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Effects of Fasting Duration and Body Weight on Fasting Heat Production in Growing Pigs

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Abstract: Two experiments were conducted to determine the effects of fasting duration and body weight on the fasting heat production of Duroc x Large White x Landrace crossbred barrows. In exp. 1, 6 pigs were fasted for 96 h. Heat production was measured every 12 h and the experiment was repeated at 3 separate body weights (31.1±1.1, 50.3±0.8 and 89.7±1.2 kg) to investigate the effects of different fasting durations on heat production and substrate oxidation. In Exp. 2, 12 Duroc x Large White x Landrace crossbred barrows were used to determine the effect of different body weights on fasting heat production. Fasting heat production was measured at 35.6±2.4, 44.7±3.1, 53.4±2.8, 63.9±2.7, 73.4±2.4, 83.3±3.0 and 95.6±2.0 kg following a fast of 48 h for the 35.6 as well as 44.7 pigs and a fast of 72 h for pigs at the remaining body weights. Before fasting, pigs were fed twice daily at 09:00 and 17:00. Fasting heat production was measured using indirect calorimetry after pigs were deprived of feed and the temperature was controlled at 24±1°C for pigs weighing 35.6 and 44.7 kg and 22±1°C for pigs weighing 53.4-95.6 kg. The results of exp. 1 showed that the heat production decreased rapidly in the first 48 (31.1 kg) and 60 h (50.3 and 89.7 kg) of fasting ($p<0.05$) and then reached a stable period ($p>0.05$) between 48-96 (31.1 kg) and 60-96 h (50.3 and 89.7 kg) of fasting, respectively. In Exp. 2, with an increase in body weights (35.6-95.6 kg) the fasting heat production of pigs went up from 1577-2683 kcal day^{-1}. In conclusion, the fasting heat production was 220 kcal/kg $BW^{0.55}$/day ($R^2 = 0.97$, $p = 0.01$) in pigs with body weights from 35.6-95.6 kg.

Key words: Body weight, fasting duration, fasting heat production, pigs, experement, China

INTRODUCTION

Accurate estimation of the energy requirements of pig is important to ensure that sufficient energy is available to allow pigs to grow to their genetic potential but not to oversupply energy as this will increase ration costs and lead to increased fat deposition in the carcass (Bikker *et al*., 1995; Weis *et al*., 2004). Although, energy requirements are commonly provided as digestible or metabolizable energy (NRC, 1998) net energy has been proposed to more accurately estimate the true energy value of feeds for pigs in recent years (Just, 1982; Noblet and Henry, 1993; Noblet *et al*., 1994b; Noblet and van Milgen, 2004). The reason for the increased accuracy is because net energy takes heat loss into account.

Because of these advantages some net energy systems and prediction equations have been developed for pigs (Nehring and Haenlein, 1973; Just, 1982; Noblet *et al*., 1994b; Van Milgen *et al*., 2008). But compared with these values and prediction equations of net energy of feed ingredients or diets it has varied mainly with difference in estimates of the Net Energy for maintenance (NE_m) and also depends on diet composition (Noblet and van Milgen, 2004).

The Ne_m can not be measured directly and has been estimated with basal metabolic rate also representing equilibrium heat production of a fasting pig (De Lange and Birkett, 2005; Noblet, 2007). The Fasting Heat Production (FHP) has been estimated to vary between 164 and 234 kcal/$kg^{0.60}$/day (Holmes and Breirem, 1974; Koong *et al*., 1982, 1983; Tess *et al*., 1984; Noblet *et al*., 1994a; Van Milgen *et al*., 1998).

Many factors influence FHP. At first the effect of FHP is dependent on the duration of fasting (Van Milgen *et al*., 1998). With the extension of fasting the FHP tends to decline (Close and Mount, 1975). However, an overly prolonged fasting duration decreases the basal metabolic rate and affects the development of

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pigs (Poczopko, 1967; Koong *et al.*, 1982) which leads to an underestimate of FHP (ARC, 1981). There is considerable variation in the literature regarding the appropriate fasting duration to use to determine FHP which was ranged from 1-15 days (Holmes and Breirem, 1974; ARC, 1981; Koong *et al.*, 1982; Noblet *et al.*, 1994a; Van Milgen *et al.*, 1998). Furthermore, there is a little information about the effect of different body weights on determining fasting duration in pigs.

Therefore, the present experiments were conducted to determine the effects of fasting duration and body weight on the FHP of Duroc x Large White x Landrace crossbred barrows based on a prescriptive condition.

MATERIALS AND METHODS

Construction and function of the respiration unit: In this experiment, an open-air-circuit respiration unit was made by China Agricultural University (Beijing, China) and used to determine O_2 consumption as well as CO_2 and CH_4 production. The open-air-circuit respiration unit was composed of 3 independently working chambers and each chamber had an inner room of 2.26×1.18×1.63 m. Gas was drawn from the chamber by means of a ventilator then the same amount of outside air went into and was mixed with the gas using fans in the chamber. Gas samples were collected from the three chambers and outside air per 3 min in turn so the gas concentrations of O_2, CO_2 and CH_4 in each chamber or outside were measured by different gas analyzes at 12 min intervals. The electronic measuring signals from the gas analyzers passed to the recording unit were recorded in the computer system. Temperature and humidity in the chamber were regulated by the air-condition system. All measurements including airflow gas concentrations (O_2, CO_2 and CH_4) environmental temperature, humidity and gas pressure in the chamber were recorded continuously for further calculation.

Before the study began, the whole system was calibrated using ethanol. Thereafter, the analytical instruments used to measure the gas were calibrated before each trial by injecting standardized mixtures of O_2, CO_2 and CH_4 with different concentrations of N_2 including:

- 100% N_2
- 20.92% O_2 and 79.08% N_2
- 18.55 O_2, 0.60%, CO_2, 0.01, CH_4 and 78.31% N_2
- 20.60% O_2, 0.30% CO_2, 0.005% CH_4 and 79.39% N_2
- 19.99% O_2, 0.048% CO_2 and 79.52% N_2
- 20.34% O_2, 0.99% CO_2 and 78.67% N_2 (Air Products and Chemicals, Inc., Beijing, China)

Animal and experimental design

Experement 1: Eighteen Duroc x Large White x Landrace barrows were purchased from the Hua du Pig Company (Beijing, China) in 3 batches of 6 pigs weighing 31.1±1.1, 50.3±0.8 or 89.7±1.2 kg, respectively. Each batch of 6 pigs was transported as a group to the Swine Metabolic Faculty at China Agriculture University (Beijing, China) and housed in a metabolic room located immediately adjacent to the respiration chambers. The 6 pigs were individually housed in metabolic cages (1.4×0.8×1.2 m) and fed *ad libitum* during a 7 days adaptation period.

Each batch was divided into 2 groups of 3 pigs and each group of 3 pigs was transferred to the respiration chambers by placing their metabolic crate directly into the respiration chamber. They were fed twice daily at 09:00 and 17:00 at 90% of *ad libitum* for a 3 days adaptation period. Pigs were subjected to fasting after a meal at 09:00 on their 4th day in the chambers and the next 96 h were used to measure heat production when the pigs were withdrawn from feed. Heat production was measured every 12 h. At the end of the 96 h fast the pigs were removed from the respiration chambers sent for slaughter and the remaining 3 pigs from the 1st batch were placed into the respiration chambers in a similar manner to the 1st 3 pigs. At this point, the 2nd batch of pigs was placed into the metabolic crates to begin their 7 days adaptation period. When the 2nd group of 3 pigs from the 1st batch was removed from the respiration chambers the 1st 3 pigs from the 2nd batch were immediately placed into the respiration chambers. The 3rd batch of pigs was handled in a similar manner.

The environmental temperature in each chamber was maintained at 22±1°C for pigs weighing 31.1 and 20±1°C for pigs weighing 50.3 and 89.7 kg. The environmental temperature was increased by 2°C in the chamber when fasting began. The relative humidity was about 70%. Water was available *ad libitum* throughout the experiment.

Experement 2: Twelve Duroc x Large White x Landrace crossbred barrows were used to determine the effects of pig body weight on FHP. The 12 barrows had an initial average body weight of 35.6±2.4 kg and were purchased in 4 batches of 3 pigs from the same source as those used for experiment 1. Each batch of 3 pigs was transported as a group to the Swine Metabolic Facility at China Agriculture University (Beijing, China) and housed in a metabolic room located immediately adjacent to the respiration chambers. The 3 pigs were individually housed in metabolic cages (1.4×0.8×1.2 m) and fed *ad libitum* during a 10 days adaptation period. The subsequent purchase of each batch of pigs was staggered in 5 days intervals so that each batch finished its 10 days adaptation period at the same time as the previous batch finished their time in the respiration chamber. Pigs were transferred to the respiration chambers in groups of 3 by placing their metabolic crate into the respiration chamber. They were fed twice daily at 09:00 and 17:00 at 90% of *ad libitum* for a 3 days adaptation period. Pigs were subjected to fasting after a meal at 09:00 on their 4th day in the chambers. For the next 2 days, fasting heat production was measured. For pigs weighing 53.4-95.6 kg an additional day was added to measure FHP meaning that the pigs were maintained in the chambers for a total of 6 days comprising 3 days in adaptation and 3 days to measure FHP.

After measurement of FHP, the pigs and metabolic crates were removed from the chambers and returned to the metabolic room to prepare for the next round of measurements. A total of 7 rounds of measurements were taken with each pig entering the respiration chambers at an average body weight of 35.6±2.4, 44.7±3.1, 53.4±2.8, 63.9±2.7, 73.4±2.4, 83.3±3.0 and 95.6±2.0 kg.

The environmental temperature in each chamber was maintained at 22±1°C for pigs weighing 35.6 and 44.7 kg and at 20±1°C for pigs weighing 53.4-95.6 kg. The environmental temperature was increased by 2°C in the chamber when fasting began. The relative humidity was about 70%. Water was available *ad libitum* throughout the experiment.

Diet: The pigs weighing 30-60 kg were offered a growing diet and the pigs weighing 60-100 kg were offered a finishing diet based on the Feeding Standards of Swine in China (Ministry of Agriculture, 2004). The ingredient composition of the experimental diets is shown in (Table 1).

Measurements and chemical analyses: Pigs were weighed at the beginning of each stage as well as at the beginning and the end of the fasting period. The total urine excreted was collected and weighed daily and mixed with 30 mL of a 10% HCL solution for each liter of urine excreted.

Airflow rate gas concentrations (O_2, CO_2 and CH_4) outside and inside of the chambers as well as environmental conditions in each chamber (temperature, humidity and pressure) were continuously measured and recorded. Urine samples were analyzed for nitrogen according to the AOAC (1997).

Table 1: Composition and nutrient levels of the experimental diets (as-fed basis exp. 1 and 2)

	Diets (kg pigs)	
Items	30-60	60-100
Ingredients (%)		
Corn	68.10	70.10
Soybean meal	24.00	18.00
Wheat bran	5.00	9.00
Dicalcium phosphate	0.50	0.60
Limestone	1.00	0.90
Salt	0.40	0.40
Vitamin-mineral premix[1, 2]	1.00	1.00
Chemical analysis[3]		
Gross energy (kcal kg^{-1})	3805.00	3712.00
Crude protein (%)	16.44	14.54
Calcium (%)	0.53	0.49
Phosphorus (%)	0.46	0.42
Lysine (%)	0.90	0.76

[1]The vitamin and mineral/kilogram of the diet provided by premix during 30-60 kg: Vitamin A, 6,000 IU; Vitamin D_3, 2,400 IU; Vitamin E, 21.6 IU; Vitamin K_3, 2 mg; Vitamin B_1, 0.96 mg; Vitamin B_2, 5.2 mg; Vitamin B_6, 2 mg; Vitamin B_{12}, 12 µg; Nicotinic acid, 22 mg; Pantothenic acid, 11.2 mg; Folic acid, 0.4 mg; Biotin, 40 µg; Choline chloride, 0.4 g; Fe, 120 mg; Cu, 140 mg; Zn, 100 mg; Mn, 16 mg; I, 0.24 mg; Se, 0.4 mg; Ca, 7.2 g; P, 0.8 g; NaCl, 4.4 g (30-60 kg). [2]The vitamin and mineral/kilogram of the diet provided by premix during 60-100 kg: Vitamin A, 5,600 IU; Vitamin D_3, 2,200 IU; Vitamin E, 21.6 IU; Vitamin K_3, 1.8 mg; Vitamin B_1, 0.88 mg; Vitamin B_2, 4 mg; Vitamin B_6, 1.8 mg; Vitamin B_{12}, 12 µg; Nicotinic acid, 20 mg; Pantothenic acid, 10 mg; Folic acid, 0.4 mg; Biotin, 40 µg; Choline chloride, 0.32 g; Fe, 88 mg; Cu, 120 mg; Zn, 96 mg; Mn, 16 mg; I, 0.24 mg; Se, 0.4 mg; Ca, 7.2 g; P, 0.8 g; NaCl, 4 g (60-100 kg), [3]Analyzed value

Calculations: Heat production was calculated based on gas exchange according to the equation of Brouwer (1965).

$$\begin{aligned}&\text{Heat production}\left(\text{Kcal h}^{-1}\right)\\&= 3.866\times O_2\left(\text{L h}^{-1}\right)+1.200\times CO_2\left(\text{L h}^{-1}\right)-\\&\quad 0.518\times CH_4\left(\text{L h}^{-1}\right)-1.431\times \text{Urinary N}\left(\text{g h}^{-1}\right)\end{aligned} \quad (1)$$

Oxidation of Protein (OXP), Carbohydrate (OXCHO) and Fat (OXF) were calculated by the method described by Chwalibog *et al.* (2005):

$$\begin{aligned}&\text{Oxidation of protein}\left(\text{Kcal h}^{-1}\right)=\\&\text{Urinary nitrogen}\left(\text{g h}^{-1}\right)\times 6.25\times 4.40\end{aligned} \quad (2)$$

$$\begin{aligned}&\text{Oxidation of carbohydrates}\left(\text{Kcal h}^{-1}\right)=\\&\begin{bmatrix}-2.968\times O_2\left(\text{L h}^{-1}\right)+4.147\times CO_2\left(\text{L h}^{-1}\right)-\\ 1.761\times CH_4\left(\text{L h}^{-1}\right)-2.466\times\\ \text{Urinary nitrogen}\left(\text{g h}^{-1}\right)\end{bmatrix}\times 4.20\end{aligned} \quad (3)$$

$$\text{Oxidation of fat}\left(\text{Kcal h}^{-1}\right) = \left[\begin{array}{l} 1.719\times O_2\left(\text{L h}^{-1}\right) - 1.719\times CO_2\left(\text{L h}^{-1}\right) - \\ 1.719\times CH_4\left(\text{L h}^{-1}\right) - 1.963\times \\ \text{Urinary nitrogen}\left(\text{g h}^{-1}\right) \end{array}\right]\times 9.50 \quad (4)$$

$$\text{Respiratory quotient} = \frac{CO_2\left(\text{L h}^{-1}\right)}{O_2\left(\text{L h}^{-1}\right)} \quad (5)$$

$$\text{Respiratory quotient}_{\text{non-protein}} = \left[\begin{array}{l} CO_2\left(\text{L h}^{-1}\right) - \text{Urinary} \\ \text{nitrogen}\left(\text{g h}^{-1}\right)\times 6.52 \\ \times 0.774 \end{array}\right] / \left[\begin{array}{l} O_2\left(\text{L h}^{-1}\right) - \text{Urinary} \\ \text{nitrogen}\left(\text{g h}^{-1}\right)\times 6.52 \\ \times 0.957 \end{array}\right] \quad (6)$$

Statistical analyses: In exp. 1, data were subjected to a repeated-measure analysis performed by the GLM procedure using a model with a 12 h fasting period as the unit of measure (SPSS, 1999). In exp. 2, data were subjected to ANOVA using the body weights of the pigs as the source of variation (SPSS, 10.0). The relationships between FHP and body weight were analyzed using a linear regression mode 1 (SPSS, 10.0). The model was FHP = a BW^b, i.e., log FHP = log a+b log BW where FHP was the fasting heat production (kcal day^{-1}) and BW was the body weight (kg). A $p<0.05$ was considered significant.

RESULTS AND DISCUSSION

Effects of fasting duration on heat production and oxidation of substrates: The fasting duration has been reported considerable variation from 1-15 days (Holmes and Breirem, 1974; ARC, 1981; Koong *et al*., 1982; Noblet *et al*., 1994a; Van Milgen *et al*., 1998). It is difficult to estimate how long pigs should be starved before they reach a postabsorptive state with different body weights. Some reports showed that the rate of passage of diet in pigs ranged from 20-80 h (Seerley *et al*., 1962; Cole *et al*., 1967; Cunningham, 1967; Keys and Debarthe, 1974) which was influenced by body weight feed intake level as well as dietcomposition and so on. Based on the rate of passage of diet in pigs we considered pigs were withdrew feed for 96 h to study the effect of fasting duration on the changes of FHP and subtract oxidation in order to determine the optimal fasting duration in pigs with different body weights. The results of exp. 1 showed that as the fasting duration was extended from 0-96 h the heat production in pigs weighing 31.1, 50.3 and 89.7 kg declined rapidly ($p<0.05$) before reaching a steady state ($p>0.05$) in Table 2. This trend was in agreement with reports from Close and Mount (1975), Su and Hu (1989) and Chwalibog *et al*. (2004a). Furthermore, the FHP reached a steady state at different fasting durations depending upon the pigs body weight in this study. In pigs weighing 31.1 kg, the total heat production declined 32% during the

Table 2: Changes of energy metabolism during a 96 h fast in pigs with different body weights (exp. 1)

	Fasting duration (h)									
Items	12	24	36	48	60	72	84	96	SEM	p-values
31.1 kg										
O_2 consumption (L h^{-1})	19.89^{a}	17.17^{b}	15.41^{c}	14.38^{d}	14.04^{d}	13.89^{d}	13.87^{d}	13.62^{d}	2.85	<0.01
CO_2 production (L h^{-1})	20.32^{a}	14.42^{b}	11.74^{bc}	10.90^{c}	10.51^{cd}	10.40^{d}	10.23^{d}	9.96^{de}	3.46	<0.01
CH_4 production (L h^{-1})	0.20^{a}	0.14^{b}	0.10^{c}	0.09^{d}	0.07^{ef}	0.07^{e}	0.07^{ef}	0.07^{f}	0.01	0.01
Urine N[1] (g h^{-1})	0.64^{a}	0.64^{a}	0.31^{b}	0.31^{b}	0.25^{c}	0.25^{c}	0.24^{c}	0.24^{c}	0.02	0.02
Total Heat Production (THP) (kcal h^{-1})	100.22^{a}	82.74^{b}	73.17^{c}	68.19^{d}	66.55^{d}	65.86^{d}	65.51^{de}	64.23^{e}	18.65	<0.01
Respiratory quotient	1.02^{a}	0.84^{b}	0.76^{c}	0.76^{bc}	0.75^{c}	0.75^{c}	0.74^{d}	0.73^{d}	0.01	<0.01
50.3 kg										
O_2 consumption (L h^{-1})	35.78^{a}	28.05^{b}	22.51^{c}	19.42^{d}	17.21^{de}	15.36^{e}	15.41^{e}	14.76^{e}	7.49	<0.01
CO_2 production (L h^{-1})	37.38^{a}	27.36^{b}	19.19^{c}	15.58^{d}	13.16^{de}	11.50^{e}	11.42^{e}	10.88^{e}	6.84	<0.01
CH_4 production (L h^{-1})	0.47^{a}	0.34^{b}	0.21^{c}	0.17^{d}	0.16^{de}	0.14^{f}	0.14^{f}	0.14^{ef}	0.01	<0.01
Urine N[2] (g h^{-1})	1.00^{a}	1.00^{a}	0.86^{b}	0.86^{b}	0.54^{c}	0.54^{c}	0.42^{c}	0.42^{c}	0.02	<0.01
Total Heat Production (THP) (kcal h^{-1})	181.54^{a}	139.70^{b}	108.75^{c}	92.76^{d}	81.50^{de}	72.35^{e}	72.62^{e}	69.43^{e}	19.20	<0.01
Respiratory quotient	1.05^{a}	0.97^{b}	0.85^{c}	0.80^{d}	0.77^{de}	0.75^{ef}	0.74^{ef}	0.74^{f}	0.01	<0.01
89.7 kg										
O_2 consumption (L h^{-1})	46.97^{a}	38.60^{b}	32.47^{c}	29.36^{d}	26.94^{e}	26.09^{e}	24.79^{e}	24.18^{e}	9.37	<0.01
CO_2 production (L h^{-1})	49.43^{a}	37.21^{b}	27.07^{c}	22.14^{d}	20.08^{e}	18.97^{e}	18.42^{e}	18.12^{e}	9.19	<0.01
CH_4 production (L h^{-1})	0.78^{a}	0.63^{b}	0.34^{c}	0.30^{d}	0.22^{e}	0.22^{e}	0.22^{e}	0.23^{e}	0.02	<0.01
Urine N[3] (g h^{-1})	1.17^{a}	1.17^{a}	0.81^{ab}	0.81^{ab}	0.59^{b}	0.59^{b}	0.65^{b}	0.65^{b}	0.15	<0.01
Total Heat Production (THP) (kcal h^{-1})	238.83^{a}	191.87^{b}	157.07^{c}	139.15^{d}	127.45^{e}	122.82^{e}	117.07^{e}	114.34^{e}	133.00	<0.01
Respiratory quotient	1.05^{a}	0.97^{b}	0.83^{c}	0.75^{d}	0.75^{de}	0.73^{e}	0.74^{de}	0.75^{de}	0.01	<0.01

$^{a-f}$Values within a row with different letters differ significantly ($p<0.05$) n = 6; [1-3]Total excreted urine was collected and weighed daily so the calculation of urine N (g h^{-1}) was the average in 1 day

1st 48 h of starvation and then stabilized and was not different (p>0.05) from 48-84 h. However when the fasting duration was extended to 96 h the total heat production was lowest (p<0.05) in pigs weighing 31.1 kg which may be due to a decrease of visceral mass and basal metabolic rate (Poczopko, 1967; Koong *et al*., 1982). In pigs weighing 50.3 and 89.7 kg the total heat production declined 55 and 47% during the 1st 60 h of starvation and then stabilized and was not different (p>0.05) between 60-96 h.

Based on the principle of indirect calorimetry, the total heat production was from the heat production due to the oxidation of protein carbohydrate and fat. Therefore, the change of heat production was related to the oxidation of substrate with the extension of fasting in pigs. As pigs are fasted body metabolism has been shown to transform from anabolism to catabolism and the source of oxidation changed from carbohydrate to fat (Chwalibog *et al*., 2004b). Using the formula from Chwalibog *et al*. (2004a) the Oxidation of Protein (OXP) Carbohydrate (OXCHO) and Fat (OXF) in pigs weighing 31.1, 50.3 and 89.7 kg were calculated as shown in Table 3-5.

In Table 3, the respiratory quotient$_{non-protein}$ was 1.07 when pigs were starved for 12 h which meant that energy was mainly provided from the oxidation of carbohydrates causing highly fat retention to occur (Jakobsen and Thorbek, 1993). As the fasting duration was extended the oxidation of carbohydrates decreased rapidly from 23.21-2.23 g h^{-1} while the oxidation of fat increased from 0-5.21 g h^{-1} during 48 h of starvation. Pigs weighing 31.1 kg then reached a steady state which indicated that the amount of carbohydrate absorbed from feed was used

Table 3: Changes of substrates oxidation during a 96 h fast in pigs weighing 31.1 kg (exp. 1)

	Fasting duration (h)									
Items	12	24	36	48	60	72	84	96	SEM	p-values
Respiratory quotient$_{non-protein}$	1.07^{a}	0.85^{b}	0.73^{c}	0.70^{d}	0.72^{c}	0.74^{bc}	0.74^{c}	0.74^{c}	0.03	<0.01
Substrate oxidation of carbohydrate and its energy										
[1]OXCHO (g h^{-1})	23.21^{a}	8.67^{b}	2.75^{b}	2.23^{b}	1.41^{bc}	1.67^{bc}	0.96^{c}	0.73^{c}	4.92	<0.01
[2]OXCHO (kcal h^{-1})	97.52^{a}	36.43^{b}	7.70^{b}	6.24^{b}	5.94^{bc}	7.01^{b}	4.04^{c}	3.05^{c}	32.00	<0.01
[3]OXCHO/THP	0.93^{a}	0.42^{b}	0.15^{c}	0.14^{c}	0.09^{cd}	0.10^{cd}	0.06^{d}	0.05^{d}	0.01	<0.01
Substrate oxidation of fat and its energy										
[4]OXF (g h^{-1})	0.00^{d}	3.13^{c}	5.52^{b}	5.21^{cb}	5.51^{ab}	5.46^{b}	5.69^{ab}	5.72^{a}	1.48	<0.01
[5]OXF (kcal h^{-1})	0.00^{c}	30.66^{b}	52.48^{a}	49.49^{ab}	52.40^{a}	51.89^{a}	54.07^{a}	54.33^{a}	18.9	<0.01
[6]OXF/THP	0.00^{c}	0.37^{b}	0.72^{b}	0.73^{b}	0.79^{ab}	0.79^{ab}	0.82^{a}	0.85^{a}	0.02	<0.01
Substrate oxidation of protein and its energy[10]										
[7]OXP (g h^{-1})	-	17.57^{a}	-	8.40^{b}	-	6.94^{bc}	-	6.62^{c}	4.51	<0.01
[8]OXP (kcal h^{-1})	-	3.99^{a}	-	1.91^{b}	-	1.58^{bc}	-	1.50^{c}	0.64	<0.01
[9]OXP/THP	-	0.21^{d}	-	0.12^{b}	-	0.11^{a}	-	0.10^{a}	0.01	<0.01

[a-d]Values within a row with different letters differ significantly (p<0.05) n = 6. [1]OXCHO (g h^{-1}): Oxidation of carbohydrate (g h^{-1}); [2]OXCHO (kcal h^{-1}): Energy from oxidation of carbohydrate (kcal h^{-1}); [3]OXCHO/THP. The contribution of carbohydrate oxidation to the total heat production; [4]OXF (g h^{-1}): Oxidation of fat (g h^{-1}); [5]OXF (kcal h^{-1}): Energy from oxidation of fat (kcal h^{-1}); [6]OXF/THP: The contribution of fat oxidation to the total heat production; [7]OXP (g h^{-1}): Oxidation of protein (g h^{-1}); [8]OXP (kcal h^{-1}): Energy from oxidation of protein (kcal h^{-1}); [9]OXP/THP: The contribution of protein oxidation to the total heat production. [10]The total excreted urine was collected and weighed daily so the calculation of substrate oxidation of protein and its energy were the average in 1 day

Table 4: Changes of substrates oxidation during a 96 h fast in pigs weighing 50.3 kg (exp. 1)

	Fasting duration (h)									
Items	12	24	36	48	60	72	84	96	SEM	p-values
Respiratory quotient$_{non-protein}$	1.09^{a}	1.02^{b}	0.87^{c}	0.81^{d}	0.76^{de}	0.73^{e}	0.73^{e}	0.72^{e}	0.02	<0.01
Substrate oxidation of carbohydrate and its energy										
[1]OXCHO (g h^{-1})	44.00^{a}	25.85^{b}	11.60^{c}	6.17^{d}	2.55^{de}	0.76^{e}	1.05^{e}	0.73^{e}	22.00	<0.01
[2]OXCHO (kcal h^{-1})	184.88^{a}	108.64^{b}	48.76^{c}	25.92^{d}	10.72^{de}	3.19^{e}	4.41^{e}	3.07^{e}	38.90	<0.01
[3]OXCHO/THP	1.04^{a}	0.79^{b}	0.43^{c}	0.27^{d}	0.14^{d}	0.04^{d}	0.06^{d}	0.04^{d}	0.10	<0.01
Substrate oxidation of fat and its energy										
[4]OXF (g h^{-1})	0.00^{d}	0.06^{c}	3.79^{b}	5.00^{ab}	6.03^{a}	5.33^{a}	5.78^{a}	5.61^{a}	0.82	<0.01
[5]OXF(kcal h^{-1})	0.00^{c}	0.56^{c}	36.00^{b}	47.50^{ab}	57.26^{a}	50.68^{a}	54.92^{a}	53.36^{a}	51.60	<0.01
[6]OXF/THP	0.00^{d}	0.01^{d}	0.34^{c}	0.52^{b}	0.67^{ab}	0.70^{a}	0.76^{a}	0.77^{a}	0.03	<0.01
Substrate oxidation of protein and its energy[10]										
[7]OXP (g h^{-1})	-	6.24^{a}		5.39^{b}		3.60^{c}		2.55^{c}	0.77	<0.01
[8]OXP (kcal h^{-1})	-	27.46^{a}		23.57^{b}		14.74^{c}		11.60^{c}	12.05	<0.01
[9]OXP/THP	-	0.20^{b}		0.23^{a}		0.20^{ab}		0.17^{c}	0.04	<0.01

[a-e]Values within a row with different letters differ significantly (p<0.05) n = 6. [1]OXCHO (g h^{-1}): Oxidation of carbohydrate (g h^{-1}); [2]OXCHO (kcal h^{-1}): Energy from oxidation of carbohydrate (kcal h^{-1}); [3]OXCHO/THP: The contribution of carbohydrate oxidation to the total heat production; [4]OXF (g h^{-1}): Oxidation of fat (g h^{-1}); [5]OXF (kcal h^{-1}): Energy from oxidation of fat (kcal h^{-1}); [6]OXF/THP: The contribution of fat oxidation to the total heat production; [7]OXP (g h^{-1}): Oxidation of protein (g h^{-1}); [8]OXP (kcal h^{-1}): Energy from oxidation of protein (kcal h^{-1}); [9]OXP/THP: The contribution of protein oxidation to the total heat production. [10]The total excreted urine was collected and weighed daily so the calculation of substrate oxidation of protein and its energy were the average in 1 day

Table 5: Changes of substrates oxidation during a 96 h fast in pigs weighing 89.7 kg (exp. 1)

	Fasting duration (h)									
Items	12	24	36	48	60	72	84	96	SEM	p-values
Respiratory quotient$_{non\text{-}protein}$	1.10[a]	1.00[b]	0.83[c]	0.75[d]	0.73[de]	0.72[e]	0.73[de]	0.74[d]	0.01	<0.01
Substrate oxidation of carbohydrate and its energy										
[1]OXCHO (g h^{-1})	61.34[a]	35.80[a]	13.33[a]	3.14[b]	2.56[b]	0.64[b]	1.52[b]	1.79[b]	94.00	0.10
[2]OXCHO (kcal h^{-1})	257.75[a]	150.41[b]	64.43[c]	13.37[d]	10.76[de]	2.69[e]	6.40[de]	8.83[de]	230.00	<0.01
[3]OXCHO/THP	1.08[a]	0.79[b]	0.41[c]	0.10[d]	0.08[d]	0.02[d]	0.09[d]	0.10[d]	0.01	<0.01
Substrate oxidation of fat and its energy										
[4]OXF (g h^{-1})	0.00[d]	0.59[c]	8.13[b]	10.85[a]	10.43[a]	10.90[a]	9.52[ab]	8.98[ab]	2.34	<0.01
[5]OXF (kcal h^{-1})	0.00[c]	5.58[c]	77.26[b]	103.10[a]	99.12[a]	103.58[a]	90.44[ab]	85.34[ab]	130.00	<0.01
[6]OXF/THP	0.00[c]	0.03[c]	0.48[b]	0.74[a]	0.77[a]	0.84[a]	0.77[a]	0.74[a]	4.64	<0.01
Substrate oxidation of protein and its energy[10]										
[7]OXP (g h^{-1})	7.28[a]	7.28[a]	5.06[ab]	5.06[ab]	3.72[b]	3.72[b]	4.03[b]	4.03[b]	5.35	0.06
[8]OXP (kcal h^{-1})	32.06[a]	32.06[a]	22.26[ab]	22.26[ab]	16.37[b]	16.37[b]	17.76[b]	17.76[b]	109.00	0.05
[9]OXP/THP	0.14	0.17	0.14	0.16	0.14	0.14	0.15	0.16	0.02	0.70

[a-e]Values within a row with different letters differ significantly ($p<0.05$), n = 6. [1]OXCHO (g h^{-1}): Oxidation of carbohydrate (g h^{-1}); [2]OXCHO (kcal h^{-1}): Energy from oxidation of carbohydrate (kcal h^{-1}); [3]OXCHO/THP: The contribution of carbohydrate oxidation to the total heat production; [4]OXF (g h^{-1}): Oxidation of fat (g h^{-1}); [5]OXF (kcal h^{-1}): Energy from oxidation of fat (kcal h^{-1}); [6]OXF/THP: The contribution of fat oxidation to the total heat production; [7]OXP (g h^{-1}): Oxidation of protein (g h^{-1}); [8]OXP (kcal h^{-1}): Energy from oxidation of protein (kcal h^{-1}); [9]OXP/THP: The contribution of protein oxidation to the total heat production. [10]The total excreted urine was collected and weighed daily so the calculation of substrate oxidation of protein and its energy were the average in 1 day

up after 48 h of fasting and the body's energy requirement was provided by the mobilization of body fat (Chwalibog *et al*., 2004b). Corresponding to this trend, the respiratory quotient decreased from 1.02-0.76 during the 1st 48 h of starvation. Furthermore, the contribution of carbohydrate oxidation to the total heat production decreased rapidly to 14% while the contribution of fat oxidation to the total heat production increased to 73% indicating that after 48 h of starvation the fasting heat production was due to fat oxidation principally. In addition, the decreased oxidation of protein to 12% of the total heat production during the 1st 48 h period of starvation was consistent with increasing gluconeogenesis from muscle-derived amino acids (Chwalibog *et al*., 2004a).

Compared with data from Table 3, the trend was similar in pigs weighing 50.3 and 89.7 kg (Table 4 and 5) but the oxidation of substrates reached a steady state at different fasting durations for these pigs. In Table 4 with the fasting duration extended the oxidation of carbohydrates decreased rapidly from 44.0-2.55 g h^{-1} while the oxidation of fat increased from 0-6.03 g h^{-1} during 60 h of starvation. Corresponding to this trend, the contribution of carbohydrate oxidation to the total heat production decreased rapidly to 14% while the contribution of fat oxidation to the total heat production increased rapidly to 67%. Then, the oxidation of carbohydrate and fat reached a steady state after 60 h of starvation, respectively.

In Table 5 with the fasting duration extended the oxidation of carbohydrates decreased rapidly from 61.34-3.14 g h^{-1} during 48 h of starvation while oxidation of fat increased from 0-10.85 g h^{-1} during 48 h of starvation. Furthermore, the contribution of carbohydrate oxidation to the total heat production decreased rapidly to 10% while the contribution of fat oxidation to the total heat production increased to 74%. Then, the oxidation of carbohydrate and fat reached a steady state after 48 h of starvation, respectively. The results are consistent with the changes of the serum biochemical index of finishing pigs during a similar fasting duration according to the study of Veum *et al*. (1970) which showed that the serum lipid levels were significantly increased after 34 h ($p<0.05$) but did not differ over the subsequent period of 58-82 h ($p>0.05$).

In summary, the heat production reached a steady state and was from fat oxidation principally when the fasting duration was 48 h for 31.1 kg pigs and 60 h for pigs weighing 50.3 and 89.7 kg.

Effects of different body weights on fasting heat production: The FHP was ranged from 164-234 kcal kg^{-1} $BW^{0.6}$ day^{-1} (Koong *et al*., 1982, 1983; Tess *et al*., 1984; Noblet *et al*., 1994a; Van Milgen *et al*., 1998). Considering the factors on FHP including the pig fasting duration nutritional plane before fast and environment conditions the FHP lacked comparability in different experiments. So, the exp. 2 aimed to develop standard conditions for measuring FHP in pigs with different body weights in order to establish a foundation for a net energy system of feedstuff in China.

Based on the results form exp. 1, the appropriate fasting duration was 48 h for pigs with a body weight of 35.6 kg and 72 h for pigs with a body weight from 44.7-95.6 kg. An overly prolonged fasting duration could decrease the basal metabolic rate and FHP (Poczopko, 1967; ARC, 1981; Koong *et al*., 1982). Van Milgen *et al*. (1998) also considered that a short-duration of fasting was probably more representative for the producing animal than long-term fasting when taking accounted for

Table 6: Effects of different body weights on fasting heat production in pigs (exp. 2)

	Body weight (kg)								
Effects	35.6	44.7	53.4	63.9	73.4	83.3	95.6	SEM	p-values
Feeding level before fasting (g day^{-1})	1425	1705	1999	2377	2724	3093	3426	-	-
Respiratory quotient	0.74	0.73	0.73	0.73	0.74	0.73	0.71	0.003	0.09
FHP (kcal day^{-1})	1577^{f}	1747^{e}	1930^{d}	2137^{c}	2307^{b}	2510^{a}	2683^{a}	54.000	<0.01
FHP (kcal/kg $BW^{0.55}$/day)	222	216	217	217	217	221	218	0.800	0.42
FHP (kcal/kg $BW^{0.75}$/day)	109^{a}	101^{b}	98^{bc}	95^{c}	92^{cd}	91^{cd}	88^{d}	0.800	<0.01
FHP (kcal/kg $BW^{0.60}$/day)	185^{a}	179^{ab}	177^{b}	176^{b}	175^{b}	177^{b}	174^{b}	0.700	0.01
FHP (kcal/kg $BW^{0.42}$ day)	352^{e}	354^{e}	363^{de}	373^{cd}	380^{bc}	392^{ab}	395^{a}	0.900	0.09

[a-f]Values within a row with different letters differ significantly ($p<0.05$). FHP: Fasting Heat Production

the heat production due to residual digestive and absorptive processes. When the nutrients including glucose, fat and protein oxidized in pigs body the respiratory quotient was 1.0, 0.71 and 0.81, respectively (Brouwer, 1965). Based on the results of exp. 2, the respiratory quotient ranged from 0.74-0.71 in pigs weighing 35.6-95.6 kg which confirmed that the energy was provided with mobilization of body fat and protein and the heat productions represented the FHP. That was to say the fast duration in exp. 2 was reasonable.

Considering the influence of the plane of nutrition on FHP (Koong *et al*., 1982; De Lange *et al*., 2006), the feeding level before the fast in the present experiment was close to *ad libitum* in order to reflect a normal state. The temperature was controlled at 24±1°C for pigs weighing 35.6 and 44.7 kg and 22±1°C for pigs weighing 53.4-95.6 kg which was within the thermoneutral range of fasting pigs (Close and Mount, 1975; Yang *et al*., 1988; NRC, 1998). In addition, FHP was calculated at 22:00-08:00 in the present experiment in which the pigs were rest and avoid the impact of physical activity on the heat production (Van Milgen *et al*., 1998). The FHP of pigs with different body weights was shown in Table 6. The respiratory quotient ranged from 0.74-0.71 and was not different ($p>0.05$) in pigs weighing 35.6-95.6 kg. With an increase of body weight the FHP increased from 1577-2683 kcal day^{-1}. This result was lower than Van Milgen *et al*. (1998) and Noblet *et al*. (1994a) but consistent with the study from Tess *et al*. (1984) as well as Close and Mount (1975). The present experiment differed from the earlier reports was due to the pig itself fasting duration nutritional plane before fast environment conditions and so on which also influenced the estimate of net energy value of feedstuff. The FHP was calculated as 220 kcal/kg $BW^{0.55}$/day (R^2 = 0.97, p = 0.01) in pigs with body weights from 35.6-95.6 kg based on a Linear Regression Model. Classically, the FHP was expressed as per kg metabolic $BW^{0.75}$ but some reports indicate that it was constant per unit of mass when the exponent was <0.75 with different body weights (Tess *et al*., 1984; Van Milgen *et al*., 1998). Noblet *et al*. (1999) reported that when comparing the maintenance energy expenditure for growing pigs at different body weights an exponent close to 0.60 was often found. Tess *et al*. (1984) calculated that the exponent was about 0.53 and Noblet *et al*. (1994a) calculated that the exponent was about 0.42 for pigs weighing between 45 and 150 kg. Using 0.75, 0.60, 0.55 and 0.42 as the exponent of metabolic BW, respectively, there was no significant difference ($p>0.05$) on FHP in pigs weighing between 35.2-95.6 kg when the exponent was 0.55 but was significant different when the exponent was 0.75, 0.60 or 0.42. It was indicated that 0.55 as the exponent of metabolic BW was optimal to estimate the FHP in present experimental condition.

CONCLUSION

The present study showed a fast of 48 h was sufficient for 31.1 kg pigs to reach a postabsorptive stable state while 60 h was sufficient for 50.3 and 89.7 kg pigs. The FHP was 220 kcal/kg $BW^{0.55}$/day for crossbred pigs (Duroc x large white x landrace) weighing from 35.6-95.6 kg in present experimental conditions.

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