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Effect of genotype on heat production and net energy value of a corn-soybean meal-based diet fed to growing pigs

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ABSTRACT: The net energy (NE) system takes into account the metabolic utilisation of energy and has been proposed as a superior system for characterising the energy value of feeds. In growing pigs, the inefficiency of ME utilisation for NE (or the heat increment, HI) is dependent on many factors, among them the genotype, which implies that published NE prediction equations may not apply across all genotypes. We conducted a study to investigate the effect of two genotypes (Yorkshire-Hampshire♀ × Duroc♂; YH × D) and Large white♀ × Landrace♂; LW × LR) on heat production (HP) and NE value of a corn soybean meal-based diet fed to growing pigs. The diet met or exceeded the nutrient specifications of 20–50 kg b.w. pigs according to NRC (1998). A total of sixteen barrows were used, eight of each genotype (initial b.w. of 20.1 ± 1.1 and 19.0 ± 0.9 kg for YH ×D and LW × LR, respectively). Pigs were initially fed at 550 kcal/kg b.w.$^{-0.60}$/day (high ME intake) for determination of DE and ME in metabolism crates. Thereafter, HP was measured using an indirect calorimeter at either high ME or 330 kcal/kg b.w.$^{-0.60}$/day (low ME intake) to estimate fasting HP (FHP) by regression. Pigs were allowed a 3-d adaptation period at low ME intake before measurement of HP. Irrespective of the genotype, a reduction of ME intake resulted in a decrease ($P < 0.0001$) of HP (352 for high ME vs. 292 kcal/kg b.w.$^{-0.60}$/day for low ME). Pigs of LW × LR tended ($P = 0.07$) to have higher HP than those of YH× D and their estimated FHP was 175 and 103 kcal/kg b.w.$^{-0.60}$/day, respectively. The determined diet NE value was lower for the YHxD genotype (2,307 vs. 2633 kcal/kg DMI, $P = 0.01$) than for the LW × LR genotype. Pigs of LW × LR genotype showed lower (179 vs. 226 kcal/kg b.w.$^{-0.60}$/day, $P = 0.003$) HI than YH × D genotype and were determined to retain less energy as protein (100 vs. 123 kcal/kg b.w.$^{-0.60}$/day, $P = 0.04$) and more energy as fat (73 vs. 42 kcal/kg b.w.$^{-0.60}$/day, $P = 0.04$). The diet NE value was 96% (LW × LR) and 81% (YH × D) of the predicted NE from published equations. In conclusion, a corn-soybean meal fed at equal amounts resulted in different HP and NE value depending on genotype.

Keywords: energy utilisation; genotype; growing pigs; heat production; net energy

In view of the great economic importance of feed energy in pork production, concerted efforts have been made to develop methods and systems adapted to evaluating the energy content and metabolic utilisation of feed (Birkett and de Lange 2001). In terms of energy systems, the NE has been proposed as the most accurate basis for predicting the quantity of feed energy actually available to the pig (Noblet 2000). Initial NE systems were developed for fattening (Schiemann et al. 1972) and growing (Just 1983) pigs. Later methods factored in feed chemical characteristics, lean-type growing pigs, progress in analytical procedures and limitations in the earlier systems (CVB 1994; Noblet et al. 1994a). Thus, equations were developed for predicting NE of feeds based on digestible nutrients or DE or ME contents Noblet et al. (1994a). For example, NE equations were applied in the French feeding standard tables (Sauvant et al. 2004) and NRC (2012).

A characteristic aspect of NE systems is that the heat increment (HI) or metabolic utilisation of ME for NE is also dependent upon animal factors (e.g. genotype, physiological status) (de Lange et al. 2001; van Milgen and Noblet 2003). For example,

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Kolstad et al. (2002) fed three genotypes differing in lean and fat accretion potentials a similar diet from 25–105 kg b.w. and observed lower HI for fat genotypes and a decrease of HI as BW increased. The peculiarity here is that the energetic efficiency for protein deposition (< 56%) is lower than for fat deposition (> 74%) (ARC 1981; NRC 1998). Lean content in pork is a key goal in swine breeding programs and a review reported an annual increment of 4 g/day since the 1990's (Knap 2009). Furthermore, different genotypes have different maintenance requirements under similar experimental conditions (van Milgen et al. 1998). It follows that the accuracy and suitability of the published NE prediction equations may not reflect modern genotypes. Therefore, it was the objective of this study to investigate the effect of two genotypes on heat production and to compare determined NE values of a corn-soybean meal diet fed to these genotypes to that predicted using published equations (Noblet et al. 1994a).

MATERIAL AND METHODS

Animals and diets. The pigs used in the study were Yorkshire-Hampshire♀ × Duroc♂ (YH × D) obtained from Glenlea Swine Research Unit, University of Manitoba and Large white♀ × Landrace♂ (LW × LR) obtained from Sunnyside colony, Oakville, MB, Canada. There were eight barrows for each genotype with initial b.w. of 20.1 ± 1.1 and 19.0 ± 0.9 kg for YH × D and LW × LR, respectively. All experimental procedures were reviewed and approved by the University of Manitoba Animal Care Protocol Management and Review Committee, and pigs were handled in accordance with the guidelines described by the Canadian Council on Animal Care (CCAC 1993). A standard corn-soybean meal diet formulated to meet or exceed NRC (1998) nutrient specifications (Table 1) for pigs in the BW range of 20–50 kg was used.

Experimental procedures. The study was conducted in two blocks with eight pigs per block and four pigs per genotype in each block. Thus, each block was run in the same facility and with similar experimental conditions and procedures but at different time periods. This was a logistical issue as there were only two respiration chambers available for this study. On the day of heat measurement, one barrow was randomly selected from the four pigs within the genotype and brought to the chambers. At the end of the heat measurements, the barrows were returned to the metabolism crates to commence the lower feed intake adaptation period as explained later. This process of chamber visitation was repeated until all pigs visited the chambers. Furthermore, to balance genotype chamber visitations, each genotype visited each chamber on alternating days. The experimental procedures were essentially as described by Noblet et al. (1994a) with modifications in heat production (HP) measurement. The eight barrows were initially housed individually in adjustable metabolism crates (1.8 × 0.6 m) with smooth transparent plastic sides and plastic-covered expanded metal sheet flooring in a temperature-controlled room (24 °C) for 10 days. During this time the barrows were fed at 550 kcal ME/kg b.w.$^{-0.60}$/day; this feeding level was designated high feeding (HF) and was close to *ad libitum* intake (Noblet et al. 1994a). The ME was derived

Table 1. Diet composition, as is

Item	% or kcal/kg
Corn	67.4
Soybean meal	27.3
Vegetable oil	1.55
Salt	0.50
Monocalcium phosphate	0.94
Limestone	1.04
L-Lys	0.20
DL-Met	0.05
L-Thr	0.04
Vitamin-mineral premix[1]	1.00
Calculated nutrient content	87.3
ME	3,283
Crude protein	18.2
Std. digestible Lys	0.97
Std. digestible Met + Cys	0.58
Std. digestible Thr	0.62
Ca	0.67
Available P	0.28
Total P	0.56

[1]Provided per kilogram of complete diet: vitamin A, 8255 IU; vitamin D3, 1000 IU; vitamin E, 10.9 IU; vitamin B12, 0.115 mg; vitamin K, 1.1 mg; Niacin, 36.8 mg; choline chloride, 781.2 mg; biotin, 0.25 mg, folic acid, 0.75 mg, Mn (as MnO), 55 mg; Zn (as ZnO), 50 mg, Fe (as $FeSO_4.H_2O$), 80 mg, Cu (as CuO), 5 mg; Se (as $NaSeO_3$), 0.1 mg; I (as Ca $(IO_3)_2$), 0.28 mg

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from the NRC (1998) equations using values derived from chemical analysis of the experimental diet. The daily feed allocation during the 10 days period was based on BW at the beginning and on Day 4. Throughout the experiment pigs were fed once daily at 08:30 h and had free access to water throughout the study.

During the last five days separate and total collection of faeces and urine for determination of coefficients of digestible nutrients, DE and ME was conducted as previously described by Woyengo et al. (2009). Briefly, on Day 5, each pig received 5 g of ferric oxide (as an indigestible marker) in the 100 g of feed that was fed in the morning. The remaining portion of morning feed was offered after all the marked feed was consumed. Faecal collection commenced when the marker appeared in faeces. On the morning of Day 10, pigs were offered 100 g of marked feed as described above, and collection of faeces was terminated when the marker appeared in faeces. Total collection of urine commenced on the morning of Day 5 and ended on morning of Day 10. Faeces were collected once daily in the morning, weighed and stored frozen at –20 °C. Urine was also collected once daily in the morning (in jags containing 10 ml of HCl to minimize N losses) and weighed, and a sample (10% of the total weight) was obtained, strained through glass wool and stored frozen at –20 °C.

The indirect calorimetry method was used to estimate HP based on O_2 consumption, CO_2 production and urine N output (Brouwer 1965). The individual respiration measurements were performed in open-air-circuit respiration chambers or using a comprehensive laboratory animal monitoring system (CLAMS, Columbus instruments, Columbus, OH). The CLAMS has three independently working air-tight sealed chambers. Each chamber (11/ft^3) is equipped with plastic-covered expanded metal flooring, an air-conditioning system for regulating temperature and humidity, a feeder, nipple drinker, a meshed trap tray for separate urine and faeces collection and capacity to accommodate pigs weighing 5 to 50 kg. The paramagnetic O_2 sensor (19.3 to 21.5%), single beam CO_2 sensor (0 to 1.0%), sample pump, gas driers, Oxymax fresh air ventilation blower and a positive mass flow controller for constant fresh air delivery constitute the integrated instrumentation control centre. The integrated instrumentation is designed to monitor O_2 consumption and CO_2 production and represents a fully automated approach utilising a terminal computer installed with Oxymax software as a dedicated controller. By means of gas-tight blowers, fresh air is drawn into the chambers where it is thoroughly mixed with the chamber air. At preset time intervals the software monitors O_2 and CO_2 gas fractions at both the inlet port (reference or room air) and output port (effluent from the chambers) of a sealed chamber through which flows a known mass of air (l/min based on b.w. of the pig). The gas fraction and flow measurements are used to compute O_2 consumption and CO_2 production. The Oxymax gas sensors measure the gas concentrations from one selected chamber at a time. A settling time is required before measurement to purge the lines and to ensure accurate sampling. The system is calibrated prior to the start of the experiment with gas of known CO_2 and O_2 concentrations. The CLAMS was validated using the alcohol combustion method (Aulick et al. 1983).

In the present study O_2 consumption and CO_2 production was measured using two of the three chambers. The system was set up with a measure time of 1 min, a settle time of 2 min, and an airflow rate calculated based on the following equation: airflow rate, l/min = 5.6 × b.w. To estimate the HI of dietary ME or its efficiency of utilisation for growth, estimation of fasting heat production (FHP) is required (Noblet et al. 1994a). To accomplish this, each pig was brought to the chambers for HP measurement when fed at HF (described previously) and again on the fourth d at lower feeding (LF) level (330 kcal ME /kg $b.w.^{-0.60}$/day) as proposed by Noblet et al. (1994a). In this way pigs were acclimatised to lower feeding levels for three days before HP measurements. Pigs were brought to the chamber within 1 h after finishing their daily feed allocation and heat was measured continuously for a 6 h period. Personnel movement around the chambers was limited to avoid disturbances. Whenever the pigs were not in the chamber for HP measurements they were confined in the metabolism cages described previously. This is in accordance with Gray and McCracken (1980) who observed that the HP of a pig which has been conditioned to a metabolism cage can be measured accurately within the first day of introduction in the chamber. Water was freely available in the chambers and urine voided during HP measurements was collected, weighed and sub-samples stored at –20 °C until required for N analysis. Pigs were kept at 24 °C and 26 °C when submitted to the HF and to the LF, respectively.

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Sample preparation and chemical analyses. Faecal samples were dried in an oven at 60 °C for four days, weighed, pooled for each pig and sub-sampled. Samples of diets and faeces were finely ground in a coffee grinder (CBG5 Smart Grind; Applica Consumer Products, Inc., Shelton, CT, USA), and thoroughly mixed for analysis. Urine samples were thawed and pooled for each pig for analysis. All samples were analysed for DM and N. The faeces and diet samples were further analysed for ash, ADF, NDF, crude fat, starch and gross energy. For DM and GE analyses in urine, 1 ml of each sample was mixed with 0.5 g of cellulose and the weight of the resulting mixture was recorded. The urine-cellulose mixtures together with samples of pure cellulose (without urine) were dried in an oven at 50 °C for 24 h. The DM and GE were then determined on the dried urine-cellulose mixtures and samples of pure cellulose, and the contents of the same in urine were calculated using the difference method (Fleischer et al. 1981).

Dry matter was determined according to the method of AOAC (1990, method 925.09) and GE was determined using a Parr adiabatic oxygen bomb calorimeter (Parr Instrument Co., Moline, IL, USA) using benzoic acid as the calibration standard. Crude protein (N × 6.25) was determined by the combustion method (method 990.03; AOAC 1990) using a combustion analyser (model CNS-2000; Leco Corp., St. Joseph, MI, USA) and EDTA as a calibration standard. Neutral detergent fibre and ADF was assayed according to the method of van Soest and Wine (1967) using α-amylase (Sigma No. A3306, Sigma Chemical Co., St. Louis, MO, USA), and sodium sulphite and corrected for ash concentration adapted for the Ankom^{200} Fiber Analyser (Ankom Technology, Fairport, NY, USA). Crude fat (CF) was determined using hexane as the solvent according to the AOAC (1990, method 920.39). Starch was analysed in a local commercial laboratory (Central Testing Laboratory Ltd., Winnipeg, MB, Canada) using starch assay kits from Sigma (Sigma No. S5296 Fluka, Sigma Chemical Co., St. Louis, MO, USA).

Calculations and statistical analysis. The apparent total tract digestible content of OM, nutrients and energy, and the ME value of the diet were calculated for each pig according to routine procedures (Adeola 2001) and were used to calculate the NE (kcal/kg of DM) value of the corn-soybean diet according to Noblet et al. (1994a):

$$NE = 2.73 \times DCP + 8.37 \times DCF + 3.44 \times ST + 0 \times \times DADF + 2.93 \times DRes$$

$$NE = 0.843 \times DE - 463$$

$$NE = 0.870 \times ME - 442$$

where:

DCP = digestible CP

DCF = digestible CF

ST = starch

DADF = digestible ADF

DRes = difference between digestible OM

and the other components considered in the equation (i.e. DCP, DEE, ST and ADF); all values were expressed in g/kg DM.

The data from the 6-h gas exchange measurements were recalculated to 24-h values. Heat production was calculated with constants by Brouwer (1965), excluding the correction for CH_4 production.

$$HP, kcal/kg\ b.w.^{-60}/day = 3.87 \times O_2, l + 1.20 \times CO_2, l - 1.43 \times urinary\ N\ (UN), g$$

The RQs were calculated as the ratio between CO_2 production and O_2 consumption.

According to the procedure of Noblet et al. (1994a) for calculating the NE of diets, it is necessary to estimate the FHP of pigs. The NE (kcal/day) corresponding to HF is then equivalent to FHP (kcal/day) plus retained energy (kcal/day) at this feeding level. For this purpose, mean HP at HF and LF in each genotype were regressed to ME intake (kcal/kg b.w.$^{0.60}$). The intercept of the regression equation then provided the FHP for each genotype. Therefore, the determined NE value of the diet was calculated as:

RE, kcal/kg DM = ME–HP (at HF feed intake)

NE, kcal/kg DM = RE + FHP

RE = retained energy

The other equations used were as follows (Hansen et al. 2006):

$$HI, kcal/kg\ b.w.^{-60}/day = ME - NE$$

Digested N (DN), g = ingested N (IN), g – Faecal N, g

Retained N (RN), g = DN, g – UN, g

$$Retained\ energy\ in\ protein\ (RPE, kcal/kg\ b.w.^{-60}/day) = (RN \times 6.25 \times 5.70\ kcal/g)/\ kg\ b.w.^{-60}$$

$$Retained\ energy\ in\ fat\ (kcal/kg\ b.w.^{-60}/day)\ kcal = = (RE - RPE)/kg\ b.w.^{-60}$$

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Data were subjected to analysis of variance using the GLM procedure (SAS software release 9.1, SAS Inst., Inc., Cary, NC). The effect of genotype and ME intake level on HP was analysed as a completely randomised block design with 2 × 2 factorial treatment arrangement. The effect of block × genotype was found to be non-significant and was dropped from the model. Other measurements were analysed with genotype being the only fixed factor and means (YH × D vs. LW × LR) were compared using *t*-test procedure. Treatment differences were considered significant at $P < 0.05$ and trends ($0.05 > P < 0.10$) were discussed.

RESULTS AND DISCUSSION

Throughout the study, pigs remained healthy, consumed their daily feed allowances and no apparent animal health or technical problems were observed. As pigs were adapted to completing their daily feed allocation within 1 hour and therefore not fed in the chamber they spent most of the time lying down during heat measurements (Yen and Nienaber 1992). The analysed nutrient contents of the experimental diet are shown in Table 2. Genotype affected ADG and G:F during the 10-days period of HF intake (Table 3). Specifically, the LW × LR genotype had higher ADG (605 vs. 511 g/day, $P = 0.002$) and G : F (0.628 vs. 0.513, $P = 0.019$) than YH × D genotype. Variations in gain efficiency in pigs fed equalised amounts of feed indicate differences in nutrient and energy digestibility, metabolic efficiency of nutrient use, basal metabolic rate and energy expenditure, or all of those (Barea et al. 2010). For example, as presented later, it was observed that the LW × LR genotype retained more energy as lipid than protein. Since ME is utilised with a greater efficiency for lipid deposition than for protein deposition (ARC 1981; NRC 1998), an increase in the proportion of energy that is partitioned to lipid deposition will produce a better overall energy efficiency.

Table 2. Analysed nutrient content, as is

Item	% or kcal/kg
DM	92.5
ADF	3.26
Ash	6.31
Crude fat	4.53
NDF	7.86
Starch	40.9
Crude protein	19.8
Gross energy	4026
Arg	1.29
His	0.56
Iso	0.87
Leu	1.80
Lys	1.29
Met	0.29
Phe	1.05
Thr	0.83
Val	0.99

There was no interaction ($P > 0.10$) between the genotype and ME intake (HF vs. LF) on O_2 consumption, CO_2 production, RQ and HP (Table 4). The main effect of the genotype was that, LW × LR had higher O_2 consumption (64.9 vs. 60.9 l/kg/b.w.$^{-0.60}$/day, $P = 0.03$) and HP expressed on a BW basis (331 vs. 313 kcal/kg b.w.$^{-0.60}$/day, $P = 0.07$) and as percentage of ME intake (85 vs. 81%, $P = 0.05$) than the YH × D genotype. This observation suggested that a higher proportion of ME intake by LW × LR was being lost as heat. As the LW × LR genotype was observed to have higher DE values (presented later) the higher HP is perhaps a reflection of energy expenditure in visceral organs and the sizes of those visceral organs (Yen et al. 1989; Noblet et al. 1999; Nyachoti et al. 2000). For example, Yen et al. (1989) showed that the portal-drained organs accounted for only 5% of BW but consumed up to 20% of total O_2 in growing pigs. As expected, reduction of ME intake from 550 to 330 kcal ME/kg

Table 3. Effects of genotype on growth performance in growing pigs fed corn soybean meal diet

Item	Genotype		SEM	*P*-value
	YH × D	LW × LR		
Initial b.w. (kg)	20.2	19.0	0.559	–
ADG (g/day)	511.3	605.1	17.48	0.002
G : F (g/g)	0.513	0.628	0.019	0.001

YH × D = Yorkshire-Hampshire♀ × Duroc♂; LW × LR = Large white♀ and Landrace♂

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Table 4. Effects of ME intake and genotype on O_2 consumption, CO_2 production and heat production in growing pigs fed corn soybean meal diet

Item	Genotype ME[1]				SEM	*P*-value		
	YH × D		LW × LR					
	high	low	high	low		ME	genotype	genotype × ME
O_2 (l/kg b.w.$^{-0.60}$/day)	67.0	54.7	68.4	61.4	1.68	< 0.0001	0.032	0.191
CO_2 (l/kg b.w.$^{-0.60}$/day)	69.6	50.4	70.6	54.5	2.15	< 0.0001	0.249	0.508
RQ	1.04	0.92	1.03	0.89	0.01	< 0.0001	0.201	0.456
Heat production								
Kcal/day	2578	2112	2646	2283	74.4	< 0.0001	0.121	0.493
Kcal/day/kg b.w.$^{-0.60}$	348	278	356	306	9.61	< 0.0001	0.073	0.312
As % of ME intake	74.8	86.4	77.7	92.4	2.11	< 0.0001	0.046	0.481

YH × D = Yorkshire-Hampshire♀ × Duroc♂; LW × LR = Large white♀ × Landrace♂
[1]high (550 kcal ME/kg $BW^{0.60}$) and (330 kcal ME/kg $BW^{0.60}$)

b.w.$^{-0.60}$/day or by 40% reduced ($P < 0.0001$) O_2 consumption, CO_2 production, RQ and HP in both genotypes in agreement with Noblet et al. (1994b), Quiniou et al. (1995), and de Lange et al. (2006). The RQ of growing pigs usually exceeds unity and declines with ME intake (Noblet et al. 1999; Noblet et al. 1994b). There is experimental evidence that as ME intake declines, growing animals mobilise body lipid (Le Dividich et al. 1980); this inevitably results in declining RQ as lipids have low RQ. A higher proportion (89.4 vs. 76.3%, $P < 0.0001$) of ME intake was lost as heat when pigs were submitted to LF (Table 4) feeding, an indication that energy was preferentially expended on maintenance requirements rather than on growth. Models addressing the response of animals to changing energy supply date back a century ago (for reviews, see Blaxter 1962; van Milgen and Noblet 2003). They converge to suggest that with a declining ME intake animals will preferentially apportion available energy to cover energy requirements for maintenance or to derive ATP for essential functions (van Milgen and Noblet 2003).

Because it is impossible to measure maintenance requirements directly in producing animals, FHP has been proposed as an indirect measure for maintenance requirement with assumptions that the efficiencies of energy utilisation below and above maintenance requirements are identical (Noblet et al. 1994a; van Milgen et al. 1998). The FHP represents the sum of basal energy requirements and energy required to generate available energy from body nutrient stores (de Lange et al. 2006). By regressing HP production on ME intake, the FHP for the two genotypes were obtained according to Noblet et al. (1994a). The FHP (kcal/kg b.w.$^{-0.60}$/day) were 102.5 ± 38.7 (R^2 = 68) and 174.9 ± 37.8 (R^2 = 59%) for YH × D and LW × LR, respectively. The estimate of FHP for the LW × LR genotype was similar to that determined for the large white boars (179 kcal/kg b.w.$^{-0.60}$/day) (Noblet et al. 1994a) and within the range of 167 to 191 kcal/kg b.w.$^{-0.60}$/day reported for pigs of diverse genotypes, ages and sexes which were offered feed close to *ad libitum* (Le Bellego et al. 2001; van Milgen et al. 2001; Le Goff et al. 2002). The FHP for the YH × D was close to that (117 kcal/kg b.w.$^{-0.60}$/day) of (Large White + Landrace)♀ × Piétrain♂ barrows (de Lange et al. 2006). As discussed extensively by Noblet et al. (1999) and Birkett and de Lange (2001), both experimental methodology and variability between pig groups contribute to variation in estimates of FHP. van Milgen et al. (1998) found that the contribution of viscera (i.e. gastrointestinal tract, liver, pancreas, spleen, kidneys, heart, lungs, bladder, and reproductive organs) to FHP was more than 4 times higher than that of lean tissue of growing pigs. As the LW × LR genotype had a higher DE (presented later), a larger digestive capacity might have partly contributed to the observed FHP for this genotype. Nonetheless, the resulting estimates of FHP have a direct impact on ingredient or diet NE values as these are calculated as RE plus FHP (Noblet et al. 1994a; de Lange et al. 2006).

The NE (kcal/kg DM) values obtained based on digestible nutrient contents (2889 vs. 2831) and DE (2854 vs. 2805) were higher for the LW × LR

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Table 5. Effect of genotype on the energy value and retained energy of corn soybean meal diet fed to growing pigs

Item	Genotype		SEM	*P*-value
	YH × D	LW × LR		
DE (kcal/kg DMI)	3876	3935	17.51	0.033
ME (kcal/kg DMI)	3795	3840	18.67	0.110
NE (kcal/kg DMI)				
Predicted[1]	2831	2889	8.633	0.000
Predicted[2]	2805	2854	14.67	0.031
Predicted[3]	2859	2898	16.23	0.111
Determined	2307	2633	122.6	0.015
Heat increment, (kcal/day/kg b.w.$^{-0.60}$)	226	179	9.36	0.003
Retained energy				
Kcal/day	1217	1278	76.4	0.582
Kcal/day/kg b.w.$^{-0.60}$	164	173	11.15	0.612
As protein[5] (kcal/day/kg b.w.$^{-0.60}$)	123	100	7.16	0.044
As fat (kcal/day/kg b.w.$^{-0.60}$)	42	73	6.09	0.003
Protein/fat ratio	3.05	1.48	0.206	0.0001
Retained N (g/kg b.w.$^{-60}$/day)	2.84	2.75	0.074	0.401

YH × D = Yorkshire-Hampshire♀ × Duroc♂; LW × LR = Large white♀ × Landrace♂

Predicted (Noblet et al. 1994)

[1]NE = 2.73 × digestible CP + 8.37 × digestible ether extract + 3.44 × Starch + 0 × digestible ADF + 2.93 × digestible residual (digestible OM – (digestible CP + digestible ether extract + starch + digestible ADF)

[2]NE = 0.843 × DE–463

[3]NE = 0.870 × ME–442

[4]retained energy in protein calculated as retained nitrogen × 6.35 × 5.7kcal/g (Hansen et al. 2006)

[5]100 = % retained as protein

genotype than for the YH × D genotype (Table 5). The influence of genotype on the digestibility of dietary energy has been studied before. In many of these studies the focus has been mainly on comparing lean vs. obese genotypes and the results have been somewhat unclear. For example, a higher digestibility of energy was reported by Sundstøl et al. (1979) for obese pigs fed a barley-sorghum-oat based diet and Wenk and Morel (1985) for lean genotypes fed a corn-barley based diet. Conversely, Yen et al. (1983) who fed a corn-based diet and Morel et al. (2006) who fed a wheat-based diet were unable to demonstrate a significant difference in the digestibility of energy between lean and fat selection lines. In the present study, the pigs were of modern lean genotype, yet the results suggest that the LW × LR genotype digested more energy from a simple 'non-fibrous' corn-soybean meal diet. Whether the effects of genotype on DE may be the result of morphological and physiological digestive differences of the two genotypes used in the present study remains to be determined. There was no genotype effect (P > 0.10) on ME and so the NE value was obtained based on a ME derivation equation (Noblet et al. 1994a, Table 5). Similar abilities among genotypes in metabolising DE have been reported by Sharma et al. (1971) and Yen et al. (1983).

The determined NE value of the corn soybean meal diet was higher (P = 0.01) for the LW × LR genotype than for the YH × D genotype and as a result HI differed among the genotypes, with the LW × LR genotype showing lower (179 vs. 226 kcal/kg b.w.$^{-0.60}$/day, P = 0.003) HI than the YH × D genotype (Table 5). The RE did not differ (P > 0.10) among the genotypes; however, on partitioning RE to the form in which it was stored, differences (P < 0.05) between genotypes were observed. Specifically, the LW × LR genotype stored less energy as protein (100 vs. 123 kcal/kg b.w.$^{-0.60}$/day, P =0.04) and more energy as fat (73 vs. 42 kcal/kg b.w.$^{-0.60}$/day, P = 0.04). Subsequently, the ratio of the energy retained as protein and fat differed (P = 0.0001) among the genotypes (Table 5). The efficiency of utilisation of either DE or ME to NE

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Table 6. Effect of genotype on the efficiency of utilisation of DE and ME for NE and the ratios of determined NE to predicted NE in corn soybean meal diet fed to growing pigs

Item	Genotype		SEM	*P*-value
	YH × D	LW × LR		
Efficiency of utilisation (%)				
DE to NE	59.6	70.0	2.789	0.021
ME to NE	60.9	71.7	2.819	0.018
Ratio of determined NE to predicted (%)				
NE to predicted[1]	79.8	97.0	3.742	0.007
NE to predicted[2]	82.4	96.4	3.857	0.023
NE to predicted[3]	80.8	95.0	3.737	0.019
Mean	81.1	96.2	3.820	0.015

YH × D = Yorkshire-Hampshire♀ × Duroc♂; LW × LR = Large white♀ × Landrace♂

[1]NE = 2.73 × digestible CP + 8.37 × digestible ether extract + 3.44 × starch + digestible ADF + 2.93 × digestible residual (digestible OM – (digestible CP + digestible ether extract + starch + digestible ADF)

[2]NE = 0.843 × DE–463

[3]NE = 0.870 × ME–442

differed ($P < 0.05$) among the genotypes (Table 6) and reflected observed differences in HI. The LW × LR genotype exhibited ~10 percentage units higher efficiency of DE or ME utilisation to NE than the YH × D genotype. The estimate (72%) for the efficiency of ME utilisation for NE of the LW × LR genotype was close to the value of 75% in the literature (Noblet et al. 1994a; Le Bellego et al. 2001). The low efficiency of ME to NE for the YH × D genotype may due to the high HI observed for this group (van Milgen and Noblet 2003).

Modeling aspects of energy metabolism in growing pigs involves establishing "rules" on the partitioning of dietary energy between protein deposition, lipid deposition, and HP at a given point in time, as well as the changes that occur during growth (van Milgen and Noblet 2003). Growing pigs rarely retain more than 50% of their ME intake; the remainder is lost as heat (de Lange 1995). Part of the heat loss is due to the HI, which includes the transformation of dietary nutrients to protein deposition and lipid deposition, and to the associated energy (ATP) cost. Consequently, different nutrients are used with different efficiencies and, due to the ATP cost associated with protein synthesis and turnover, protein is energetically less efficient than lipid deposition (ARC 1981; NRC 1998). The relevance of this for the present study is that the YH × D genotype had higher HI which resulted in lower NE values for the corn-soybean meal diet.

Although the ratio of the determined NE to predicted NE based on published equations differed ($P < 0.05$) among the genotypes (Table 6), the ratios for determined NE to predicted NE values for the LW × LR genotype using the published equations (Noblet et al. 1994a) was more than 95%, an indication of close agreement. However, for the genotype YH × D, the ratio of determined NE to predicted values was approximately 80% indicating that the published equations may not be accurate for this genotype. Pettigrew (2009) reported an evaluation of the European NE systems under North American conditions through comparison of measured (serial slaughter technique) NE values and predicted (published equations) NE values. The NE values (expressed as ratios of NE value of corn) of the ingredients presented indicated that the European NE systems (i.e. INRA, CVB, Danish potential physiological energy system, PPE) did not accurately predict measured NE values in North America. For example, the measured value for soybean meal in growing pigs was 0.82 whereas the predicted values were 0.72 (INRA), 0.94 (CVB) and 0.78 (PPE) (Pettigrew 2009).

Both experimental methodology and variability between pig groups are known to contribute to variation in estimates of heat production (Noblet et al. 1999; and Birkett and de Lange 2001). For example, Koong et al. (1982) showed that fasting heat measurement plateaued at 6-8 hours after meal intake. It is possible that prolonged heat measurements (> 6 h) would have resulted in different outcomes. Nonetheless, the two genotypes were subjected to the same conditions allowing us to make comparative

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deductions from the present data. In conclusion, the present study indicates substantial genotype differences in energy partitioning in the growing animal fed equalised amounts of feed. The main differences are due to FHP and HI resulting in differing NE values for a corn-soybean meal diet. Thus, it appears that the NE value of feed ingredients and/or diets will vary depending on the way it is used by pigs. A comparison of measured and predicted NE value (using published equations) of the corn-soybean meal diet showed a better prediction for the LW × LR genotype and a poorer prediction for the YH × D genotype. The genotype differences observed in the present study argue for the presence of a genotype correction factor in future refinement of the NE prediction equations.

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REFERENCES

Adeola OA (2001): Swine nutrition. In: Lewis AJ, Southern LL (eds.): Digestion and Balance Techniques in Pigs. 2nd ed. CRC Press, Boca Raton, FL. 912–915.

AOAC (1990): Official Methods of Analysis. 15th ed. Association of Official Analytical Chemists, Washington, DC.

ARC (1981): The Nutrient Requirement of Pigs: Technical Review. Revised edition, Commonwealth Agricultural Bureau, Slough, England.

Aulick LH, Arnhold H, Hander EH, Mason JR AD (1983): A new open and closed respiration chamber. Q. J. Experimental Physiology 68, 351–357.

Barea R, Dubois S, Gilbert H, Sellier P, van Milgen J, Noblet J (2010): Energy utilization in pigs selected for high and low residual feed intake. Journal of Animal Science jas.2009-2395v1-20092395.

Birkett SH, de Lange CFM (2001): Calibration of a nutrient flow model of energy utilization by growing pigs. British Journal of Nutrition 86, 675–689.

Blaxter KL (1962): The Energy Metabolism of Ruminants. Hutchinson Scientific and Technical, London, U.K.

Brouwer E (1965): Report of sub-committee on constants and factors. In: Proceedings 3rd European Association for Animal Production, Blaxter KL (ed.): Publication No. 11, Academic Press, London, U.K. 441–443.

CCAC (1993): Guide to Care and Use of Experimental Animals. Vol. 1. Canadian Council for Animal Care, Ottawa, Ontario, Canada.

CVB (1994): Table of Feedstuffs. Information about Composition, Digestibility and Feeding Values. Centraal Veevoederbureau, Lelystad, The Netherlands.

de Lange CFM (1995): Framework for a simplified model to demonstrate principles of nutrient partitioning for growth in the pig. In: Moughan PJ, Verstegen MWA, Visser-Reyneveld MI (eds.): Modelling Growth in the Pig. Wageningen Pers, Wageningen, The Netherlands. 71–85.

de Lange CFM, Marty BJ, Birkett S, Morel P, Szkotnicki B (2001): Application of pig growth models in commercial pork production. Canadian Journal of Animal Science 81, 1–8.

de Lange CFM, van Milgen J, Noblet J, Dubois S, Birkett S (2006): Previous feeding level influences plateau heat production following a 24 h fast in growing pigs. British Journal of Nutrition 95, 1082–1087.

Fleischer JE, Tomita Y, Hayashi K, Hashizume T (1981): A modified method for determining energy of fresh feces and urine of pig. Memoirs of Faculty of Agricuture, *Kagoshima University*17, 235–241.

Gray R, McCracken KJ (1980): Effect of confinement in a respiration chamber and changes in temperature and plane of nutrition on heat production of 25 kg pigs. Journal of Agricultural Science 95, 123–133.

Hansen MJ, Chwalibog A, Tauson A-H, Sawosz E (2006): Influence of different fibre sources on digestibility and nitrogen and energy balances in growing pigs. Archives of Animal Nutrition 60, 390–401.

Just A. Jørgensen H., Fernandez JA (1983): Maintenance requirement and the net energy value of different diets for growth in pigs. Livestock Production Science 10, 487–506.

Knap JM (2009): Voluntary feed intake and pig breeding. In: Torrallardona D, Roura E (eds.): Voluntary Feed Intake in Pigs. Wageningen Academic Publishers, Wageningen, The Netherlands. 13–35.

Kolstad K, Brenøe UT, Vangen O (2002): Genetic differences in energy partitioning in growing pigs. Acta Agriculturae Scandinavica Section A: Animal Science 52, 213–220.

Koong L-J, Nienaber JA, Pekas JC, Yen J-T (1982): Effects of plane of nutrition on organ size and fasting heat production in pigs. Journal of Nutrition 112, 1638–1642.

Le Bellego L, van Milgen J, Dubois S, Noblet J (2001). Energy utilization of low protein diets in growing pigs. Journal of Animal Science 79, 1259–1271.

doi: 10.17221/8440-VETMED

Le Dividich J, Vermorel M, Noblet J, Bouvier JC, Aumaitre A (1980): Effects of environmental temperature on heat production, energy retention, protein and fat gain in early weaned piglets. British Journal of Nutrition 44, 313–323.

Le Goff G, Dubois S, van Milgen J, Noblet J (2002): Influence of dietary fibre level on digestive and metabolic utilization of energy in growing and finishing pigs. Animal Research 51, 245–259.

Morel PCH, Lee TS, Moughan PJ (2006): Effect of feeding level, live weight and genotype on the apparent faecal digestibility of energy and organic matter in the growing pig. Animal Feed Science and Technology 126, 63–74.

Noblet J (2000): Digestive and metabolic utilization of feed energy in swine: application to energy evaluation systems. Journal of Applied Animal Research 17, 113–132.

Noblet J, Fortune H, Shi XS, Dubois S (1994a): Prediction of net energy value of feeds for growing pigs. Journal of Animal Science 72, 344–354.

Noblet J, Shi XS, Dubois S (1994b): Effect of body weight on net energy value of feeds for growing pigs. Journal of Animal Science 72, 648–657.

Noblet J, Karege C, Dubois S, van Milgen J (1999): Metabolic utilization of energy and maintenance requirements in growing pigs: Effects of sex and genotype. Journal of Animal Science 77, 1208–1216.

NRC (1998): Nutrient Requirements of Swine. 10th ed. National Academy Press, Washington, DC.

NRC (2012): Nutrient Requirements of Swine. 12th ed. National Academy Press, Washington, DC.

Nyachoti CM, de Lange CFM, McBride BW, Leeson S, Schulze H (2000): Dietary influence on organ size and in vitro oxygen consumption by visceral organs of growing pigs. Livestock Production Science 65, 229–237.

Pettigrew J (2009): Effective nutrient utilization in the non-ruminant animal. In: Proceedings 30th Western Nutrition Conference, Winnipeg, MB, Canada, 47–54.

Quiniou N, Noblet J, van Milgen J, Dourmad JY (1995): Effect of energy intake on performance, nutrient and tissue gain and protein and energy utilization in growing boars. Animal Science 61, 133–143.

Sauvant D, Perez JM, Tran G (2004): Tables of Composition and Nutritional Value in Feed Materials. INRA Editions, Wageningen Academic Publishers, Wageningen, The Netherlands.

Schiemann R, Nehring K, Hoffmann L, Jentsch W, Chudy A (1972): Energetische Futterbevertung und Energienormen. VEB Deutscher Landwirtschaftsverlag, Berlin, Germany.

Sharma VD, Young LG, Smith GC (1971): Energy utilisation by the Lacombe and Yorkshire breeds of pig. Canadian Journal of Animal Science 51, 761–770.

Sundstøl F, Standal N, Vangen O (1979): Energy metabolism in lines of pigs selected for thickness of backfat and rate of gain. Acta Agriculturae Scandinavica 29, 337–345.

van Milgen J, Noblet J (2003): Partitioning of energy intake to heat, protein, and fat in growing pigs. Journal of Animal Science 81, E86–93E.

van Milgen J, Bernier JF, Locozler Y, Dubois S, Noblet J (1998): Major determinants of fasting heat production and energetic cost of activity in growing pigs for different body weight and breed/castration combination. British Journal of Nutrition 79, 509–517.

van Milgen J, Noblet J, Dubois S (2001): Energetic efficiency of starch, protein, and lipid utilization in growing pigs. Journal of Nutrition 131, 1309–1318.

van Soest PJ, Wine RH (1967): Use of detergents in the analysis of fibrous feeds. IV. Determination of plant cell-wall constituents. Journal of AOAC 50, 50–55.

Wenk C, Morel P (1985): Genetic variation of the digestibility of energy in growing pigs. In: Proceedings 3rd International Seminar on Digestive Physiology in the Pig. National Institute of Animal Sciences, Copenhagen, Denmark, 396–399.

Woyengo TA, Dickson T, Sands JS, Nyachoti CM (2009): Nutrient digestibility in finishing pigs fed phytase-supplemented barley-based diets containing soybean meal or canola meal as a protein source. Archives of Animal Nutrition 63, 137–148.

Yen JT, Nienaber JA (1992): Influence of carbadox on fasting oxygen consumption by portal vein-drained organs and by the whole animal in growing pigs. Journal of Animal Science 70, 478–483.

Yen JT, Tess MW, Pond WG, Dickerson GE (1983): Digestibility and metabolism of dietary nitrogen and energy in contemporary, genetically lean and obese pigs as estimated by total faecal collection and acid insoluble ash. Journal of Animal Science 56, 426–430.

Yen JT, Nienaber JA, Hill DA, Pond WG (1989): Oxygen consumption by portal vein-drained organs and by whole animal in conscious growing swine. Proceedings of the Society of Experimental Biology and Medicine190, 393–398.

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