energy-protein ratio which caused the low deposition of protein. This is in agreement with previous research (Whitney et al. 2006; Gaines et al. 2007). However, the backfat depth and LMA in pigs fed the diet calculated by prediction equation did not differ compared with the control diet. This may be due to the proper energy-amino acids ratio which caused improved meat quality and this is in agreement with previous research (Lee et al. 2011; Duttlinger et al. 2012; Rickard et al. 2012; Schiavon et al. 2015).

Meat quality indicators such as pH, drip loss and IMF were not affected by the experimental diets. However, b* yellowness in Longissimus of pigs fed the diets containing DDGS was higher compared with pigs fed the control diet. No previous information is available on the effect of feeding diets containing corn DDGS on meat colour. Because corn DDGS are processed to transform starch into ethanol but other ingredients are not changed, other nutrient levels are increased three times in corn DDGS. As a result, the pigments in corn DDGS such as lutein, zeaxanthin and cryptoxanthin may be deposited in high levels in Longissimus (Lu & Mao 2003).

Fatty acid composition and iodine value of jowl and belly fat

The quality of carcass fat is important for meat processors who discriminate against soft bellies because they are difficult to process into bacon (Wood & Enser 1997). Carcass fat IV, which provides an overall estimation of fatty acid unsaturation, is an indirect indicator of belly firmness (Hugo & Roodt 2007). A maximum IV has not been universally accepted by the pork industry. However, a range from 70 to 74 has been recommended to be a maximum value (Boyd et al. 1997; Cromwell et al. 2011). In this experiment, no difference in fatty acid composition and IV of jowl and belly fat was observed. This is in agreement with Widmer et al. (2008) and Lee et al. (2011) but in contrast with some
other papers (Benz et al. 2010; Rickard et al. 2012) which reported an increase in IV as the concentration of DDGS increased. However, in this experiment, the fat concentrations between each group were similar and the lipid in diets was mainly supplied by corn oil and soybean oil. The IV of corn oil and soybean oil were similar which are 125 and 132, respectively (NRC 2012). This may be the reason why no increase in the IV was observed for pigs fed the DDGS-containing diets. Another reason may be that the short duration of the experiment (28 d) was not long enough to alter fat deposition.

Serum indexes

Indexes related to energy metabolism in serum were determined in this experiment. The decreased serum glucose and low-density lipoprotein levels in the diet calculated by NRC (2012) indicate a lack of energy intake which is in agreement with the poor performance in the treatment. The low level of glucose also resulted in low secretion of leptin which is a function of decreasing energy intake (Mueller et al. 1998). The lipase level in the diet calculated by prediction equation was high compared with the diet calculated by NRC (2012) which may be due to the addition of soybean oil in the treatment. However, a difference in digestion and metabolism between the oil bound in DDGS and soybean oil has not been previously reported.

However, there was an issue should be pointed out which was the higher protein concentration in the diets containing corn DDGS compared with a corn-soybean meal. The high concentration of CP may lead to high N excretion which may be detrimental to water and air quality. So, the further study to increase the utilisation of N in corn DDGS or reduce N excretion of pigs fed high-level protein diets is necessary.

Conclusions

In conclusion, the prediction equation of ME content in de-oiled DDGS was more accurate than the NRC (2012) value and its use resulted in improved pig performance.

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