Effects of Dietary Energy Level during Late Gestation on Reproductive Performance and Blood Lipid Metabolism-Related Indices in Sows (Postprint)

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Abstract

This experiment aimed to investigate the effects of energy feeding level during late gestation on reproductive performance and blood lipid metabolism-related indices in sows. Forty-eight Landrace × Yorkshire crossbred multiparous gestating sows were selected and randomly divided into four groups with different energy feeding levels (n=12) according to body weight and parity starting from day 85 of gestation. The four energy feeding levels were 1.12, 1.32, 1.52, and 1.72 times the maintenance metabolizable energy requirement, and were designated as 1.12M, 1.32M, 1.52M, and 1.72M groups, respectively. The experimental diet was a corn-soybean meal diet with metabolizable energy (ME) of 13.38 MJ/kg and crude protein (CP) content of 15.09%. The moderate energy feeding level was based on the effective metabolizable energy recommendation for gestating sows by NRC (2012), while the low, high, and very high energy feeding levels were reduced by 15%, increased by 15%, and increased by 30% based on this recommendation, respectively. The daily feed intake of sows in the 1.12M, 1.32M, 1.52M, and 1.72M groups was 2.17, 2.56, 2.94, and 3.33 kg/d, respectively, with metabolizable energy intake of 29.10, 34.23, 39.37, and 44.50 MJ/d. The experimental period lasted for 23 days. The results showed that with increasing energy feeding level during late gestation, the average daily feed intake of lactating sows decreased significantly ($P<0.05$). On day 100 of gestation, with increasing energy feeding level, sow serum total cholesterol and low-density lipoprotein concentrations increased linearly ($P<0.05$), while serum total cholesterol, triglyceride, and high-density lipoprotein concentrations increased quadratically ($P<0.05$). During late gestation, sow serum total cholesterol concentration decreased significantly with prolongation of gestation ($P<0.05$); serum high-density lipoprotein and low-density lipoprotein concentra-

tions on day 107 of gestation were significantly lower than those on days 100 and 85 of gestation (P<0.05); serum triglyceride concentration on day 100 of gestation was significantly higher than that on days 85 and 107 of gestation (P<0.05), and was also significantly higher on day 107 than on day 85 (P<0.05). These results indicate that increasing energy feeding level during late gestation can reduce feed intake during the lactation period; blood lipids in sows during late gestation are at a relatively high physiological level, and increasing energy feeding level on this basis can further lead to elevated serum triglyceride, high-density lipoprotein, low-density lipoprotein, and total cholesterol concentrations.

Full Text

Effects of Energy Feeding Level in Late Gestation on Reproductive Performance and Blood Lipid Metabolism Related Indicators of Sows

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Abstract

This experiment was conducted to investigate the effects of energy feeding level in late gestation on reproductive performance and blood lipid metabolism related indicators of sows. A total of 48 multiparous Large White × Landrace crossbred sows were randomly allocated into four groups (n = 12) at day 85 of gestation based on body weight and parity, with low, medium, high, and extremely high energy feeding levels. The four groups received energy at 1.12, 1.32, 1.52, and 1.72 times the maintenance metabolic energy requirement, designated as 1.12M, 1.32M, 1.52M, and 1.72M groups, respectively. The experimental diet was a corn-soybean meal type diet with a metabolic energy (ME) content of 13.38 MJ/kg and crude protein (CP) content of 15.09%. The medium energy feeding level corresponded to the NRC (2012) recommended effective metabolic energy for pregnant sows, while the low, high, and extremely high levels represented a 15% reduction, a 15% increase, and a 30% increase from this baseline, respectively. Daily feed intake for the 1.12M, 1.32M, 1.52M, and 1.72M groups was 2.17, 2.56, 2.94, and 3.33 kg/d, respectively, corresponding to metabolic energy intakes of 29.10, 34.23, 39.37, and 44.50 MJ/d. The trial period lasted 23 days. Results showed that with increasing energy feeding level in late gestation, the average daily feed intake (ADFI) of lactating sows decreased significantly (P < 0.05). At day 100 of gestation, serum total cholesterol (TC) and low-density lipoprotein (LDL) concentrations increased linearly with energy feeding level (P

< 0.05), while serum TC, triglyceride (TG), and high-density lipoprotein (HDL) concentrations showed a quadratic increase ($P < 0.05$). During late gestation, serum TC concentration decreased significantly as gestation progressed ($P < 0.05$). Serum HDL and LDL concentrations at day 107 of gestation were significantly lower than those at days 100 and 85 ($P < 0.05$). Serum TG concentration at day 100 was significantly higher than at days 85 and 107 ($P < 0.05$), and it was also significantly higher at day 107 than at day 85 ($P < 0.05$). These findings indicate that increasing energy feeding level during late gestation reduces feed intake during lactation. Blood lipid concentrations are at a physiologically high level during late gestation, and further increasing the energy feeding level can elevate serum TG, HDL, LDL, and TC concentrations.

Keywords: sows; late gestation; energy feeding level; reproductive performance; blood lipid metabolism related indicators

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Reproductive performance of sows is a critical technical factor in China' s swine industry and represents an important bottleneck affecting farm economic efficiency [1]. Sow reproductive performance is influenced by multiple factors including genetics, nutrition, health status, and environment, with nutrition being one of the most important [2]. In recent years, genetic improvement and enhanced health status have substantially improved sow reproductive capacity and production efficiency. However, compared with swine production levels in developed countries, current domestic sows of the same breeds perform far below their potential, achieving only 70% of their reproductive capacity, with the remaining 30% lost due to improper nutrition and feeding management [3]. Nutrition during gestation primarily supports maternal body condition recovery, uterine content development, and mammary gland growth [4]. As sows have different physiological functions at various gestation stages, their nutritional requirements also differ. Late gestation is a period of rapid fetal growth, during which energy requirements increase exponentially [5]. Increasing dietary energy level during late gestation can improve piglet birth weight, thereby increasing survival rates and subsequent weaning weights [6]. However, excessive energy levels during late gestation can lead to excessive fat deposition, resulting in overweight sows and causing problems such as dystocia and metabolic disorders [7]. Energy provision during gestation, especially in late gestation, is crucial for sow reproductive performance and health, warranting continuous systematic and in-depth research.

Blood lipids, comprising neutral fats and lipids in blood, mainly include total cholesterol (TC) and triglycerides (TG). Under normal conditions, blood lipid components and concentrations maintain dynamic equilibrium. In human medicine, TG, TC, high-density lipoprotein (HDL), and low-density lipoprotein (LDL) concentrations are commonly used to assess lipid abnormalities [8]. When blood TG, TC, and LDL concentrations are too high or HDL concentration is too low, lipid metabolism becomes abnormal, resulting in hyperlipidemia [9]. The incidence of lipid abnormalities during human pregnancy is higher than in the general population, with blood TG, TC, LDL, and HDL concentrations all elevated compared with non-pregnant states, becoming more pronounced in mid-to-late pregnancy [10]. Pigs share similar physiological and metabolic characteristics with humans, particularly in the cardiovascular and digestive systems [11]. Torres-Rovira et al. [12] used sows as a model, inducing obesity with high-fat diets and confirming that high energy intake leads to metabolic disorders and dyslipidemia in sows. Therefore, research on the relationship between energy, metabolism, and health in pregnant sows has become a hot topic in animal nutrition. This study investigated the effects of energy feeding level in late gestation on sow reproductive performance and blood lipid metabolism indicators to explore the relationship between dietary energy and changes in sow reproductive performance and lipid indicators, providing experimental evidence for precision feeding technology in pregnant sows.

1.1 Experimental Animals, Grouping and Management

The animal feeding trial was conducted in July 2017 at the Animal Experimental Base of the Feed Industry Center, Ministry of Agriculture, China Agricultural University (Fengning, Hebei). The gestation sow house was a closed facility, with experimental sows housed in individual crates after weighing and grouping. All procedures complied with relevant animal welfare protocols and requirements of China Agricultural University.

A total of 48 multiparous (parity 2) Large White × Landrace pregnant sows were randomly divided into four groups (n = 12 each) based on body weight and parity. Before the experiment (during early and mid-gestation), all sows were fed the base gestation diet. Starting at day 85 of gestation, the four groups received restricted feed intake according to low, medium, high, and extremely high energy feeding levels. The medium energy level corresponded to the NRC (2012) recommended effective metabolic energy for pregnant sows at 1.32 times the maintenance metabolic energy requirement (M). The low, high, and extremely high levels represented a 15% reduction, a 15% increase, and a 30% increase from this baseline, respectively, corresponding to 1.12, 1.52, and 1.72 times the maintenance metabolic energy requirement. These groups were designated as 1.12M, 1.32M, 1.52M, and 1.72M. The late gestation diet was a corn-soybean meal type diet with a metabolic energy (ME) content of 13.38 MJ/kg and crude protein (CP) content of 15.09%; its composition and nutrient levels are shown in Table 1 . Daily feed intake for the low, medium, high, and extremely high groups was 2.17, 2.56, 2.94, and 3.33 kg/d, respectively, with metabolic energy intakes of 29.10, 34.23, 39.37, and 44.50 MJ/d (Table 2). Other dietary nutrients including amino acids, vitamins, and minerals met or exceeded NRC (2012) recommendations for pregnant sows. Sows were fed at 05:30, 11:00, and 16:30 daily with free access to water. After farrowing, all sows received the same complete lactation feed; the composition and nutrient levels of the lactation diet are shown in Table 3 . Lactating sows were fed three times daily with ad libitum access to feed and water, and feed intake was recorded. Deworming and vaccination were performed according to routine farm management procedures.

Table 1 Composition and nutrient levels of the diet for sows in late gestation (as-fed basis)

Items	Content
Ingredients	
Corn	
Soybean meal	
Wheat bran	
Soybean oil	
Limestone	
CaHPO	
NaCl	
Vitamin-mineral premix[1)]	
Lys	
Choline chloride	
Total	
Nutrient levels[2)]	
ME/(MJ/kg)	
CP	
Lys	
Trp	
Thr	
Met	
TP	

[1)] The vitamin-mineral premix provided the following per kg of the diet: VA 10,000 IU, VD 2,000 IU, VE 24 IU, VK 2 mg, VB 2 mg, VB 6 mg, VB 4 mg, VB 0.024 mg, pantothenic acid 20 mg, nicotinic acid 30 mg, biotin 0.4 mg, folic acid 3.6 mg, Zn (ZnSO ·H O) 120 mg, Fe (FeSO ·H O) 96 mg, Mn (MnSO · H O) 40 mg, Cu (CuSO ·5H O) 8 mg, I (Ca(IO)) 0.56 mg, Se (Na SeO) 0.24 mg.

[2)] CP was a measured value, while the others were calculated based on the nutrients and metabolic energy in feedstuffs of NRC (2012).

Table 2 Daily feed intake and metabolic energy intake of sows in late gestation

Groups	Daily feed intake (kg/d)	Metabolic energy intake (MJ/d)
1.12M	2.17	29.10
1.32M	2.56	34.23
1.52M	2.94	39.37
1.72M	3.33	44.50

Table 3 Composition and nutrient levels of the diet for lactating sow (as-fed basis)

Items	Content
Ingredients	
Corn	
Soybean meal	
Wheat bran	
Soybean oil	
Premix[1)]	
Total	
Nutrient levels[2)]	
GE/(MJ/kg)	
CP	
Lys	
TP	

[1)] The premix provided the following per kg of the diet: VA 5,600 IU, VD 4,000 IU, VE 25 IU, VK 2.25 mg, VB 2.5 mg, VB 5.0 mg, VB 7.5 mg, VB 0.025 mg, nicotinic acid 32.5 mg, pantothenic acid 22.5 mg, folic acid 4 mg, biotin 0.5 mg, Mn 100 mg, Fe 120 mg, Zn 75 mg, Cu 40 mg, Se 0.25 mg, I 1.5 mg, Ca 12.5 g, P 1.0 g, NaCl 3.0 g, choline 0.5 g, Lys 0.6 g.

[2)] GE, CP, Lys, Ca, and TP were all measured values.

1.2 Sample Collection

Sows were weighed and backfat thickness measured at days 85 and 107 of gestation and at weaning. After farrowing, litter size was recorded, including total born, born alive, and stillborn piglets. Piglets were weighed within 24 h of birth, and litter weight and number of piglets were recorded at weaning. Sow feed intake during lactation was recorded to calculate average daily feed intake. Blood samples were collected from the ear marginal vein at days 85, 100, and 107 of gestation, 4 h after feeding at 05:30 and before feeding at 11:00. Non-anticoagulated blood was allowed to stand at room temperature for 1 h, then centrifuged at 3,000 r/min for 10 min at 4 °C to separate serum, which was stored at -20 °C.

1.3 Determination of Blood Lipid Metabolism Related Indicators

Serum samples were thawed at 4 °C, and concentrations of TG, TC, LDL, and HDL were determined using an automatic biochemical analyzer (Hitachi 7600, Japan). Assay kits were purchased from Beijing Laibang Biotechnology Co., Ltd.

1.4 Data Processing and Analysis

Data were analyzed using the General Linear Model (GLM) in SPSS 20.0 statistical software. Sow and piglet performance and litter were used as statistical units, with treatment as the main effect factor. One-way ANOVA was performed on blood lipid metabolism indicators at each gestation time point, with treatment as the main effect factor. Results are expressed as means and standard error of the mean (SEM). Differences were considered statistically significant at $P < 0.05$, and trends were identified at 0.05 $P < 0.10$.

2.1 Effects of Energy Feeding Level in Late Gestation on Reproductive Performance of Sows

As shown in Table 4 , with increasing energy feeding level in late gestation, the average daily feed intake of lactating sows decreased linearly (4.86, 4.46, 4.28, and 3.95 kg/d, respectively), with significant differences among groups ($P < 0.05$). No significant differences were observed among the low, medium, high, and extremely high energy feeding level groups for total born, born alive, litter weaning weight, or number of weaned piglets ($P > 0.05$). Piglet birth weight showed a linear increasing trend ($P = 0.057$).

Table 4 Effects of energy feeding level in late gestation on reproductive performance of sows

Items	1.12M	1.32M	1.52M	1.72M	SEM	P-value	Linear	Quadratic
Parity								
Sows' body weight (kg)								
Day 85 of gestation								
Day 107 of gestation								
Weaning								
Body weight changes of sows (kg)								

Items	1.12M	1.32M	1.52M	1.72M	SEM	P-value	Linear	Quadratic
Body weight gain from day 85 to 107 of gestation	12.3	15.0	18.5					
Body weight loss from day 107 of gestation to weaning	33.6	12.3	15.0	18.5				
Litter size								
Total number born	35.4	40.5	45.1					
Number born alive								
Piglets' body weight (kg)								
Litter wean weight of piglets (kg)								
Number of weaned piglets								

Items	1.12M	1.32M	1.52M	1.72M	SEM	P-value	Linear	Quadratic
ADFI of lactating sows (kg/d)	4.86	4.46	4.28	3.95				

Values in the same row with different letter superscripts differ significantly (P < 0.05). The same applies below.

2.2 Effects of Energy Feeding Level in Late Gestation on Blood Lipid Metabolism Related Indicators of Sows

As shown in Table 5 , no significant differences were observed among groups for blood lipid metabolism indicators at days 85 and 107 of gestation ($P > 0.05$). At day 100 of gestation, serum TC and LDL concentrations increased linearly with energy feeding level ($P < 0.05$), while serum TC, TG, and HDL concentrations showed a quadratic increase ($P < 0.05$).

Table 5 Effects of energy feeding level in late gestation on blood lipid metabolism related indicators of sows (mmol/L)

Items	1.12M	1.32M	1.52M	1.72M	SEM	P-value	Linear	Quadratic
Parity								
Day 85 of gestation								
TC (mmol/L)								
TG (mmol/L)								
HDL (mmol/L)								
LDL (mmol/L)								
Day 100 of gestation								
TC	1.16	1.29	1.60	1.37				
TG	0.44	0.51	0.60	0.49				
HDL	0.55	0.60	0.76	0.66				

Items	1.12M	1.32M	1.52M	1.72M	SEM	P-value	Linear	Quadratic
LDL								
Day 107 of gestation								
TC								
TG								
HDL								
LDL								

2.3 Effects of Gestation Time on Blood Lipid Metabolism Related Indicators of Sows

As shown in Figure 1 [Figure 1: see original paper], during late gestation, serum TC concentration decreased significantly with prolonged gestation ($P < 0.05$), with values of 1.64, 1.35, and 1.08 mmol/L at days 85, 100, and 107, respectively. Serum TG concentration first increased then decreased, being significantly higher at day 100 (0.71 mmol/L) than at days 85 and 107 (0.36 and 0.58 mmol/L, respectively), while day 107 remained significantly higher than day 85 ($P < 0.05$). Serum HDL concentration remained stable initially then decreased, being significantly lower at day 107 (0.41 mmol/L) than at days 85 and 100 (0.56 and 0.55 mmol/L, respectively) ($P < 0.05$). Serum LDL concentration decreased gradually, being significantly lower at day 107 (0.50 mmol/L) than at days 85 and 100 (0.68 and 0.62 mmol/L, respectively) ($P < 0.05$).

Figure 1 Effects of gestation time on blood lipid metabolism related indicators of sows

Data columns with different lowercase letters differ significantly ($P < 0.05$).

Discussion

Energy requirements during gestation are used to support maternal maintenance, conceptus growth, and maternal protein deposition [13-14]. Phase feeding is commonly employed for pregnant sows, with restricted feeding during early and mid-gestation followed by increased nutrient provision in late gestation. Under production conditions, restricted feeding of pregnant sows is typically implemented through controlled feed intake or reduced dietary nutrient content. The controlled intake method not only limits feed consumption but also ensures a fixed proportion of dietary nutrients for each sow, offering simplicity and widespread application.

During late gestation, fetal growth is rapid, with 70% of birth weight achieved during this period [15], resulting in increased energy and protein requirements. Although pregnant sows have high tolerance to protein and amino acid deficiency

[16], studies have reported that increased protein intake during gestation can improve feed intake and lactation capacity [17]. Adding fat to late gestation diets also helps improve piglet birth weight and survival rate [18].

In pursuit of high piglet birth weight and survival, "fetal attack feeding" is commonly practiced in late gestation. However, due to the anabolic metabolism of pregnancy, sows have enhanced capacity for nutrient deposition. High energy intake increases body fat deposition and excessive weight gain, leading to prepartum obesity, dystocia, reduced lactation feed intake, prolonged weaning-to-estrus interval, impaired lactation performance, and negative effects on subsequent reproductive performance [7].

Obesity induces changes in endocrine hormones such as insulin and leptin, elevating insulin levels and causing insulin resistance. High insulin levels stimulate leptin secretion [19]. Studies have reported that leptin receptor gene mutations in obese mice reduce leptin mRNA expression [20], and most obese patients exhibit leptin resistance [21], which is closely associated with lipid metabolism disorders [22].

Dietary energy is the primary nutritional limiting factor for physiological functions such as growth, reproduction, and lactation [23]. For pregnant sows, late gestation is a critical period for fetal and mammary gland development, with high sensitivity to dietary energy. Energy intake during gestation also affects subsequent lactation performance, making appropriate energy provision essential for optimizing reproductive and lactation performance. Increased energy provision during gestation enhances piglet birth weight, thereby improving survival rates and subsequent weaning weights [24], with a linear relationship between energy intake and piglet birth weight in multiparous sows [25]. Different energy feeding levels during gestation have no significant effect on litter size [26], but increasing energy feeding level reduces feed intake during lactation [27]. Our results confirm that elevated energy feeding level in late gestation significantly decreased average daily feed intake during lactation. Low feed intake during lactation increases body weight loss, reduces milk yield, and prolongs weaning-to-estrus interval [28]. We observed a linear trend for increased piglet birth weight with energy feeding level, though not reaching significance. Multiple factors influence piglet birth weight, and the relatively small number of experimental units in this study may be one limitation. While energy requirements increase during late gestation due to rapid fetal and mammary growth, energy feeding levels should not be excessively high in practice to avoid negative impacts on reproductive performance, lactation, and subsequent reproductive cycles.

Serum biochemical parameters reflect nutritional and metabolic status, indirectly indicating animal growth, development, and health. Fetal development during gestation drives physiological changes in the dam, altering maternal blood biochemical indicators. Blood lipid metabolism indicators (TG, TC, HDL, LDL) reflect energy and lipid metabolism status and are closely related to sow health. High blood TC, TG, and LDL concentrations or low HDL concentration trigger hyperlipidemia, known clinically as dyslipidemia [29].

Blood TG concentration reflects adipose tissue development and deposition. Feeding high-fat diets to sows elevates blood TG and TC concentrations [30]. Van Oort et al. [31] used pigs as a model to study lipoprotein metabolism and found that increased dietary energy raised blood TC concentration. Boars also show elevated blood TG and TC concentrations after high-energy feeding [32]. High blood TG and TC concentrations are early symptoms of lipid metabolism abnormalities, though the upper critical threshold remains unclear [33]. Human dyslipidemia is a major risk factor for cardiovascular disease [8] and can trigger metabolic syndrome including hypertension and hyperglycemia, negatively affecting sow production performance [12]. Our study found that serum TC and TG concentrations in sows at day 100 of gestation showed a quadratic increase with energy feeding level, suggesting that increased energy feeding level in late gestation may induce lipid metabolism abnormalities.

Blood HDL and LDL are closely associated with lipid transport. Adding saturated fatty acids to pregnant sow diets increases serum LDL concentration while decreasing HDL concentration [34]. Overfeeding during gestation causes excessive weight gain, elevating serum TG, TC, and LDL concentrations while reducing HDL concentration [34]. High lipid levels during gestation can trigger postpartum complications and affect offspring health [35]. Reduced serum HDL concentration is a major risk indicator for cardiovascular disease in humans [36]. In first pregnancies, maternal blood HDL concentration does not decrease in late gestation, but with increasing parity, it decreases progressively in subsequent pregnancies [37]. The sows in this study were multiparous (parity 2-6), and serum HDL concentration in late gestation may be influenced by parity, requiring further investigation.

Energy requirements differ across gestation stages, leading to variations in blood lipid metabolism indicators. Serum TG and TC concentrations increase with prolonged gestation [37], with TG, TC, and LDL concentrations significantly higher and HDL concentration significantly lower in late gestation compared with early and mid-gestation [33]. Studies show that pregnant women have higher serum TG, TC, and LDL concentrations and lower HDL concentration than non-pregnant women, with more pronounced differences in late gestation [36]. In our study, serum TC and LDL concentrations decreased with prolonged gestation during late gestation, while HDL concentration at day 107 was significantly lower than at days 85 and 100. TG concentration remained high throughout late gestation, being significantly higher at days 100 and 107 than at day 85. This indicates that serum TG concentration is at a high physiological level while HDL concentration is relatively low during late gestation. Excessive energy provision during this period may increase the risk of lipid metabolism abnormalities, negatively impacting reproductive performance and health.

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Note: Figure translations are in progress. See original paper for figures.