Effects of intact and extracted lipid in diets fed to growing pigs on the digestible energy content and the digestibility of various chemical constituents

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ABSTRACT
The effects of dietary lipid source (corn germ vs. corn oil) on digestible energy (DE) and apparent total tract digestibility (ATTD) of various chemical constituents were evaluated in diets fed to growing pigs. Thirty barrows were allotted to one of five treatments with six replicates per treatment. The five diets were comprised of a corn-based basal diet with 15.64 MJ/kg of GE, LCO and LCG diets (containing 1% extracted corn oil or 2% corn germ, respectively) were formulated to maintain 16.00 MJ/kg of GE, as well as HCO and HCG diets (containing 2% extracted corn oil or 12% corn germ, respectively) were formulated to maintain 16.94 MJ/kg of GE. The differences in ATTD of NDF and ADF were neither observed between the LCO and LCG diet nor between the HCO and HCG diet. LCO diet had greater DE and ATTD of GE and EE ($p<.01$) compared with LCG diet, and HCO diet exceeded HCG diet in these traits ($p<.01$). Results from this research indicate that dietary corn oil inclusion increased the DE and ATTD of GE and EE of the diet in comparison with diets using corn germ. These results imply that the additional lipid from extracted corn oil results in a more digestible diet compared to diets using intact corn germ and the fibrous components in diets containing corn germ can decrease the ATTD of EE, GE and the DE of diets.

Introduction
Dietary lipids are an important component of diets fed to swine because of their high energy content (Stahly & Cromwell 1979). The lipid in high-oil corn, roasted soybeans and sunflower seeds can be effectively utilised by the growing pig (Adams & Jensen 1982). These grains have been incorporated into diets and posed none of the feed-handling problems frequently associated with the addition of other processed fats and oils to diets (Pettigrew 1981). Lipids in swine diets may originate from either intact feed ingredients or supplemented extracted oil, and the digestibility of different forms of lipids have been reported (Adams & Jensen 1984; Kil et al. 2010). However, reports on the effect of the form of the lipid feed on its energy value are limited. Therefore, the objective of this experiment was to study the influence of two forms of lipid (intact and extracted) on the digestible energy (DE) content and the apparent total tract digestibility (ATTD) of various dietary chemical constituents in diets fed to growing pigs.

Materials and methods
The animal portion of this experiment was conducted in the Metabolism Laboratory of the Ministry of Agriculture Feed Industry Centre (China Agricultural University, Beijing, China). The protocol for the experiment was reviewed and approved by the Institutional Animal Care and Use Committee at China Agricultural University (Beijing, China).

Sample preparation
Yellow-dent corn and corn germ were obtained from the China Agriculture University Animal Experimental Base (Fengning, China). Analysed dry matter, crude protein, ether extract, neutral detergent fibre, acid detergent fibre and gross energy of corn germ used in

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this experiment were 87.7, 18.5, 25.6, 27.5, 6.7% and 23.94 MJ/kg, respectively.

**Animals, housing and experimental design**

Thirty barrows (Duroc × Landrace × Yorkshire; initial average BW of 43.1 ± 2.9 kg) were individually housed in stainless-steel metabolism crates (1.4 × 0.7 × 0.6 m) at the Fengning Swine Research Unit of China Agricultural University (Hebei, China). A feeder and a nipple drinker were installed in each pen. The crates were located in an environmentally controlled room with a temperature of 22 ± 1°C. Pigs were allotted to one of five diets according to a completely randomised design, and each diet was fed to six pigs.

**Diets, feeding and measurements**

The GE of extracted corn oil is almost two times that of corn germ. Therefore, the five diets were: a corn-based diet (CTL) with 15.64 MJ/kg of GE; LCO and LCG diets (containing 1% extracted corn oil or 2% corn germ, respectively) formulated to maintain 16.00 MJ/kg of GE; HCO and HCG diets (containing 6% extracted corn oil or 12% corn germ, respectively) formulated to maintain 16.94 MJ/kg of GE. Ingredients and calculated gross energy (GE) content of the experimental diets are listed in Table 1.

The experiment included a 7 day adaptation to the diet and cage followed by a 5 day collection of total faeces. During the 7 day adaptation period, the daily amount of feed was gradually increased until it was equivalent to 4% of the BW determined at the beginning of the experiment. The daily intake was divided equally into two feedings provided at 0800 and 1600 h.

Pigs were weighed individually at the beginning of the adaptation and at the end of collection period. The amount of feed provided was recorded at each feeding time. Orts were removed and weighed at each meal and daily feed consumption was calculated. Water was available ad libitum for each pig. The crates were located in an environmentally controlled room with a temperature of 22 ± 1°C.

**Sample collection**

Samples of diets and ingredients were collected and stored at −20°C until analysis. During the 5 day collection period, all faeces were promptly collected into plastic bags and stored at −20°C. The 5 day of faecal production from each pig were pooled and weighed and a 300 g sample was taken and dried in a forced-draft oven at 65°C for 72 h. After drying and grinding, sub-samples were stored at −20°C for further chemical analysis. The collection and sample preparation of faeces were conducted according to the methods described by Song et al. (2003).

**Chemical analyses**

The dry matter (method 934.01), EE (method 920.39) and CP (method 990.03) of the diets and faeces were analysed according to the procedures of the AOAC International (AOAC 2007). Neutral detergent fibre and acid detergent fibre were determined using fibre bags (model F57; Ankom Technology, Macedon, NY) and a fibre analyser (ANKOM200 Fibre Analyser; Ankom Technology) after an adaptation of the procedure as described by Van Soest et al. (1991). The concentration of NDF was analysed using heat-stable α-amylase and sodium sulphite without correction for insoluble ash. The GE of materials, diets and faeces were measured using an Automatic Isoperform Oxygen Bomb Calorimeter (Parr 1281 Calorimeter; Parr Instrument Co., Moline, IL). The analysed chemical composition of the diets is shown in Table 2.

**Calculations and statistical analyses**

The DE and ATTD of chemical constituents in the five feed samples were measured. The small portion of the experimental diets that consisted of minerals and

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**Table 1. Ingredient composition and calculated nutrient content of the experimental diets (% of as-fed basis).**

| Ingredient              | CTL  | LCO  | LCG  | HCO  | HCG  |
|-------------------------|------|------|------|------|------|
| Corn                    | 96.8 | 95.8 | 94.8 | 90.8 | 84.8 |
| Corn oil                | 1.0  | 1.0  | 1.0  | 1.0  | 1.0  |
| Corn germ               | 2.0  | 2.0  | 2.0  | 2.0  | 2.0  |
| Dicalcium phosphate     | 1.7  | 1.7  | 1.7  | 1.7  | 1.7  |
| Salt                    | 0.3  | 0.3  | 0.3  | 0.3  | 0.3  |
| Limestone               | 0.6  | 0.6  | 0.6  | 0.6  | 0.6  |
| Antioxidant*            | 0.1  | 0.1  | 0.1  | 0.1  | 0.1  |
| Vitamin and mineral premix*b | 0.5  | 0.5  | 0.5  | 0.5  | 0.5  |
| Gross energy, MJ/kgd    | 15.6 | 16.0 | 16.0 | 16.9 | 16.9 |

*Calculated value.
*bPremix provided the following per kg of complete diet for growing pigs: vitamin A, 5512 IU; vitamin D3, 2200 IU; vitamin E, 30 IU; vitamin K3, 2.2 mg; vitamin B12, 27.6 µg; riboflavin, 4 mg; pantothenic acid, 14 mg; niacin, 30 mg; choline chloride, 400 mg; folacin, 0.7 mg; thiamine 1.5 mg; pyridoxine 3 mg; biotin, 44 µg; Mn, 40 mg (MnO); Fe, 75 mg (FeSO4·H2O); Zn, 75 mg (ZnO); Cu, 100 mg (CuSO4·H2O); I, 0.3 mg (KI); Se, 0.3 mg (Na2SeO3).
*aSantoquin MAX composite antioxidant, contained no less than 10% ethoxyquin, no less than 3% butylated hydroxytoluene (BHT) and citric acid, provided by Novus International, Inc. (St. Louis, MO).
*bPremix provided the following per kg of complete diet for growing pigs: vitamin A, 5512 IU; vitamin D3, 2200 IU; vitamin E, 30 IU; vitamin K3, 2.2 mg; vitamin B12, 27.6 µg; riboflavin, 4 mg; pantothenic acid, 14 mg; niacin, 30 mg; choline chloride, 400 mg; folacin, 0.7 mg; thiamine 1.5 mg; pyridoxine 3 mg; biotin, 44 µg; Mn, 40 mg (MnO); Fe, 75 mg (FeSO4·H2O); Zn, 75 mg (ZnO); Cu, 100 mg (CuSO4·H2O); I, 0.3 mg (KI); Se, 0.3 mg (Na2SeO3).
*dCTL: corn-based diet; LCO: diet containing 1% of extracted corn oil; LCG: diet containing 2% of corn germ; HCO: diet containing 6% of extracted corn oil; HCG: diet containing 12% of corn germ.
vitamins (3.2%) was assumed to have a negligible contribution to the digestibility of GE.

The DE content of the diets were calculated using Eq: $\text{DE} = \frac{(\text{GE}_{\text{in}} - \text{GE}_{\text{out}})}{\text{F}_{\text{in}}}$, where DE is the DE content in diets (MJ/kg of DM), $\text{GE}_{\text{in}}$ is the total GE intake (MJ of DM), $\text{GE}_{\text{out}}$ is the GE content in faeces (MJ of DM), $\text{F}_{\text{in}}$ is the total feed intake (kg of DM). The ATTD for energy, ether extract, ADF, NDF and CP was calculated using the Equation: $\text{ATTD} = \frac{[(\text{F}_{\text{in}} - \text{F}_{\text{out}})/\text{F}_{\text{in}}] \times 100\%}{C_2}$, where ATTD is the apparent total tract digestibility of energy, ether extract, ADF, NDF and CP (%); $\text{F}_{\text{in}}$ is the total intake of energy (kcal), ether extract (g), ADF (g), NDF (g) and CP (g) from day 8 to 12; and $\text{F}_{\text{out}}$ is the total faecal output of energy (kcal), ether extract (g), ADF (g), NDF (g) and CP (g) originating from the feed that was fed from day 8 to 12.

Analysis of variance was conducted for a completely randomised design using the General Lineal Model (GLM) procedures of the Statistical Analysis System Institute (Cary, NC). Contrasts (corn oil vs. corn germ and low addition level vs. high addition level) were used to assess the effect of treatments. Statistical significance was declared at $p < .05$. Values in the tables are means and pooled SEM.

**Results**

**DE and ATTD of GE**

All pigs maintained good health status during the study. The DE and ATTD of GE for the five diets are shown in Table 3. The DE was lower ($p < .01$) for LCG diet than for the LCO diet but did not differ from the CTL diet. The DE was greater ($p < .01$) for the HCO diet than for the HCG diet, and DE was lower ($p < .01$) for the LCO diet than for the HCO diet. However, there were no differences between the CTL and the LCG, HCG and LCO diet, respectively. The ATTD of GE was greater for the HCO diet than for the other diets with the exception of the LCO diet. The ATTD of GE was greater for the LCO diet than for the LCG diet and HCG diet, but not different from the CTL diet.

**ATTD of EE, CP, ADF and NDF**

No differences for the ATTD of EE were observed among the CTL, LCG and HCG diets. The ATTD of EE was lower ($p < .01$) for these diets than for the LCO and HCO diets (Table 4). The ATTD of EE was greater ($p < .01$) for the HCO diet than for the LCO diet. The ATTD of CP did not differ among diets. The ATTD of NDF and ADF was greater ($p < .01$) for the HCG diet than for the LCG diet. No differences for the ATTD of NDF and ADF were observed between the LCG diet and the LCO diet as well as the HCG diet and the HCO diet, respectively.

**Discussion**

The current results indicate that the ATTD of GE in HCG diet decreased when lipid was increased in composition with the LCG diet. The reason for this is the increased fibre in the diet as a result of corn germ meal. Moreover, the fact that the ATTD of GE in corn oil diets was higher than in corn germ diets indicates that EE from extracted corn oil is more digestible than that from corn germ.

Inclusion of intact dietary lipid did not affect the apparent digestibility of nitrogen and fibre. No differences were observed as a result of differences in the form of dietary lipid or lipid level on protein digestibility. These results agree with previous data obtained in pigs (Greeley et al. 1964; Leek et al. 2004; O’Doherty et al. 2002). Reasons for this are not clear.
However, Adams and Jensen (1984) also reported that form of fats (in-seed fat and extracted fat) did not affect the digestibility of N in corn and sunflower diets. However, N digestibility for the soybean diet with in-seed fat was less than for the diet with extracted fat.

In the present study, DE increased as dietary EE concentration increased, regardless of the form of lipid. This response agrees with previous data obtained in pigs (Jørgensen & Fernández 2000; Kil et al. 2010; Leek et al. 2004) and poultry (San Juan & Villamide 2000). Greater apparent digestibility of extracted lipid than of intact lipid has also been reported for soybean oil (Agunbiade et al. 1992), palm kernel oil (Agunbiade et al. 1999) and sunflower oil (San Juan & Villamide 2000). The data also indicate that the energy value of corn oil is dependent on the form in which the corn germ product is incorporated into the diets. Thus, the DE of lipid was higher when added in the form of free corn oil than in the form of corn germ.

The improvement in ATTD as dietary lipid concentration increased reflects the fact that the endogenous loss of lipid contributes more to the total output of lipid, and therefore has a greater effect on the apparent digestibility of lipid at lower concentrations of dietary lipid than at higher concentrations (Jørgensen et al. 1993; Kil et al. 2010).

The reason for the reduced ATTD of the intact lipid compared with the extracted lipid is most likely that some of the lipid in corn is bound or encapsulated in cell membranes or fibre compounds in the ingredients (Adams & Jensen 1984), and thereby influence the digestibility of lipid in the small intestine (Just et al. 1980; Just Nielsen & Mason 1974). Thus, it can be concluded that the ATTD of lipid appears to be the main factor influencing energy utilisation of corn germ products and supports similar conclusions reached in studies in which rapeseed and soybean products were fed to growing pigs (Agunbiade et al. 1992).

The improvement in the ATTD of GE and EE for the LCO and HCO diets in comparison with the LCG and HCG diets increased the DE level of diets. These findings indicate that the form of dietary lipid will influence the energy efficiency in animal production with extracted lipid been more digestible than intact dietary lipid when fed to pigs.

In the current experiment, similar ATTD of ADF and NDF suggests that dietary lipids form did not affect the digestion of fibrous fraction. However, the DE as well as the ATTD of GE and EE were greater for the LCO and HCO diets than for the LCG and HCG diets, respectively. These results indicate that dietary NDF and ADF concentration may reduce the ATTD of ether extract and then result in the lower ATTD of GE and DE. This study agrees with previous reports showing that an increased supply of dietary NDF decreases the apparent digestibility of energy and lipid (Hansen et al. 2006; Just et al. 1980). Bach Knudsen and Hansen (1991) showed that dietary NDF may decrease apparent digestibility of fat. Previous studies indicated that a high level of fibre in the diet resulted in some of the organic matter, protein and energy in the diet being unavailable. This may be due to fibre limiting the access of digestive enzymes to cell contents (Knudsen et al. 1993). Fibre can increase the rate of passage of digesta and this may also reduce the time available to the digestive enzymes to act on the other substrates (Low 1993).

**Conclusions**

In conclusion, dietary corn oil inclusion increased the ATTD of EE and DE of diet in comparison with corn germ which indicates that the EE from extracted corn oil is more digestible than oil in corn germ and that fibrous component in diets containing corn germ can decrease the ATTD of EE, GE and the DE of diets.

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**Disclosure statement**

The authors report no conflicts of interest. The authors alone are responsible for the content and writing of this article.
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