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Article

Impact of piglet birth weight on nitrogen and energy balances in the growth phase

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Abstract:

Low birth weight in pigs may compromise lifelong growth potential and productive performance. An evaluation was done of how birth weight affects nitrogen and energy balances in growing pigs. Assays of nitrogen and energy balances were done of five pairs of sibling piglets (n= 10), each pair consisting of a low birth weight (LBW= 912 ± 40 g) and a normal birth weight (NBW= 1,610 ± 223 g) individual. The pigs were managed normally until 90 days of age, then transferred to metabolic cages for the balance assays. These were done when both pigs attained 50 kg weight and again when they were the same age (when the LBW pig weighed 50 kg). The NBW pigs digested more (*P*<0.05) dry matter at 50 kg and at the same age (86.9 *vs* 86.0). Nitrogen digestibility tended to be higher (*P*<0.10) in the NBW at 50 kg (77.6 *vs* 76.7) and was clearly higher (*P*<0.05) at the same age (78.0 *vs* 76.7). Retained nitrogen as a percentage of intake was higher (*P*<0.01) in the NBW (61.1% *vs* 57.7 %) at the same age, which also occurred (*P* <0.10) for nitrogen retained as a percentage of absorbed nitrogen (78.4 % *vs* 75.2 %). Energy digestibility was higher (P<0.05) in the NBW both at 50 kg (85.1 *vs* 84.1%) and at the same age (P<0.01) (85.4 *vs* 84.1 %). Metabolizable energy was higher in the NBW both at 50 kg (P<0.05) (83.0 *vs* 82.0 %) and at the same age (P<0.01) (83.5 *vs* 82.0 %). The low birth weight piglets were generally less efficient than the normal birth weight pigs.

Key words: Low birth weight, Energy balance, Nitrogen balance, Swine.

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Introduction

The efficiency with which pigs obtain and use energy from feed is possibly determined at birth. Fetal growth is a dynamic process that depends on the harmonious interaction of the mother, the fetus and the placenta. During fetal development the genome plays a limited role(1), meaning fetus growth depends largely on nutrient availability. Genetic selection in pigs has focused on prolificity which has raised the incidence of low-weight births(2-4). Nutrient shortage can impair development of the embryo / fetus or its organs during pregnancy. Because the intrauterine environment modulates expression of the fetal genome it can permanently affect the animal through “fetal programming”(5); for instance, low birth weight animals may suffer inadequate postnatal development. The impact of low birth weight has been studied mainly in muscle and nervous tissue(6-8). These tissues are used because their postnatal development occurs through hypertrophy(9), meaning that, in principle, any negative effects will persist throughout an animal’s life. However, modulation of gene expression in the small intestine and colon can affect various gastrointestinal (GI) tract functions. The affected genes are related to cell metabolism, biosynthesis, signal transduction and cell death(10).

In pigs the GI tract matures physiologically after birth. Changes are mainly induced by the transition from parenteral nutrition to enteral nutrition as well as the presence of a large number of bioactive substances in colostrum and milk(11). Under this scenario the assumption had been that any negative impact of low birth weight on GI tract function would manifest itself only during the early stages of life, however growing evidence suggests negative impacts can continue into adulthood. Piglets have a lower capacity to digest protein than do growth-finishing pigs. This lower digestive capacity is more evident when diet raw materials include vegetal ingredients rich in fiber or anti-nutritional factors(12,13), since no differences between piglets and pigs have been reported when using the highly digestible protein casein(14). However, this type of lower digestive capacity differs from developmentally determined digestive deficiencies since the latter would occur in animals of the same chronological age[10,15].

The present study objective was to compare digestibility and nitrogen and energy balances between low birth weight pigs and normal birth weight pigs in animals of same weight or same age.

Material and methods

The study was carried out at the Metabolic Unit of the National Center for Disciplinary Research (CENID) Physiology of the National Institute of Forestry, Agriculture and Livestock Research (INIFAP). The research protocol was reviewed and approved by the Technical Scientific Committee of CENID Physiology. Animal management practices complied with federal guidelines for the production, care and use of laboratory animals[16], as well as the International Guiding Principles for Biomedical Research Involving Animals[17].

Animals

Five pairs of siblings were chosen (n= 10). Each consisted of one low birth weight (LBW) piglet weighing less than one kilogram at birth (0.912 ± 0.040 kg), and one normal birth weight (NBW) piglet (1.612 ± 0.223 kg) selected from among the siblings weighing nearest the average litter weight. The animals were selected from five litters containing more than twelve live-born piglets. All ten piglets were fed normally and remained on the farm under normal management conditions until ninety days of age. After this period, they were moved to the Metabolic Unit to a room with controlled temperature (19 to 22 °C). Each animal was housed individually in a metabolic cage with a dedicated drinking trough and feeder. A mesh allowed separation and collection of feces, and urine was collected through funnels under the cage floor.

When the NBW pigs had reached 50 kg weight, the first nitrogen and energy balance assays were done, and only involved the NBW animals. Nitrogen and energy balance assays were done of the LBW pigs when they reached 50 kg weight, and the NBW were assayed again. This approach produced data for both groups at 50 kg weight, as well as for both groups at the same age.

Experimental diet and feed management

At the beginning of the adaptation period to the experimental diet and throughout the experimental period the pigs were fed based on their metabolic weight (555 kcal DM x $Kg^{0.60}$); they also became accustomed to consuming the allotted food within one hour[18]. The experimental diet (Table 1) was a sorghum-soybean diet enriched with vitamins and minerals and provided the requirements recommended by the NRC for this productive stage[19].

Table 1: Experimental diet composition and estimated nutrient content (g/kg)

Ingredients		g/kg
Sorghum		731.6
Soybean meal		200.0
Corn oil		24.5
L-Lysine HCl		7.9
L-Threonine		0.9
DL-Methionine		0.9
L-Tryptophan		0.0
Salt		5.0
Calcium carbonate		6.3
Dicalcium phosphate		10.3
Mineral premix		8.0
Vitamin premix		4.5
Chemical analysis:		
Dry matter	%	95.55
Crude energy	Kcal/kg	3,985.00
NDF	%	9.36
ADF	%	4.26
Crude protein	%	14.75
Estimated analysis		
Digestible lysine	%	0.85
Digestible threonine	%	0.52
Digestible sulphur amino acids	%	0.48
Digestible tryptophan	%	0.15
Calcium	%	0.59
Total phosphorous	%	0.52

[a] The trace mineral premix provided the following amounts per kg feed: Co, 0.60 mg; Cu, 14 mg; Fe, 100 mg; I, 0.80 mg; Mn, 40 mg; Se, 0.25 mg; Zn, 120 mg.

[b] The vitamin premix provided the following amounts per kg feed: vitamin A, 4,250 UI/g; vitamin D3, 800 UI/g; vitamin E, 32 UI/g; menadione, 1.5 mg/kg; biotin, 120 mg/kg;

cyanocobalamin, 16 µg/kg; choline, 250 mg/kg; folic acid, 800 mg/kg; niacin, 15 mg/kg; pantothenic acid 13 mg/kg; pyridoxine 2.5 mg/kg; riboflavin 5 mg/kg; thiamin, 1.25 mg/kg.

NDF = Neutral detergent fiber; ADF = Acid detergent fiber.

Nitrogen and energy balance

During the balance assays, water provided to the pigs was limited to 3 L of water per kilo dry matter consumed. This functioned to control water intake for total collection of urine. Each experimental period consisted of five days of adaptation. At the beginning of the experimental period the feed contained a ferric oxide marker included at a rate of 3 g/kg. Total feces collection was done every 12 hours beginning from the moment the feed was marked. On the sixth day (the first day after the experimental period), the feed was again marked with ferric oxide (3 g/kg). Feces collection ended when marked feces was excreted again. All collected feces were stored at -20 °C until processing. Urine was collected twice daily for five days. The urine collection container contained 40 ml 6M HCl to acidify the urine and prevent ammonia loss by volatilization. Each day of the experiment the collected urine was filtered through gauze and fiberglass, weighed, and a 5 % aliquot was taken and stored at -20 °C until analysis.

Laboratory analysis

Feces samples were partially dried at 55 °C and ground in a laboratory mill (Arthur H. Thomas Co., Philadelphia, PA) until passing through a 0.5 mm mesh. Established methods were used to quantify dry matter (DM) content (934.01) and crude protein (CP) (976.05) in the raw materials, experimental diets and feces[(20)]. Energy content was measured with an adiabatic calorimetric pump (model 1281, Parr, Moline, IL). Urine nitrogen content was quantified following an established protocol (976.05)[(20)]. The energy content of lyophilized urine was estimated according to Le Bellego[(21)].

Data analysis

Daily feed intake was recorded to calculate intake of DM (g/day), nitrogen (N) (g/d) and energy (E) (Kcal/day) by multiplying feed intake by each nutrient's diet concentration. Excretion of DM (g/day), nitrogen (g/d) and energy (Kcal/d) in feces was estimated by multiplying the amount of feces produced on a dry basis by the nutrient concentration in the feces. Excretion of nitrogen (g/d) and energy (Kcal/d) in urine was estimated by multiplying the total urine produced by nutrient concentration in the urine. Fecal digestibility of DM, nitrogen and energy was estimated using the following equation proposed by Adeola[22]:

$$ATD = ((NC-NX)/NC)\times 100$$

Where ATD = apparent total digestibility; NC= nutrient consumed (g/d); and NX = nutrient excreted (g/d). Nitrogen retention (g/d) and digestible and metabolizable energy (Kcal/d) were calculated by subtracting the amount of nutrients excreted in feces and urine from the amount of nutrients consumed.

Statistical analysis

Data were analyzed using a completely random block design (each sibling pair was a block) and two comparisons: N and E balances at same weight (50 kg); and N and E balances at same age (when LBW pigs weighed 50 kg)[23]. Statistical analyses were run using the GLM procedure in the SAS statistical package[24]. Significance was set at $P<0.05$, and a trend identified when $0.05<P<0.10$.

Results

Average birth weight differed ($P<0.001$) between the LBW piglets (912 ± 40 g) and the NBW piglets (1,610 ± 223 g) (Table 2). The NBW piglets attained 50 kg weight at 109 days, which is faster ($P<0.001$) than the 127.8 d of the LBW piglets. Resulting daily weight gain (DWG) was 513 g for the NBW pigs and 451 g for the LBW pigs. The difference in average weight between the two pig types at 127.8 d of age was 12.2 kg (63.8 [NBW] *vs* 51.6 kg [LBW]). This difference did not result from the LBW animals suffering any disease or consuming different diets from the NBW pigs during the growth phase. During the balance assays the animals were offered feed at a rate of 555 kcal per $kg^{0.60}$, and feed intake did not differ between groups ($P>0.10$)(545 [NBW] *vs* 540 [LBW] kcal per $kg^{0.60}$); indeed, intake of offered feed ($kg^{0.60}$) was almost the same between the NBW (98.1 %) and LBW (97.2 %). However, the NBW pigs exhibited higher DM digestibility ($P<0.05$) than the LBW pigs both at 50 kg weigh and at the same age.

Table 2: Pig weight at birth and beginning of nitrogen and energy balance assays; kilocalorie intake per metabolic weight and balance; and dry matter digestibility

	Weight		Age		Contrasts		
	NBW[1]	LBW[2]	NBW	LBW	P weight[3]	P age[4]	SEM[5]
Birth weight, kg	1.610	0.912	1.610	0.912	0.001	0.001	0.048
Weaning weight, kg	6.310	3.616	6.310	3.616	0.001	0.001	0.222
ADG, kg	0.513	0.451	0.540	0.451	0.001	0.001	0.008
Weight beginning balance, kg	51.4	51.6	63.8	51.6	NS	0.001	0.554
Age beginning balance (days)	109.0	127.8	127.8	127.8	0.001	NS	1.564
ME intake kcal /$kg^{0.60}$	545.1	540.3	544.9	540.3	NS	NS	3.186
DM intake, g/d	1,729	1,722	1,987	1,722	NS	0.001	14.747
DM excretion, g/d	227	241	261	241	0.10	0.05	4.730
DM digestibility, %	86.9	86.0	86.9	86.0	0.05	0.05	0.255

[1]NBW= normal birth weight group; [2]LBW= low birth weight group; [3]Weight contrast probability; [4]Age contrast probability. [5]SEM= standard error of the mean; ADG= average daily weight; ME = metabolizable energy; DM = dry matter.

NS= not significant (*P*>0.10).

Nitrogen balance

At the same age N intake was higher (*P*<0.001) in the NBW pigs (48.9 g/d) than in the LBW pigs (42.4 g/d) (Table 3). At the same weight (50 kg) N digestibility tended (*P*<0.10) to be higher in the NBW pigs (77.6) than in the LBW pigs (76.7) but at the same age it was significantly higher (*P*<0.05) in the NBW pigs (78.0) than in the LBW pigs (76.7). Nitrogen excretion in urine was 8.3 g N/d in both groups regardless of age and weight (*P*>0.10). At 50 kg the N retained as a percentage of feed intake (57.4 %) did not differ (*P*>0.10) between groups, but at the same age it was higher (*P*<0.01) in the NBW pigs (61.1 %) than in the LBW pigs (57.7 %). This difference remained (*P*<0.10) in the N retained as a percentage of absorbed N, with the NBW pigs having higher values (78.4 %) than the LBW pigs (75.2 %).

Table 3: Nitrogen balance results

	Weight		Age		Contrasts		
	NBW[1]	LBW[2]	NBW	LBW	*P* weight[3]	*P* age[4]	SEM[5]
Nitrogen intake, g/d	43.0	42.4	48.9	42.4	NS	0.001	0.432
Nitrogen in feces, g/d	9.6	9.9	10.8	9.9	NS	0.01	0.176
Digestible nitrogen, %	77.6	76.7	78.0	76.7	0.10	0.05	0.334
Nitrogen absorbed, g/d	33.4	32.5	38.2	32.5	NS	0.001	0.383
Nitrogen in urine, g/d	8.8	8.1	8.3	8.1	NS	NS	0.361
Nitrogen excreted, g/d	18.5	18.0	19.0	18.0	NS	0.05	0.283
Nitrogen retained, g/d	24.6	24.5	29.9	24.5	NS	0.001	0.514
Nitrogen retained, % intake	57.1	57.7	61.1	57.7	NS	0.01	0.719
Nitrogen retained, % absorbed	73.6	75.2	78.4	75.2	NS	0.10	0.999

[1]NBW= normal birth weight group; [2]LBW= low birth weight group; [3]Weight contrast probability; [4]Age contrast probability; [5]SEM= standard error of the mean.

NS= not significant (*P*>0.10).

Energy balance

At the same age energy intake was higher (*P*<0.001) for the NBW pigs (8,289 kcal/day) than the LBW pigs (7,183 kcal/d)(Table 4). At the same weight energy digestibility was higher (*P*<0.05) in the NBW pigs (85.1 %) than in the LBW pigs (84.1 %), which was more significant (*P*<0.01) at the same age (85.4 % [NBW] *vs* 84.1 % [LBW]). The energy excreted in the urine was 153 kcal/day and did not differ (*P*>0.10) between the groups. At 50 kg, metabolizable energy (ME) was higher (*P*<0.05) in the NBW pigs (83.0 %) than in the LBW pigs (82.0 %). At the same age ME differed even more (*P*<0.01) (83.5 % [NBW] *vs* 82.0 % [LBW]).

Table 4: Energy balance results

	Weight		Age		Contrasts		
	NBW[1]	LBW[2]	NBW	LBW	*P* weight[3]	*P* age[4]	SEM[5]
Energy intake, kcal/d	7,212	7,183	8,289	7,183	NS	0.001	63.429
Energy in feces, kcal/d	1,080	1,141	1,211	1,141	0.05	0.01	15.453
Digestible energy, %	85.1	84.1	85.4	84.1	0.05	0.01	0.222
Digestible energy, kcal/kg	3,547	3,508	3,563	3,508	0.05	0.01	9.245
Energy excreted, kcal/d	1,231	1,292	1,370	1,292	0.10	0.05	20.237
Energy in urine, kcal/d	151	151	159	151	NS	NS	6.150
ME, %	83.0	82.0	83.5	82.0	0.05	0.01	0.278
ME, kcal/kg	3,459	3,420	3,483	3,420	0.05	0.01	11.529

[1] NBW= normal birth weight group; [2]LBW= low birth weight group; [3]Weight contrast probability; [4]Age contrast probability; [5]SEM= standard error of the mean; ME= Metabolizable energy;
NS= not significant (*P*>0.10).

Discussion

Growth

Low birth weight (LBW) pigs were lighter at weaning and throughout the growth stage, the result of overall lower daily weight gain. The currently higher frequency of LBW piglets in pig production is due to selection for prolificity in females. This has generated a greater frequency of LBW piglets (<1 kg)[2-4]; indeed, among all domestic species the pig exhibits the highest rate of low weight births[7]. Piglets born with low weight are characterized by a higher mortality rate, lower weight gain during lactation and consequent lower weight at weaning[25]. Their post-weaning growth rate is also lower than siblings born with normal weight[3,25,26], which leads to lower carcass quality[26].

Digestibility

The lower N and E digestibility observed in the LBW piglets has been reported mainly in piglets[11,27-31]. Various explanations for this phenomenon have been proposed and include lower digestive capacity due to a shorter GI tract length and area in piglets[11,28,30]; compromised intestinal histological structure in piglets[10]; lower lactase and aminopeptidase concentrations and smaller pancreas size, which may reduce digestive enzyme secretion capacity[27]; and lower neutral amino acid transporter concentrations[29]. Studies in this area are fewer for growing animals, although there are reports of decreased aminopeptidase enzyme concentrations and a lower relative GI tract weight in pigs[31], and smaller GI tract size in cattle[32].

Energy and nitrogen balances

The LBW pigs exhibited lower nutrient absorption efficiency, as shown by the lower N retention and ME levels in the LBW pigs when both groups were the same age. Perhaps some enzymes and metabolites were altered in the LBW animals consequently affecting intermediate metabolism. For example, increased plasma concentrations of fructosamine and cholesterol in conjunction with low-density lipoproteins have been reported in LBW piglets, indicating a tendency towards insulin resistance in these animals[26]. Low birth weight piglets also exhibit lower serum concentrations of serotonin and tryptophan[33], a lower protein synthesis rate[34], a higher protein degradation rate[35], and a smaller number of muscle cells[2,36-38]. It is not known if these characteristics continue during post-weaning growth. All the aforementioned factors may affect metabolic use of nutrients since lean tissue (protein) deposition capacity is reduced under these conditions. This would imply that weight gain would have a higher metabolic cost, which would agree with the higher relative fat content of these animals[26].

Feed intake

During the balance phase at the same age, feed intake was lower in the LBW, which was a result of the 555 kcal DMS per $kg^{0.60}$ ration for both groups. Nonetheless, LBW pigs also tend to eat less throughout their lives than NBW piglets[6,36-38]. In piglets, feed intake is affected by diet digestibility[39] and LBW animals have lower digestion capacity. Some animals have fewer ghrelin-secreting gastric cells; this hormone stimulates feed intake by generating the hunger sensation[40]. All the above characteristics help explain the lower feed intake observed throughout their lives in the LBW animals.

Conclusions and implications

The low birth weight piglets were generally less efficient than the normal birth weight piglets. This phenomenon is due to the lower nitrogen and energy digestibility, and reduced nitrogen retention, in the low birth weight piglets, which makes weight gain more metabolically expensive.

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