Comparative energy digestibility of protein feed ingredients in crossbred barrows in different growing stages

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ABSTRACT
This study was conducted to determine the effect of different growing stages on digestible energy (DE) and metabolizable energy (ME) in soybean meal (SBM), cottonseed meal (CSM), rapeseed meal (RSM), corn gluten meal (CGM), and corn distillers dried grains with solubles (DDGS) fed to crossbred barrows. Thirty-six growing barrows (GS 1: 29.1 ± 2.85 kg BW), 36 growing barrows (GS 2: 59.2 ± 4.91 kg BW), and 36 finishing barrows (GS 3: 105.4 ± 6.91 kg BW) were allotted to 6 diets in a completely randomized design with 6 replicated pigs per diet per growth stage or BW. Faecal and urine samples were collected for 5 days after a 12-day adaption period. The results showed that the concentration of DE in corn for pigs at GS 3 was greater (P < .05) than that for pigs at GS 1. The concentration of DE and ME in CSM were lower (P < .05) fed to pigs at GS 1 and 2 compared with those at GS 3. Similar effects of BW were observed with corn DDGS. In conclusion, different DE values for corn, and DE and ME values for CSM and corn DDGS, should be used when formulating diets for growing and finishing barrows.

1. Introduction
Despite the favourable nutritional value of soybean meal (SBM) in swine diets, a number of other protein-rich ingredients are commonly fed to pigs as an alternative to SBM (Zijlstra and Beltranena 2013). Similar to SBM, cottonseed meal (CSM) and rapeseed meal (RSM) are the co-products of cottonseed and rapeseed processing, respectively. The oil extracted from these oilseeds is used in food for human consumption and the remaining CSM and RSM are used in animal diets (Stein et al. 2016). Corn gluten meal (CGM) is one of the major co-products from the wet milling industry of corn grain (Ji et al. 2012), and the corn distillers dried grains with solubles (DDGS) is the major co-product of the corn dry grind industry (Li et al. 2015). In addition to supplying comparable crude protein (CP) as SBM, the utilization of these protein-rich ingredients in the industry could greatly reduce feed costs by taking advantage of the large number of those co-products generated in the local market (Woyengo et al. 2014). The chemical compositions of these co-products can vary a lot; many factors such as the breed of pig, variety of cereal grain, and processing method of co-products affected the evaluation of their energy values (Stein et al. 2016; Urriola and Stein 2012). Body weight (BW) is an important factor that could influence the nutritional value of the feedstuff, and it is generally accepted that both energy and nutrient digestibility improve with increased BW or age of pigs (Noblet and Shi 1994; Noblet and van Milgen 2004). Determining the energy values of ingredients for pigs at different growth stages is important for accurate diet formulation. However, only one available DE or ME value was reported for most ingredients in existing feedstuff tables, regardless of the growth stage of pigs (NRC 2012). Therefore, the objective of this study was to investigate the effect of different growing stages or BW (GS 1: 29.1-kg BW; GS 2: 59.2-kg BW; GS 3: 105.4-kg BW) on the concentration of DE and ME in SBM, CSM, RSM, CGM, and corn DDGS.

2. Materials and methods
All procedures used in the experiment were approved by the China Agricultural University Institutional Animal Care and Use Committee (Beijing, China). This study was conducted in the Metabolism Laboratory of the National Feed Engineering Technology Research Center (Hebei, China).

2.1. Experimental design and diets
Ingredients of yellow dent corn and SBM were supplied by the China Agricultural University Animal Experiment Base (Fengning, China). Cottonseed meal was provided by Kuntai Company (Xinjiang, China), RSM by Yi Hai Kerry Company (Yingkou, China), CGM by Fufeng (Inner Mongolia, China), and corn DDGS by the New Tianlong Company (Jilin, China). The analysed chemical compositions of the ingredients were presented in Table 1.

Three GS groups (29.1 ± 2.85 kg BW, 59.2 ± 4.91 kg BW, and 105.4 ± 6.91 kg BW), each with 36 crossbred (Duroc × Landrace × Yorkshire) barrows, were randomly allotted to 1
of 6 diets resulting in 6 replicated pigs per treatment diet per GS. The experimental diets (Table 2) included a corn basal diet containing 97.35% corn and 5 test diets formulated by including SBM, CSM, and RSM at 25%, and CGM at 20%, at the expense of the corn in the basal diet. Corn DDGS was included at 30%, at the expense of the corn and SBM, in the SBM test diet. The substitution proportions (25% and 20%) were identified based on previous literature to achieve good evaluation results (Stein et al. 2016; Urriola and Stein 2012). The SBM test diet was used as the basal diet when determining the energy values of corn DDGS, in order to meet the requirement of crude protein (CP) in growing and finishing pigs (Li et al. 2015; NRC 2012).

2.2. Animals housing, feeding, and sample collection

Barrows were individually housed in metabolism crates (1.4 m × 0.5 m × 0.6 m) equipped with a feeder, a nipple drinker, and a faecal collection tray allowing for total, but separate, collection of faeces and urine. During the experiment, the room temperature was controlled at 22 ± 2°C, humidity varied from 35 to 63%, and the light and dark cycle controlled at 12 h each. Pigs were allowed a 10-day adaptation to the metabolism crates and the environmental conditions. During this period, a commercial diet was provided and feed intake gradually increased until the intake of the daily feed allowance was reached. Daily feed allowance was set at 4% of their BW measured at the start of the initial diet adaptation period and divided into 2 equal meals supplied at 0730 and 1630 h every day. Drinking water was available ad libitum during the experiment.

After adaptation to the new environment, pigs were adapted to their experimental diets for 7 days, followed by 5 days total collection of faeces and urine. Faeces were collected beginning at 1600 h on day 7 and ceased at 1600 h on day 12, and immediately stored at −20°C after removal from the pen. A bucket containing 50 mL 6 N HCl was put under each crate for urine collection. The volume of collected urine was measured daily and a 20% subsample was stored at −20°C. At the end of the experiment, faeces and urine were thawed, pooled by pig, homogenized and sub-sampled. Before analysis, faecal sub-samples were oven-dried for 72 h at 65°C and then ground through a 1-mm screen. Urine samples (4 mL) were dried at 65°C for 8 h with quantitative filter paper in crucibles for analysis of gross energy (GE).

2.3. Chemical analysis and calculations

Ingredients, diets, faeces, and urine were analysed for GE using an Automatic Isoperibol Oxygen Bomb Calorimeter (Parr 6300 Calorimeter, Moline, IL, USA). Other proximate analyses included dry matter (DM; procedure 930.15; AOAC 2006), CP (procedure 984.13; AOAC 2006), crude fibre (CF; procedure 978.10; AOAC 2006), ether extract (EE, method 920.39; AOAC 2006), and ash (procedure 942.05; AOAC 2006) in ingredients, diets and faeces. Neutral detergent fibre (NDF) and acid detergent fibre (ADF) were also determined (procedure 2012.97; AOAC 2006) using fibre bags and Fiber Analyzer (Ankom Technology, Macedon, NY, USA). The proportion of NDF was estimated using heat stable α-amylase and sodium sulphite without correction for insoluble ash. The ADF fraction was expressed with the inclusion of crude ash. Ingredients were also analysed for Ca (procedure 968.08; AOAC 2006) and total phosphorus (procedure 946.06; AOAC 2006). All chemical analyses were conducted in duplicates.

The apparent total tract digestibility (ATTD) of nutrients in diets and the concentration of DE or ME in ingredients were calculated according to the difference method described by Kong and Adeola (2014) using the following equation:

\[
AE_{\text{nutrient}} = \left( \frac{AE_{\text{test}} - AE_{\text{basal}}}{1 - Nutrient_{\text{basal}}} \right)
\]

where \(AE_{\text{nutrient}}\) is the ATTD of energy or nutrient in the ingredient (%), \(AE_{\text{test}}\) is the ATTD of energy or nutrient in the test diet, and \(Nutrient_{\text{basal}}\) is the concentration of the nutrient in the basal diet (%).
diet (%), $A_{\text{basal}}$ is the ATTD of energy or nutrient in the basal diet (the corn basal diet for calculating in SBM, CSM, RSM, and CGM, and the SBM diet for calculating in corn DDGS), and $N_{\text{basal}}$ is the contribution of the nutrient from the basal diet to the test diet (relative ratio). Organic matter (OM) was calculated as the difference between DM (%) and ash (%).

### 2.4. Statistical analysis

Normality of the data was verified and outliers were detected using the UNIVARIATE procedure of SAS (SAS Institute, Cary, NC, USA). Data were analysed using the PROC GLM procedure of SAS with pig as the experimental unit. Data were analysed as a $3 \times 6$ factorial design including the main effects of ingredient (or diet) and GS and their interaction. Treatment means were calculated using the LSMEANS statement and statistical differences among the treatments were separated using the Tukey’s HSD test. Statistical significance was declared at $P < .05$.

### 3. Results

#### 3.1. Daily feed intake and energy balance

In our experiment, pigs at GS 2 and 3 did not consume daily feed allowance equivalent to 4 of their BW. Average daily feed intake was equivalent to 3.8% of BW for SBM diet and 3.9% of BW for the other diets at GS 1, 3.2% of BW for CGM diet and 3.5% of BW for the other diets at GS 2, and 2.5% of BW for SBM diet and 2.7% of BW for the other diets at GS 3 (data not shown). However, daily GE intake on a metabolic weight basis remained stable across experimental diets within each GS (Table 3). Daily GE intake on a metabolic weight basis for pigs at GS 2 was greater ($P < .05$) than that for pigs at GS 3, but not different compared with pigs at GS 1 when fed the corn, CSM, or corn DDGS diets. Daily GE intake on a metabolic weight for pigs at GS 2 was greater ($P < .05$) than that for pigs at GS 1 and 3 when fed the SBM or RSM diet. No significant differences were observed for daily GE intake on a metabolic weight basis of pigs between GS 3 and 1 when fed each of the experimental diets.

Greater ($P < .05$) loss of GE in faeces was observed in pigs fed the CSM, RSM, or corn DDGS diets compared with that in faeces of pigs fed the corn, SBM, or CGM diets within each GS. When fed the corn, SBM, or CSM diets, loss of GE in faeces of pigs at GS 1 was lower ($P < .05$) compared with that of pigs at GS 2 and 3, but not different between pigs at GS 2 and 3. Moreover, daily loss of GE in faeces of pigs fed the RSM, CGM, or corn DDGS diet at GS 2 was greater ($P < .05$) than that of pigs at GS 1 but lower ($P < .05$) than that of pigs at GS 3.

At GS 2, loss of GE in urine was greater ($P < .05$) when fed CCM or corn DDGS diets compared with that of corn, SBM, or CSM diets, but not different from the RSM diet. There was no effect of diet on GE loss in urine for pigs at GS 1 or 3. Daily GE loss in the urine of pigs fed SBM, CSM, or CGM diet at GS 1 was lower ($P < .05$) than that of pigs at GS 3 with GE loss in the urine of pigs at GS 2 intermediate.

#### 3.2. The ATTD of nutrients and DE or ME values in diets

There was no interaction between GS and experimental diet on ATTD of CP and EE, and ME and ME/DE ratio of diets (Table 4). The greatest and lowest ATTD of CP and ME were observed in the CGM and CSM diet, respectively, with the other four diets intermediate ($P < .01$). Corn DDGS diet contained the greatest ATTD of EE, and the lowest ATTD of EE was observed in the

### Table 3. Daily balance of gross energy (GE, as-fed) for pigs fed diets containing different test ingredients in three growing stages or body weight (BW)$^1$.

| Item       | Corn | SBM$^2$ | CSM$^3$ | RSM$^4$ | CGM$^5$ | cDDGS$^6$ | SEM | P-value |
|------------|------|---------|---------|---------|---------|-----------|-----|---------|
| GE intake (MJ/kg) BW 0.75 |       |         |         |         |         |           |     |         |
| GS 1, 29.1 kg | 1.51$^{AB}$ | 1.40$^{B}$ | 1.49$^{AB}$ | 1.48$^{B}$ | 1.56$^{B}$ | 1.56$^{AB}$ | 0.07 | NS      |
| GS 2, 59.2 kg | 1.54$^{A}$ | 1.55$^{A}$ | 1.56$^{A}$ | 1.61$^{A}$ | 1.52$^{A}$ | 1.68$^{A}$ | 0.07 | NS      |
| GS 3, 105.4 kg | 1.41$^{B}$ | 1.28$^{B}$ | 1.42$^{B}$ | 1.42$^{B}$ | 1.50$^{B}$ | 1.47$^{B}$ | 0.07 | NS      |
| SEM         | 0.04 | 0.04    | 0.03    | 0.04    | 0.03    | 0.04     |     |         |

$P_{\text{stage}} < .05$ $P_{\text{diet}} = \text{NS}$ $P_{\text{stage*diet}} = \text{NS}$

GE in faeces (MJ)

| Item       | Corn | SBM$^2$ | CSM$^3$ | RSM$^4$ | CGM$^5$ | cDDGS$^6$ | SEM | P-value |
|------------|------|---------|---------|---------|---------|-----------|-----|---------|
| GS 1, 29.1 kg | 2.31$^{Bb}$ | 2.07$^{Bb}$ | 3.66$^{B}$ | 3.19$^{Ca}$ | 2.13$^{Cb}$ | 3.44$^{Ca}$ | 0.16 | <.05    |
| GS 2, 59.2 kg | 3.96$^{Ab}$ | 3.86$^{Ab}$ | 6.23$^{Ba}$ | 5.59$^{Ba}$ | 3.65$^{Ba}$ | 6.25$^{Ba}$ | 0.32 | <.05    |
| GS 3, 105.4 kg | 4.72$^{Ab}$ | 3.81$^{Ab}$ | 6.36$^{Ba}$ | 6.43$^{Ba}$ | 4.59$^{Ab}$ | 7.16$^{Ba}$ | 0.36 | <.05    |
| SEM         | 0.31 | 0.21    | 0.40    | 0.27    | 0.27    | 0.29     |     |         |

$P_{\text{stage}} < .05$ $P_{\text{diet}} < .05$ $P_{\text{stage*diet}} = \text{NS}$

GE in urine (MJ)

| Item       | Corn | SBM$^2$ | CSM$^3$ | RSM$^4$ | CGM$^5$ | cDDGS$^6$ | SEM | P-value |
|------------|------|---------|---------|---------|---------|-----------|-----|---------|
| GS 1, 29.1 kg | 0.24 | 0.18$^{B}$ | 0.20$^{B}$ | 0.53    | 0.39$^{B}$ | 0.85     | 0.18 | NS      |
| GS 2, 59.2 kg | 0.39$^{B}$ | 0.37$^{B}$ | 0.54$^{Ab}$ | 0.65$^{Ab}$ | 0.89$^{Ba}$ | 0.90$^{a}$ | 0.11 | <.05    |
| GS 3, 105.4 kg | 0.56 | 0.86$^{A}$ | 0.89$^{A}$ | 1.11    | 1.38$^{A}$ | 0.78     | 0.26 | NS      |
| SEM         | 0.09 | 0.09    | 0.13    | 0.29    | 0.18    | 0.26     |     |         |

$P_{\text{stage}} < .05$ $P_{\text{diet}} < .05$ $P_{\text{stage*diet}} = \text{NS}$

$^1$Means in the same row bearing different lower case superscripts, or in the same column bearing different capital superscripts, differ significantly ($P < .05$); NS: not significant.

$^2$Soybean meal.

$^3$Cottonseed meal.

$^4$Rapeseed meal.

$^5$Corn gluten meal.

$^6$Corn distillers dried grains with solubles.
Table 4. The apparent total tract digestibility (%) of nutrients, digestible energy (DE, DM basis) and metabolizable energy (ME, DM basis) in diets fed to pigs in three growing stages or body weight (BW).1

| Item                  | CP        | EE        | NDF       | ADF       | OM        | GE        | DE, MJ/kg | ME, MJ/kg | ME/DE, % |
|-----------------------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|----------|
| Diets                 |           |           |           |           |           |           |           |           |          |
| Corn                  | 84.24b    | 24.20d    | 66.74     | 63.14     | 91.17     | 88.55     | 15.93     | 15.72c    | 98.65a   |
| SBM                   | 88.79b    | 37.84c    | 75.80     | 75.57     | 91.22     | 89.14     | 16.38     | 16.12c    | 98.43b   |
| CSM                   | 81.05d    | 46.67b    | 57.10     | 39.02     | 85.09     | 82.71     | 15.23     | 14.95d    | 98.15ab  |
| RSM                   | 84.06b    | 40.65bc   | 61.37     | 46.64     | 86.86     | 84.30     | 15.51     | 15.06d    | 97.87ab  |
| CGM                   | 91.14a    | 23.37d    | 74.83     | 68.10     | 91.38     | 89.44     | 17.07     | 16.58a    | 97.17bc  |
| cDDGS                 | 85.85c    | 56.11a    | 67.03     | 65.44     | 85.40     | 83.40     | 15.98     | 15.58b    | 97.36c   |
| SEM                   | 0.51      | 1.81      | 1.00      | 1.25      | 0.27      | 0.30      | 0.06      | 0.07      | 0.24     |

1Means in the same column bearing different superscripts differ significantly (P < .05); NS: not significant; ADF, acid detergent fibre; CP, crude protein; EE, ether extract; GE, gross energy; NDF, neutral detergent fibre; OM, organic matter.

Corn and CGM diets, with the other three diets intermediate (P < .01). Corn diet had comparable ME/DE ratio to SBM diet, which was greater (P < .05) than that of the CGM and corn DDGS diets. The ATTD of CP in diets fed to pigs at GS 2 was greater (P < .05) than that in diets fed to pigs at GS 1, but lower (P < .05) than that in diet fed to pigs at GS 3. The ATTD of EE in diets fed to pigs at GS 1 was greater (P < .05) than that in diets fed to pigs at GS 2, but lower (P < .05) than that in diets fed to pigs at GS 3. Diets fed to pigs at GS 3 contained greater (P < .05) ME value compared with diets fed to pigs at GS 1 and 2.

For the other parameters with a significant interaction between GS and diet, the effect of GS was analysed within each diet and the results presented in Table 5. In corn diet, ATTD of ADF was lower (P < .05) when fed to pigs at GS 2 than pigs at GS 3, but not different from pigs at GS 1. The ATTD of OM, GE, and the concentration of DE fed to pigs at GS 3 was greater (P < .05) than pigs at GS 1, but not different from pigs at GS 2. In SBM diet, the ATTD of ADF, OM, GE, and the concentration of DE fed to pigs at GS 2 was lower (P < .05) than pigs at GS 3, but no difference compared with pigs at GS 1. The ATTD of NDF fed to pigs at GS 3 was greater (P < .05) than pigs at GS 1, but not different from pigs at GS 2. In CSM, RSM, CGM, and corn DDGS diets, the ATTD of NDF, ADF, OM, GE, and the concentration of DE fed to pigs at GS 2 was lower (P < .05) than pigs at GS 3, but not different from pigs at GS 1, except that the ATTD of ADF in RSM diet and the ATTD of OM in CGM diet fed to pigs at GS 3 were greater than pigs at GS 1 and not different from pigs at GS 2.

4. Discussion

Many factors such as a variety of the seed, environmental conditions the seed grown in, and the processing procedure of a certain meal co-product may contribute to the differences of the nutrient components among different types of meals or within the same type of meal products (Stein, Lagos, and Gasas 2016). In our study, the concentrations of each tested chemical component in corn, CSM, RSM, CGM, and corn DDGS were within the ranges of previously reported values (Ji et al. 2012; Li et al. 2012, 2014, 2015; NRC 2012; Zhang et al. 2012; Lagos and Stein 2017). The relatively high concentration of CP in CSM makes it a suitable alternative to SBM in swine diets. The low concentration of EE (0.28%, on as-fed basis) in CSM observed in this study indicated that oil in cottonseed was almost completely extracted. While lower in CP content compared with SBM, corn DDGS contained more EE content than the other 4 protein-rich ingredients, which makes it both a good protein and energy source for pigs. Corn gluten meal contained a higher concentration of CP and lower fibre content compared with SBM. Therefore, CGM is a good alternative for
Table 6. The concentration of digestible energy (DE, as-DM) and metabolizable energy (ME, as-DM) in ingredients fed to pigs in three growing stages or body weight (BW)1.

| Item          | DE, MJ/kg | ME, MJ/kg | ME/DE, % |
|---------------|-----------|-----------|----------|
| Diets         |           |           |          |
| Corn          | 16.43     | 16.21     | 98.65    |
| SBM2          | 17.15     | 16.78     | 97.90    |
| CSM3          | 14.65     | 14.14     | 96.71    |
| RSM4          | 15.78     | 15.17     | 95.74    |
| CGM5          | 21.65     | 20.20     | 93.39    |
| cDDGS6       | 16.90     | 16.11     | 95.02    |
| SEM          | 0.20      | 0.23      | 0.86     |

Body weight (kg)1:

- GS 1, 29.1: 16.63, 16.09, 96.77
- GS 2, 59.2: 16.82, 16.05, 95.55
- GS 3, 105.4: 17.81, 17.17, 96.39

1Means in the same row bearing different lower case superscripts differ significantly (P < .05); NS: not significant.
2Soybean meal.
3Cottonseed meal.
4Rapeseed meal.
5Corn gluten meal.
6Corn distillers dried grains with solubles.

SBM in swine diets. On the contrary, RSM contained lower CP content but higher fibre content compared with SBM, which makes it a less valuable alternative than CGM as a substitute for SBM in swine diets. The higher concentration of Ca and total P in SBM, CSM, and RSM than that in corn and CGM were in agreement with the previous results from our lab (Huang et al. 2017).

During the animal trial, the actual average daily feed intake for individual pigs were all under feed allowance (4 and 3% of BW) in growing and finishing stages, which indicates that all pigs consumed their feed *ad libitum* during the whole study. The greater daily GE intake on a metabolic weight basis of pigs at GS 2 could be explained by the greater energy requirement resulted from the faster growth rate of pigs at GS 2 compared with pigs at GS 1 or 3. While the greater daily GE loss in faeces and urine of pigs at GS 3 may be due to its greater daily feed intake. The greater daily output of GE in faeces of pigs fed the CSM, RSM, or corn DDGS diets compared with that fed corn grain, SBM, or CGM diets could be explained by the combined effects of greater fibre content and lower fibre digestibility in CSM, RSM, or corn DDGS diets. It was demonstrated that increased dietary fibre could speed up the passage rate of digesta through the entire gastrointestinal tract, allowing for less exposure of feed to enzymes and bacteria, and less absorption of energy and other nutrients in small and large intestine (Le Goff et al. 2002; Serena et al. 2008; Zhang et al. 2013). The greater excretion of GE in the urine of pigs fed CGM or corn DDGS diets may result from the combined effects of high dietary CP and fibre levels, because the nitrogen (N) excretion
in urine increased as dietary CP level increased (Gatel and Grosjean 1992; Lynch et al. 2008). Moreover, the high dietary fibre level was reported to increase the endogenous excretion of N and decreased the ratio of urinary to faecal N excretion, both contributed to the increased GE in urine (Zhang et al. 2013; Schulze et al. 1994; Widmer et al. 2007).

Corn gluten meal showed the greatest ATTD of all detected nutrients, except for EE, ADF, and ME/DE ratio, among all the feed ingredients used in this study, supporting the statement that CGM could be a good alternative to SBM in swine diets. The lowest ATTD of EE in CGM diet and the greatest ATTD of EE in corn DDGS diet are reflective of the inherent EE content in the CGM and the corn DDGS diets (i.e. lowest and highest dietary EE content), respectively. The lower ME/DE ratio in CGM and corn DDGS diets compared with SBM diet could be explained by the greater dietary CP content in CGM and corn DDGS diets. The high dietary CP content increased urinary N excretion and therefore decreased the ME value of the diet. Cottonseed meal diet contained the lowest ATTD of all detected nutrients except for EE and ME/DE ratio, similarly supporting the statement that CSM is a less valuable alternative for SBM compared to CGM, RSM or corn DDGS. The low nutrient digestibility in CSM diet may be primarily due to the high level of dietary fibre in CSM, which was reported to decrease nutrient digestibility (Zhang et al. 2013; Widmer et al. 2007).

The different feed intakes may be a possible reason for the different effects of BW on the ATTD of nutrients (Shi and Noblet 1993; Morel et al. 2006; Liu et al. 2016). In addition, it was reported that the small intestine of pigs is almost fully developed at 20 kg BW, while the hindgut is still growing at 150 kg BW (Morel et al. 2006). Greater ATTD of detected nutrients in diets fed to pigs was observed at GS 3, and this is mainly because adult pigs have larger, more developed intestinal tract and thus, greater capacity for digestion and absorption in gut (Fernández et al. 1986; Cervantes-Pahm et al. 2014; Lowell et al. 2015). In this study, we further found that the BW of pigs had different effects on the ATTD of different nutrients. For example, the ATTD of CP linearly increased as the BW of pig increased from GS 1–3, while the ATTD of EE firstly decreased and then increased when the BW of pig increased from GS 1–3, and the dietary ME concentration remained unchanged from GS 1–2, but increased from GS 2 to GS 3.

In summary, corn contained greater DE value when fed to pigs at GS 3 compared with pigs at GS 1, and no difference between the DE value in corn fed to pigs at GS 1 and 2. This indicated that different DE or ME values should be chosen when formulating diets for pigs at GS 1 and 3. For instance, if the DE or ME values evaluated by pigs at GS 1 were used to formulate diet for pigs at GS 3, the concentration of DE or ME in corn would be underestimated, leading to larger corn inclusion rate in diets and thus a waste of corn. Similar situation would also happen when using the same value of ME in corn DDGS to formulate diet for pigs at different growth stages. The BW of pigs had no significant effects on DE, ME, and the ME/DE ratio of SBM, RSM, and CGM, which indicated that the same DE or ME value in each of the above three ingredients could be used for pigs at different GS.

5. Conclusions

Different energy values need to be used when feeds are formulated for animals in different growing stages or BW. The effect of BW on the energy value depended on the ingredient, and different DE and ME values of corn, CSM, and corn DDGS should be used when formulate diets for pigs at GS 2 and GS 3. Same DE and ME value in SBM, RSM, and corn DDGS could be used when formulate diets for pigs at different growth stages.

Disclosure statement

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