Nutritional Regulation of Within-Litter Body Weight Variation in High-Producing Sows: Postprint

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Abstract

With the advancement of modern breeding technologies, litter size in sows has continually increased; however, this has been accompanied by an increase in within-litter birth weight variation in newborn piglets, resulting in higher pre-weaning mortality and greater weight disparities post-weaning, which has emerged as a primary constraint affecting precise nutritional delivery, management efficiency, and overall production profitability in modern swine production. This review summarizes the factors influencing within-litter birth weight variation in newborn piglets, examines the regulatory roles and underlying mechanisms of energy sources, protein and amino acid levels, and functional additives in mitigating such variation, and provides a theoretical basis for enhancing within-litter uniformity through nutritional strategies.

Full Text

Nutritional Regulation of Within-Litter Weight Variation in Hyperprolific Sows

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Abstract: With the development of modern breeding technology, the live litter size of sows has increased continuously. However, this has been accompanied by greater within-litter birth weight variation, leading to increased pre-weaning mortality and larger discrepancies in weaning weight. These issues have become major limiting factors affecting precise nutritional delivery, management efficiency, and economic returns in modern swine production. This paper reviews the primary factors influencing within-litter birth weight variation in newborn piglets and explores the regulatory effects and potential mechanisms of energy sources, protein and amino acid levels, and functional additives in reducing this variation, providing a reference for improving within-litter uniformity through nutritional approaches.

Keywords: newborn piglets; within-litter weight variation; nutritional regulation

Litter size has long been a core production indicator for measuring sow reproductive efficiency [?]. With advances in modern breeding technology and swine production levels, sow litter size has increased substantially, rising from 11.9 piglets in 1996 to 13.8 in 2006 [?]. Research indicates that sow litter size is negatively correlated with piglet survival rate to weaning, pre-weaning daily gain, and average weaning weight [?]. Additionally, low birth weight piglets experience significantly delayed market times [?]. Within a litter, low-birth-weight piglets exhibit poor competitiveness, struggle to secure productive teats, receive less passive immunity, show reduced resistance to stress and disease, and obtain inadequate nutrient intake [?], all of which adversely affect their survival.

According to reports, when comparing litters of 11 versus 15 piglets, average birth weight decreased from 1.65 kg to 1.42 kg, within-litter birth weight coefficient of variation (CV) increased from 0.160 to 0.187, and pre-weaning survival rate dropped from 91.8% to 74.5% (Table 1) [?]. Moreover, as litter size increases, the proportion of small piglets continues to rise, and piglets with birth weight below 1 kg have minimal survival likelihood from birth to weaning [?]. Meanwhile, low uniformity among newborn piglets leads to large weight variations after weaning, creating extremely unfavorable impacts on precise nutritional delivery, management efficiency improvement, and production benefit enhancement. Therefore, in-depth analysis of factors affecting within-litter birth weight variation and investigation of how nutrients, nutrient sources, and nutritional levels influence piglet birth weight and within-litter uniformity are of paramount importance for advancing modern swine production.

1.1 Genetic Factors

The Meishan pig, a Chinese indigenous breed renowned for high prolificacy, exhibits notably small within-litter birth weight variation despite large litter sizes. This characteristic is associated with higher placental efficiency and larger uterine capacity, as Meishan sows can regulate their own metabolism to inhibit excessive growth of some fetuses and improve fetal homogeneity [?]. Comparative studies across breeds revealed that between days 70 and 110 of gestation, Yorkshire pigs showed 40% increases in placental surface area, weight, and length, whereas Meishan pigs displayed minimal changes in placental dimensions. However, Meishan pigs exhibited increased numbers and diameters of placental blood vessels, doubling vascular density, while Yorkshire pigs showed declining vascular density. Consequently, Meishan sows at day 110 of gestation demonstrated higher fetal-to-placental weight ratios, indicating superior placental efficiency [**?**]. These findings demonstrate that placental efficiency plays a decisive role in within-litter birth weight variation across breeds, and placental angiogenesis and distribution may be crucial factors influencing placental efficiency. This provides important theoretical basis for investigating relationships between nutrition, angiogenesis, and placental efficiency, thereby establishing nutritional regulation theories and technologies to improve newborn piglet uniformity.

1.2 Uterine Position

Research has shown that at day 30 of gestation, fetal weight is independent of uterine position; however, by day 70, lighter fetuses concentrate at the cervical end while heavier fetuses occupy the oviductal end, and this pattern persists through day 104. Notably, placental vascular density increases progressively from the cervix to the uterine horn throughout gestation. As placental blood vessels serve as the hub for material and information exchange between the mother and fetoplacental unit, differential vascular density distribution may be an important cause of fetal weight variation across uterine positions [**?**]. Therefore, in-depth investigation of the relationship between maternal nutrition and placental angiogenesis could provide crucial theoretical support for establishing nutritional strategies to improve newborn piglet uniformity.

1.3 Sow Parity

Studies indicate that while average piglet birth weight is unaffected by parity, within-litter birth weight variation and the proportion of piglets weighing less than 800 g increase gradually with advancing parity. The CVs for within-litter birth weight were 21.3%, 23.2%, and 24.8% for parity 2, 3-4, and 5, respectively, while the proportions of piglets under 800 g were 6.2%, 8.7%, and 13.6% [**?**]. Further research suggests that declining uniformity in newborn piglets with increasing sow age, particularly after parity 5, may be related to changes in follicular development and oocyte quality [**?**].

Collectively, these analyses reveal that breed and uterine position effects on birth weight uniformity likely depend fundamentally on differences in placental angiogenesis and vascular distribution density, whereas parity effects may be associated with follicular development and oocyte quality. Since both follicular development and placental angiogenesis rely on adequate nutrient supply, these findings provide a potential theoretical foundation for improving within-litter uniformity through nutritional interventions.

2 Nutritional Regulation of Within-Litter Weight Variation in Hyperprolific Sows

Nutrition is fundamental to animal survival and reproduction. Current nutritional research on reducing within-litter weight variation in hyperprolific sows has focused primarily on three aspects: energy sources, protein and amino acid levels, and functional additives.

2.1 Energy Sources

Research on energy effects on within-litter birth weight variation has concentrated on energy sources, which are therefore the focus of this discussion.

Studies have shown that during oogenesis, factors affecting porcine embryo survival and development may play a decisive role in oocyte maturation, which subsequently influences embryonic developmental uniformity and potential birth weight variation [**?**]. Therefore, nutritional regulation of sows before mating can substantially reduce within-litter birth weight variation [**?**].

Research demonstrated that supplementing 150 g/d glucose to the diet of sows (Large White × Landrace, parity 1-5) from weaning to estrus significantly reduced birth weight variation [**?**]. The basal diet contained 9.4 MJ/kg net energy (NE) and 156 g/kg crude protein (CP) with 3.5 kg/d feed intake. Another study found that supplementing 25 g/d glucose + 25 g/d lactose during the last week of gestation through pre-weaning, and 150 g/d glucose + 150 g/d lactose post-weaning (lactation diet: 9.5 MJ/kg NE, 16.5% CP; weaning-to-estrus diet: 9.4 MJ/kg NE, 15.8% CP, 3.6 kg/d intake) significantly reduced within-litter birth weight variation in multiparous sows (Topigs 20 and Topigs 30) [**?**]. These results indicate that dietary glucose supplementation benefits within-litter uniformity.

Additional research showed that feeding gilts (Large White × Landrace) diets containing starch, glucose, or animal fat according to isoenergetic and isonitrogenous principles resulted in higher plasma insulin levels in the glucose group compared to the fat group 36 minutes post-feeding, with the starch group intermediate [values of (62.0\$±12.2)$\mu IU/mL$, (9.1±9.1)$\mu IU/mL, and$(43.5±10.1)$\mu IU/mL, respectively].Maximumplas$
 IU/mL for the three groups [**?**]. Similarly, gilts (Large White × Landrace) fed a corn-soybean basal diet with starch (containing 20% corn starch) during the estrous cycle showed higher postprandial plasma insulin levels at 30 minutes on days 14 and 21 compared to the soybean oil group, along with higher ovulation rates, embryo numbers, embryo weights, and placental weights on day 28 of gestation [**?**]. These results demonstrate that feeding diets containing glucose or partial starch substitution during the estrous cycle can regulate serum insulin levels, thereby promoting embryonic uniformity.

However, other studies indicated that feeding multiparous sows (average parity 4.7, Topigs 20) isoenergetic and isonitrogenous diets containing glucose+corn starch, glucose+corn starch+animal fat, or animal fat during the weaning-to-estrus interval showed no significant changes in plasma insulin or insulin-like growth factor I (IGF-I) levels. Further analysis revealed a trend toward separation in plasma insulin levels among groups at 2-3 days post-weaning. Therefore, insulin-stimulating diets (with added starch or glucose) have potential to stimulate insulin secretion post-weaning, but the short weaning-to-estrus interval may prevent effective insulin production [?]. Thus, application of insulin-stimulating diets should focus on the post-lactation period.

Research indicates that in catabolic sows, insulin-stimulating diets may enhance IGF-I production by increasing hepatic growth hormone binding [?]. During lactation, feeding sows diets rich in starch versus fat revealed that starch-fed sows had higher plasma IGF-I levels on days 7, 21, and 22, with an increasing trend on day 3 post-weaning (234 ng/mL vs. 205 ng/mL). Additionally, day 21 plasma IGF-I levels showed a positive correlation trend with luteinizing hormone (LH) pulsatility and concentration on day 22 (weaning), while day 22 plasma IGF-I levels were positively correlated with LH pulsatility and concentration [?]. Furthermore, day 22 (weaning) LH pulsatility was positively correlated with follicle size [?].

Therefore, in modern commercial production, feeding insulin-stimulating diets before mating (20% starch substitution or 150 g/d glucose supplementation) while reducing fat usage can regulate insulin levels, stimulate IGF-I production, increase the number of large follicles, promote early embryonic development, and reduce within-litter weight variation coefficient.

2.2 Protein and Amino Acid Levels

Proteins serve multiple functional and biological roles, including molecular structure, nutritional physiology, enzymatic catalysis, molecular transport, and immune defense, making them crucial for both maternal and fetal growth [?].

2.2.1 Protein Level Studies show that feeding gilts diets containing only 0.5% CP versus 13% CP after mating reduced concentrations of basic amino acids such as arginine (Arg), lysine (Lys), and ornithine (Orn), as well as neutral amino acids including alanine (Ala), glutamine (Gln), glycine (Gly), branched-chain amino acids (BCAAs), proline (Pro), serine (Ser), and threonine (Thr) by 16-30% in placenta and endometrium at days 40 or 60 of gestation. Protein restriction also decreased nitric oxide synthase (NOS) activity, citrulline synthesis, and Orn concentration in placenta and endometrium, potentially reducing maternal capacity to transport nutrients and oxygen to fetuses and negatively affecting fetal uniformity [?]. During early gestation (0-63 days), gilts fed 0.5% CP diets showed significantly reduced placental weight and impaired fetal growth compared to those fed 13% CP diets [?]. Thus, reducing dietary protein levels may diminish maternal ability to transport nutrients and oxygen to fetuses, negatively impacting within-litter birth weight variation.

2.2.2 Arg The Arg family plays important roles in placental vascular regeneration and development, particularly during early gestation [?]. High concentrations of Arg and Orn were found in porcine allantoic fluid during days 35-40 of gestation, a period of rapid placental growth [?]. Supplementing 1.0% Arg to corn-soybean diets [metabolizable energy (ME): 13 MJ/kg, CP: 12.2%, intake: 2 kg/d] of gilts (Camborough 22) at day 30 of gestation increased live litter size and total litter birth weight significantly [?]. Adding 25.5 g/d (0.77%) Arg to barley-wheat diets (NE: 9 MJ/kg, CP: 13.1%, intake: 3.3 kg/d) of sows (Large White × Landrace) at day 77 of gestation significantly reduced birth weight variation [?]. Yang et al. [?] fed sows (Large White × Landrace, parity 2) corn-soybean basal diets [digestible energy (DE): 13.14 MJ/kg, CP: 14.17%, intake: 2.6 kg/d] with 1.0% Arg supplementation from mating day, resulting in increased live litter size and total litter birth weight. From days 30-144 of gestation, supplementing 8 g/d Arg and 12 g/d Gln (total dietary content: 1.1% Arg and 1.8% Gln) to gilt diets (ME: 13 MJ/kg, CP: 12.2%, intake: 2 kg/d) reduced maternal plasma ammonia and urea nitrogen, increased live litter size and weight by 15%, and decreased piglet birth weight variation [?]. These results demonstrate that Arg supplementation in sow diets benefits within-litter uniformity in hyperprolific sows.

2.2.3 BCAAs BCAAs, including leucine (Leu), isoleucine (Iso), and valine (Val), serve as substrates for synthesizing glutamate (Glu) and Arg [?]. Zheng et al. [?] fed 900 mice purified diets supplemented with BCAAs under gestational feed restriction, with Arg and Ala as positive and negative controls, respectively. Results showed significant increases in litter size, embryo weight, and litter weight. Further analysis revealed that the BCAA group enhanced maternal uterine and placental function by increasing embryonic hepatic gluconeogenesis and upregulating expression of IGF-I, uterine estrogen receptor-α (ER-α), progesterone receptor (PR), and placental insulin-like growth factor II (IGF-II), thereby ensuring fetal nutrient supply and promoting fetal uniformity.

2.2.4 Potential Mechanisms of Arg and BCAAs in Regulating Within-Litter Weight Variation The crucial role of Arg in fetal growth and development is well recognized. Arg supplementation increases synthesis of nitric oxide (NO) and polyamines, which play key roles during gestation, including placental vascular regeneration and embryogenesis [?].

Functional amino acids in porcine placenta regulate protein synthesis. Arg is metabolized to Orn and Pro in extra-placental tissues. Within the placenta, Pro degrades to Orn, which synthesizes polyamines via ornithine decarboxylase (ODC). ODC expression requires Gln. Additionally, protein synthesis is regulated by the mammalian target of rapamycin (mTOR) signaling pathway, which is stimulated by Arg, Gln, Leu, and Pro. Arg also stimulates placental NO production by increasing expression of guanosine triphosphate cyclohydrolase I, a key step in NO synthesis [?]. As an important endogenous vasodilator, NO critically regulates uterine and fetoplacental blood flow. Research indicates that NO synergizes with angiogenic factors to promote placental vascular regeneration and increase blood flow velocity, which is vital for placental vascular formation and fetal growth [?].

Arg also serves as a precursor for polyamines and NO [?], playing important roles in fetal muscle development. Early gestation Arg supplementation increases the secondary-to-primary muscle fiber ratio at day 70 of gestation [?]. NO prevents fat deposition and stimulates fatty acid and glucose oxidation in muscle [?]. Polyamines are equally important in cell proliferation and differentiation, regulating fetal muscle fiber and adipocyte growth and development [?]. NO, polyamines, Arg, and other functional amino acids also regulate embryonic and fetal muscle growth via the mTOR signaling pathway [?], all contributing to fetal uniformity.

3 Functional Additives

3.1 Inulin

Inulin, derived from chicory tubers and Jerusalem artichoke, is a mixture of soluble fibers that can be used as a purified soluble fiber source. Studies found that supplementing 1.5% inulin to diets of parity 2-3 sows (Large White × Landrace) under isoenergetic and isonitrogenous conditions significantly reduced within-litter birth weight variation and increased the proportion of piglets weighing 1.0-1.5 kg. Further analysis revealed that inulin supplementation significantly increased serum total superoxide dismutase (T-SOD) and glutathione peroxidase (GSH-Px) activities while reducing malondialdehyde (MDA) levels in both sows and piglets [?]. Richter et al. [?] demonstrated that melatonin supplementation (with free radical scavenging and oxidative pathway regulation functions) in undernourished pregnant rats increased serum manganese superoxide dismutase and GSH-Px expression, significantly improving placental efficiency. This suggests that antioxidant treatment of pregnant mothers may enhance placental function and reduce intrauterine growth retardation (IUGR). Whether improving maternal antioxidant status can enhance placental efficiency and ensure newborn piglet uniformity requires further investigation.

3.2 β-Hydroxy-β-Methylbutyrate (HMB)

HMB, a metabolite of Leu, promotes protein synthesis in skeletal muscle, thereby improving animal performance [?]. Research showed that supplementing 4 g/d HMB to corn-soybean diets of sows (Large White × Landrace, parity 3) from day 35 of gestation until farrowing did not significantly affect total born or live born numbers but significantly reduced stillbirths. Additionally, litter birth weight tended to increase ($P=0.08$), and the proportion of low-birth-weight piglets (<1 kg) decreased from 11.59% to 5.60% [?]. Further analysis revealed that HMB increased mRNA levels of myogenic factors, including muscle regulatory factor 4, myogenic differentiation factor, and IGF-I, which regulate myocyte formation and increase secondary muscle fiber proportion in piglets [?], thereby promoting fetal muscle development. This establishes a solid foundation for further fetal development and benefits fetal uniformity.

3.3 N-Carbamylglutamate (NCG)

NCG, a metabolically stable analog of N-acetylglutamate (NAG) that is an intermediate in the urea cycle for citrulline synthesis from ornithine, activates carbamoyl phosphate synthetase-1, the rate-limiting enzyme in endogenous Arg synthesis, thereby promoting Arg synthesis [?].

Supplementing 0.1% NCG to corn-soybean diets (ME: 13.5 MJ/kg, CP: 14.7%, intake: 2 kg/d) of sows (Large White × Landrace, parity 3.2$±$0.7) at day 90 of gestation significantly increased litter birth weight [?]. Similarly, Jiang et al. [?] fed sows (Large White × Landrace, parity 3-4) 0.1% NCG from mating in corn-soybean diets (DE: 12.55 MJ/kg, CP: 13.68%, intake: 2.4 kg/d), with 1.7% Ala as control. Compared to control, NCG increased live litter size by 0.55 piglets, litter birth weight by 1.39 kg, and individual piglet birth weight by 70 g. Further analysis revealed significantly increased plasma NO concentration on days 30, 60, and 90 of gestation, and significantly elevated total nitric oxide synthase and inducible nitric oxide synthase activities on day 90. As previously discussed, NO critically regulates uterine and fetoplacental blood flow and synergizes with angiogenic factors to promote placental vascular regeneration and accelerate blood flow, which is essential for placental vascular formation and fetal growth. Therefore, NCG provides adequate nutrition to fetuses by increasing blood flow velocity and improving placental efficiency [?], reducing variation in nutrient supply among fetuses and consequently decreasing within-litter birth weight variation [?].

Follicular development and placental efficiency are crucial factors for fetal uniformity and can be regulated through nutritional measures. Feeding insulin-stimulating diets with partial starch substitution before mating in hyperprolific sows can increase plasma IGF-I levels and promote follicular development. Arg or NCG supplementation during gestation can enhance NO production, promote angiogenesis and nutrient transport, and improve placental efficiency. Some functional additives also improve within-litter uniformity, though their mechanisms remain unclear. In conclusion, improving fetal uniformity is critically important for enhancing modern swine production levels and economic benefits, and achieving this through nutritional means is feasible. However, how to implement scientifically sound and rational nutritional strategies requires further in-depth research.

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