Effects of Maternal Nutrition during Pregnancy on the Body Weight, Muscle Fiber Number, Carcass Traits, and Pork Quality Traits of Offspring*

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ABSTRACT : The purpose of the current study was to examine the influence of different maternal nutrition treatments during pregnancy on body weight, muscle fiber number, carcass traits, and pork quality traits of offspring. A total of 18 crossbred sows (Landrace×Yorkshire×Duroc) were randomly assigned to one of three nutritional treatment groups; control, high energy, and high protein. The control group was fed a standard diet, the high energy group was fed a diet that contained 30% increased metabolizable energy, and the high protein group was fed a diet that contained 30% increased limiting amino acids compared to the control. The sows in each group were fed equal quantities of each diet (1.9 kg/d) for the entire gestational period. A total of 36 piglets from each sow were used to evaluate changes in body weight, muscle fiber number in the *longissimus dorsi* muscle at birth, carcass traits, and pork quality traits. Birth weight of offspring born to sows in the high energy diet group was significantly higher compared to the high protein diet group (p<0.05). However, body weight of offspring after birth was not significantly different between the groups. Muscle fiber number for the *longissimus dorsi* muscle at birth was not significantly different between the groups. In addition, there were no significant differences in carcass traits or pork quality traits between offspring born to sows in the control group and those born to sows that received high energy or high protein diets during pregnancy. Based on these results, it appears that maternal nutrition treatment during pregnancy, regardless of whether it is with high energy or high protein diets, does not have a significant effect on body weight, muscle fiber number at birth, carcass traits, or pork quality traits. (**Key Words:** Maternal Nutrition, High Energy, High Protein, Birth Weight, Muscle Fiber Number, Pork Quality)

INTRODUCTION

Birth weight is an important economic attribute in pig production. Previous studies have shown that birth weight is related to muscle fiber number, growth, and meat quality. Compared to their heavier birth weight littermates, pigs with low birth weight have exhibited low total number of muscle fibers (Wigmore and Stickland, 1983), growth retardation (Rehfeldt and Kuhn, 2006), and reduced weights after birth (Hegarty and Allen, 1978; Powell and Aberle, 1981). In addition, low birth weight pigs had larger muscle fiber areas at slaughter (Gondret et al., 2005) and exhibited

impaired ultimate pork quality defined by greater drip loss and lower tenderness scores compared to their heavier birth weight littermates (Gondret et al., 2005; Gondret et al., 2006; Rehfaldt and Kuhn, 2006).

Muscle fiber number is also important in rearing of animals for commercial purposes, because muscle fiber number is known to be a determinant of muscle mass (Miller et al., 1975; Ryu et al., 2004). Stickland and Handel (1986) suggested that differences in muscle fiber number are responsible for differences in muscle size. Fiedler et al. (1993) showed that low muscle fiber number was correlated with muscle fiber hypertrophy. Moreover, muscle fiber number was positively associated with growth rate (Dwyer et al., 1993; Fahey et al., 2005), and the total number of muscle fibers was also positively related to the proportion of lean meat (Larzul et al., 1997). So, pigs with an ideal number of muscle fibers can maximize commercial profit.

Muscle fibers develop during the fetal stage, and fiber

number is fixed at birth in pigs (Ashmore et al., 1972; Wigmore and Stickland, 1983; Nissen et al., 2003). To achieve the maximal number of muscle fibers, optimal conditions for muscle development are necessary during the fetal stage. Because the fetus is dependent on maternal nutrition during gestation, nutrition of sows during pregnancy may influence muscle fiber number in offspring (Wu et al., 2006). Some studies have documented the positive influence of maternal nutrition on muscle development in offspring (Buitrago et al., 1974; Hegarty and Allen, 1978; Schoknecht et al., 1993; Dwyer et al., 1994), but other studies reported the negative influence of maternal nutrition (Beermann, 1983; Nordby et al., 1987; McCoard et al., 2000).

Therefore, the objective of this study was to examine the influence of various maternal nutrition treatments on body weight, muscle fiber number at birth, carcass traits, and pork quality traits of offspring.

MATERIALS AND METHODS

Animals and maternal nutrition treatments

A total of 18 crossbred sows (Landrace×Yorkshire× Duroc), each in their second parity, were randomly assigned to one of three nutritional treatment groups. The sows in each group were all mated to the same boar. Control sows were fed a standard diet (control), which was given restrictively throughout gestation. One of the two experimental groups was fed a high energy diet (HE), which contained 30% more metabolizable energy per unit weight due to the presence of extra lipid compared to the control diet. The other experimental group was fed a high protein diet (HP), which contained 30% more limiting amino acids (lysine, methionine, threonine, and tryptophane) per unit weight than the control diet. The sows in each group were fed equal amounts of the respective diet (1.9 kg/d) for the entire gestational period. During lactation, all sows were fed a commercial diet specifically designed for lactating sows.

Table 1. Composition of the control diet (basal diet) and the experimental diets (high energy and high protein)

Composition (%)	Control	HE	HP
Corn	52.50	39.38	51.45
Wheat	10.00	7.50	9.80
Tapioca	3.00	2.25	2.94
Wheat bran	17.02	12.77	16.68
Soybean meal	8.00	6.00	7.84
Molasses	4.00	3.00	3.92
Tallow	2.00	1.50	1.96
Sodium chloride	0.30	0.23	0.29
Limestone	0.90	0.68	0.88
Total crude protein	1.40	1.05	1.37
Vitamin	0.10	0.08	0.10
Mineral	0.15	0.11	0.15
Additives	0.50	0.38	0.49
Chlorine chloride (50%)	0.10	0.08	0.10
Powdered fat		16.05	0.62
Soybean meal		5.35	0.00
Soy hull		2.80	0.55
Lysine		0.00	0.19
Methionine		0.04	0.17
Threonine		0.02	0.19
Tryptophan		0.00	0.03
Total crude protein		0.68	0.25
Limestone		0.00	0.00
Vitamin		0.01	0.001
Mineral		0.06	0.004
Total	100.00	100.00	100.00

HE = High energy; HP = High protein.

The composition of diets used during gestation in this study is shown in Table 1 and 2.

Body weight, slaughter procedure, and measurement of loin eye area and back fat thickness

A total 36 of piglets (one male and one female piglet

Table 2. Calculated values of the control and the experimental diets

	Control	HE	HP
Metabolizable energy (kcal/kg)	2,800	3,645	2,805
Crude protein (%)	13.5	13	13.7
Available lysine (%)	0.50	0.55	0.65
Available methionine (%)	0.13	0.15	0.21
Available TSAA (%)	0.25	0.28	0.33
Available threonine (%)	0.30	0.33	0.39
Available tryptophane (%)	0.10	0.11	0.13
Fat (%)	3.00	18.1	3.56
Fiber (%)	5.0	5.0	5.1
Calcium (%)	0.80	0.87	0.88
Available phosphorus (%)	0.40	0.44	0.44

HE = High energy; HP = High protein; TSAA = Total sulfur amino acids.

from each sow) were used to evaluate changes in body weight, muscle fiber number, carcass traits and pork quality traits. Immediately after birth, the weight of newborn pigs was measured before onset of lactation. Within 30 min of birth, muscle samples (about 2.0×2.0×2.0 cm) for histochemical analysis were taken from the middle of *longissimus dorsi* under local anaesthetic. After weaning, piglets were fed a commercial diet for weaned pigs. The treatment conditions for all pigs were similar both before and after slaughter, and all treatment conditions and experimental procedures were approved by the Ministry for Food, Agriculture, Forestry, and Fisheries of Korea. The body weight of the pigs was measured at ages of 3 weeks, 8 weeks, and 16 weeks. The change of body weights of the pigs were expressed as growth rate (kg/d). The pigs were transported to a commercial abattoir under similar conditions and handling, and were slaughtered at similar live weights (105±10 kg). During the winter, the pigs were slaughtered at the slaughter plant following standard procedures under the supervision of the Korean grading service for animal products. The slaughter plant used electrical stunning and a traditional scalding-singeing process. Following electrical stunning, the pigs were exsanguinated, and the carcasses were weighed. The backfat thickness was measured at the 11th and last thoracic vertebra. The mean of these two measurements was used as the backfat thickness. The loin eye area was measured at the level of the last rib.

Muscle fiber number in newborn pigs

Within 30 min of birth, muscle samples were cut into 0.5×0.5×1.0 cm pieces, promptly frozen in isopentane cooled by liquid nitrogen, and stored at -80°C until analysis. Using a cryostat (CM1850, Leica, Germany) at -20°C, serial transverse muscle sections (10 μm) were obtained from each sample and mounted on glass slides. All histochemical samples were examined at a magnification of 100 with an image analysis system that consisted of an optical microscope equipped with a CCD color camera (IK-642K, Toshiba, Japan) and a standard workstation computer (Image-Pro Plus, Media Cybernetics, L.P., USA). All portions of the analyzed sections were free from tissue disruption and freeze-damage; at least 600 fibers per sample were evaluated. Muscle fiber number (fiber number/mm^2) was calculated as the mean number of fibers per mm^2.

Pork quality traits

Muscle pH at 24 h postmortem (pH$_{24\,h}$) was measured directly on the *longissimus dorsi* muscle of carcasses at the 7th/8th thoracic vertebra using a portable pH meter (HM-17MX, TOADKK, Japan). All muscle pH measurements were performed in a cold room.

Pork loin (the 10th-13th thoracic vertebra) was taken from the *longissimus dorsi* muscle of the left side of carcasses for measurements of pork quality traits. In order to evaluate the water holding capacity (WHC) of the muscles, drip loss (Honikel, 1998) and filter-paper fluid uptake (FFU) (Kauffman et al., 1986) were measured. To determine drip loss, meat samples (about 80-100 g) were cut from the pork loin at 24 h postmortem in a 4°C cold room and weighed immediately (initial weight for drip loss). Samples were placed in netting and suspended in an inflated bag, with care taken to ensure that the samples did not contact the bag. After 48 h at 4°C, samples were taken from the bag, gently blotted dry and weighed. Drip loss was expressed as the percentage of the initial sample weight. For FFU, additional samples (about 20 mm thickness chops) were cut from the pork loin at 24 h postmortem in a 4°C cold room and filter-paper (Whatman #2, 42.5 mm in diameter) was pre-weighed. The filter-paper was then placed on the surface (about of the sample for <2 s) and weighed again to determine the amount of absorbed fluids. FFU was expressed as milligrams of exudate absorbed into the filter-paper per unit area (mg/cm^2).

Meat color was measured with a Minolta chromameter (CR-300, Minolta Camera Co., Japan). Samples (about 20 mm thickness chops) were cut from the pork loin at 24 h postmortem in a 4°C cold room and allowed to rest on the table for 30 min at 4°C to expose the surface of the samples to air prior to color measurement. The CR-300 contains a pulsed xenon lamp in the measuring head as a light source, and was calibrated using the calibration plate supplied by the manufacturer. The illuminant used was C, and the standard observer position was 2°. Only the light reflected perpendicular to the specimen surface was collected by the optical fiber cable for color analysis. The average of triplicate measurements was recorded and the results were expressed as Commission Internationale de l'Eclairage (C.I.E, 1978) lightness (L^*), redness (a^*), and yellowness (b^*).

Statistical analysis

A General Linear Model from the SAS Institute (2004) was used to evaluate significant differences between the nutrition treatment groups (control, HE, and HP). For analyzing effect of nutrition treatment, treatment groups and sex were used as class variables. When significant differences (p<0.05) were detected, the mean values were separated at the level of 5%. The results were presented the means with the standard error of means.

RESULTS AND DISCUSSION

Body weight and muscle fiber number of offspring

Table 3 and Figure 1 present the effects of maternal nutrition treatment during pregnancy on body weight and

Table 3. Effect of maternal nutrition treatments during pregnancy on the body weight of offspring

	Control (n = 36)	HE (n = 36)	HP (n = 36)	SEM[1]	Level of significance
Birth (kg)	1.48[ab]	1.56[a]	1.44[b]	0.04	*
Final weight (kg)	105.8	106.7	95.50	7.82	NS
Growth rate (kg/d)	0.93	0.94	0.84	0.07	NS

HE = High energy; HP = High protein; ADG = Average daily gain. Level of significance: NS = Not significant; * $p < 0.05$.

[1] Standard error of means.

[a, b] Means with different superscripts in the same row differ significantly.

muscle fiber number of offspring at birth. There was a significant difference in the birth weight of offspring born to sows treated by different maternal nutrition regimens ($p < 0.05$). Pigs born to sows that received high energy diets during pregnancy presented with significantly heavier birth weight than pigs born to sows that received high protein diets during pregnancy ($p < 0.05$). However, the body weight of offspring at later time points was not influenced by the type of maternal nutrition treatment administered during pregnancy.

Dwyer et al. (1994) reported that high feed energy intake during different periods of pregnancy did not affect average pig birth weights. Nissen et al. (2003) showed similar results indicating that the birth weight of offspring was not affected by high energy feed intake by sows during different periods of pregnancy. On the other hand, according to the results of Bee (2004), high energy treatment of sows during early gestation had a measureable influence on the birth weight of offspring. However, high energy feed during gestation had no effect on the slaughter weight of offspring. Based on these results, maternal nutrition treatment during pregnancy, even high energy treatment, does not appear to have a lasting effect on subsequent body weight of offspring.

When muscle fiber number was measured, no significant difference was detected between pigs born to sows that had received different maternal nutrition treatments (Figure 1). This suggests that high energy and high protein maternal nutrition supplements did not significantly affect muscle fiber development. Previous studies reported that maternal nutrition has no influence or adverse effects on the development of muscle fibers in offspring (Nissen et al., 2003; Bee, 2004; Heyer et al., 2004). Moreover, although there was a significant difference in the ratio of secondary fiber number to primary fiber number, maternal nutrition treatment during pregnancy did not significantly influence the total number of muscle fibers in semitendinosus muscle (Dwyer et al., 1994).

In pigs, developing muscle fibers can be classified into primary and secondary fibers (Swatland, 1975). Primary muscle fibers develop from approximately 25 to 50 d of gestation. The development of secondary muscle fiber begins at around 45 to 50 d of gestation and continues until 85 to 90 d (Ashmore et al., 1973; Swatland and Cassens, 1973; Wigmore and Stickland, 1983; Dwyer et al., 1994). Moreover, secondary muscle fibers are formed using primary muscle fibers as templates, and are reported to be more susceptible to the effects of environmental factors, such as maternal nutrition, than primary fibers (Wigmore and Stickland, 1983; Dwyer and Stickland, 1991; Gatford et
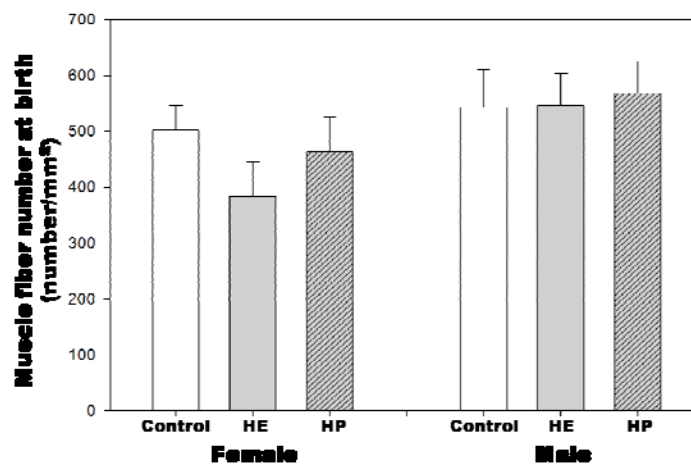
Figure 1. Muscle fiber number of the *longissimus dorsi* muscle of offspring born to sows that received different maternal nutrition treatment during pregnancy. HE = High energy (gray bar with SEM); HP = High protein (hatched bar with SEM).

Table 4. Effect of maternal nutrition treatments during pregnancy on carcass traits and pork quality traits of offspring

	Control (n = 36)	HE (n = 36)	HP (n = 36)	SEM[1]	Level of significance
Carcass traits					
Slaughter weight (kg)	83.05	83.79	75.00	6.09	NS
Loin eye area (cm^2)	54.87	59.82	49.84	4.61	NS
Back fat thickness (mm)	19.25	20.50	18.00	3.40	NS
Pork quality traits					
Muscle pH_{24h}	5.40	5.48	5.48	0.06	NS
Drip loss$_{48h}$ (%)	3.79	2.70	2.66	0.65	NS
FFU (mg/cm^2)	1.33	1.36	1.66	0.20	NS
Lightness	47.41	45.37	45.30	1.06	NS
Redness	7.11	6.99	6.89	0.32	NS
Yellowness	4.06	3.99	3.83	0.19	NS

HE = High energy; HP = High protein; FFU = Filter-paper fluid uptake. Level of significance: NS = Not significant.
[1] Standard error of means.

al., 2003; Nissen et al., 2003). Maternal undernutrition, both prior to and during the period of secondary muscle fiber development in the fetus, reduces the number of secondary muscle fibers in offspring (Dwyer et al., 1994; Gatford et al., 2003). In addition, Nissen et al. (2003) reported that feeding under the required intake level affects myogenesis, whereas feeding at or above the required intake levels has little to no effect on muscle fiber development in the fetus. Therefore, the results of previous and current studies indicate that although high energy diets to sows during pregnancy may influence the number of secondary muscle fibers, especially during the period of secondary muscle fiber development, this treatment does not significantly influence the total number of muscle fibers.

Carcass traits and pork quality traits of offspring

Differences in carcass traits and pork quality traits of offspring born to sows that received different nutritional diets during pregnancy are presented in Table 4. Carcass weight of pigs born to the sows that received high energy or high protein feed during pregnancy were not significantly different from that of pigs born to sows that received control feed during pregnancy. The same tendency was observed with regard to loin eye area and back fat thickness. These results are consistent with the findings of other studies. According to the results of Bee (2004), no significant differences in loin muscle area were observed between pigs born to sows with a high energy intake during early gestation and those born to sows fed a control diet. Heyer et al. (2004) reported that the back fat thicknesses of offspring were not different between pigs born to sows fed a control diet and those provided extra feed during early gestation, regardless of the amount of feed.

A similar tendency was observed in measurements of pork quality (Table 4). There were no significant differences in all measured pork quality traits between pigs born to

sows in any of the nutritional treatment groups. These results also agree with those of previous studies. Nissen et al. (2003) reported no differences in pH, drip loss, or meat color between pigs born to sows in a control group and those from a group that received increased nutrition during gestation. According to Heyer et al. (2004), pH, water holding capacity, and meat color of pigs born to sows with a high feed intake during early gestation were not different than those of pigs born to control feed intake sows. The study by Cerisuelo et al. (2009) also reported similar results.

The histochemical and biochemical properties of a given muscle, such as the number of muscle fibers, the mean area, or the fiber type composition, are important factors that can influence pork quality (Larzul et al., 1997; Karlsson et al., 1999; Ryu and Kim, 2005; Choe et al., 2008). According to Nissen et al. (2003), maternal nutrition treatments should not be expected to have a substantial effect because increased maternal nutrition of sows does not affect the fiber number, fiber area, or fiber type distribution of offspring. In summary, maternal nutrition treatment during pregnancy, regardless of whether it is high energy or high protein, does not have a significant effect on body weight, muscle fiber number at birth, carcass traits, or pork quality traits of offspring.

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