Effects of Selenium Source and Vitamin E Level in Gestation and Lactation Diets of Sows on Organ Indices and Serum Hormone Levels in Offspring Piglets

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Abstract

This experiment was conducted to investigate the effects of selenium source and vitamin E level in sow diets on organ indices and serum hormone levels in newborn and weaned piglets. A 2×2 factorial design was employed, with two selenium sources [sodium selenite (SS) and selenium yeast (SY)] both at a supplementation level of 0.30 mg/kg (expressed as selenium), and two vitamin E supplementation levels (30 and 90 IU/kg). A total of 296 multiparous "Landrace × Large White" sows with 3–8 parities were selected and randomly allocated to 4 groups according to the principle of balanced distribution of parity and body condition: 0.30 mg/kg SS + 30 IU/kg vitamin E group, 0.30 mg/kg SS + 90 IU/kg vitamin E group, 0.30 mg/kg SY + 30 IU/kg vitamin E group, and 0.30 mg/kg SY + 90 IU/kg vitamin E group, with 74 replicates per group and 1 sow per replicate. The experimental period lasted from day 1 of mating to weaning of piglets at 21 days of age. On the days of farrowing and weaning, 8 piglets per group (1 piglet per litter, with body weight close to the litter average, and 4 males and 4 females) were selected, weighed, and bled for serum preparation to determine serum insulin (Ins), glucagon (Glu), triiodothyronine (T3), thyroxine (T4), and insulin-like growth factor-1 (IGF-1) levels. Immediately after blood collection, piglets were slaughtered to isolate and weigh the heart, liver, spleen, kidney, pancreas, thymus, and thyroid gland. The results showed that: 1) Compared with SS supplementation, SY supplementation in sow diets had no significant effects on organ indices of newborn piglets ($P>0.05$), but significantly increased the thyroid index of weaned piglets ($P<0.05$), highly significantly decreased the thymus index of weaned piglets ($P<0.01$), and increased serum Ins ($P<0.05$), T3 ($P<0.05$), and IGF-1 levels ($P=0.086$) in newborn piglets, while highly significantly decreasing serum Glu and T4 levels in newborn piglets ($P<0.01$) and significantly decreasing serum

T4 level in weaned piglets (P<0.05). 2) Compared with 30 IU/kg vitamin E supplementation, 90 IU/kg vitamin E supplementation in sow diets increased the pancreas index (P<0.05) and thymus index (P<0.05) of newborn piglets, as well as the spleen index (P<0.01) and pancreas index (P=0.056) of weaned piglets, and significantly decreased serum Glu level in newborn piglets (P<0.05), but had no significant effects on serum hormones in weaned piglets (P>0.05). 3) The thymus index of newborn piglets and serum T4 level of weaned piglets were affected by the interaction between selenium source and vitamin E level in sow diets (P<0.05). It can be concluded that supplementation of different selenium sources and vitamin E levels in sow diets during gestation and lactation affects the development of visceral organs in newborn and weaned piglets, and SY supplementation compared with SS supplementation can increase serum IGF-1, Ins, and T3 levels in newborn piglets; furthermore, SY and vitamin E can promote the conversion of T4 to T3 in serum of weaned piglets through interaction effects.

Full Text

Effects of Dietary Selenium Sources and Vitamin E Levels during Sows' Gestation and Lactation on Organ Indices and Serum Hormone Levels of Their Progeny

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Abstract: This experiment was conducted to investigate the effects of dietary selenium sources and vitamin E levels in sow diets on organ indices and serum hormone levels of neonatal and weaned piglets. A 2×2 factorial design was employed with two selenium sources [sodium selenite (SS) and selenium yeast (SY)] both supplemented at 0.30 mg/kg (as selenium), and two vitamin E supplementation levels (30 and 90 IU/kg). A total of 296 Landrace × Yorkshire multiparous sows (parity 3–8) were randomly allocated to 4 groups according to parity and body condition: 0.30 mg/kg SS + 30 IU/kg vitamin E, 0.30 mg/kg SS + 90 IU/kg vitamin E, 0.30 mg/kg SY + 30 IU/kg vitamin E, and 0.30 mg/kg SY + 90 IU/kg vitamin E. Each group comprised 74 replicates with one sow per replicate. The experimental period spanned from day 1 of gestation to weaning at 21 days postpartum. On the day of farrowing and at weaning, eight piglets per group (one per litter, with body weight close to the litter average and balanced for sex) were selected, weighed, and blood samples were collected to prepare serum for determination of insulin (Ins), glucagon (Glu), triiodothyronine (T3), thyroxine (T4), and insulin-like growth factor-1 (IGF-1) levels. After blood collection, piglets were immediately slaughtered to separate and weigh the heart, liver, spleen, kidney, pancreas, thymus, and thyroid.

The results showed: (1) Compared with SS supplementation, SY supplementa-

tion in sow diets had no significant effect on organ indices of neonatal piglets (P>0.05), but significantly increased the thyroid index of weaned piglets (P<0.05) and extremely significantly decreased the thymus index of weaned piglets (P<0.01). SY also significantly increased serum Ins (P<0.05) and T3 levels (P<0.05) in neonatal piglets, with a trend to elevate IGF-1 levels (P=0.086), while extremely significantly decreasing serum Glu and T4 levels (P<0.01) in neonatal piglets and significantly reducing serum T4 levels (P<0.05) in weaned piglets. (2) Compared with 30 IU/kg vitamin E supplementation, 90 IU/kg vitamin E supplementation significantly increased pancreas and thymus indices in neonatal piglets (P<0.05), extremely significantly increased spleen index (P<0.01), and tended to increase pancreas index (P=0.056) in weaned piglets. High-level vitamin E also significantly decreased serum Glu levels in neonatal piglets (P<0.05) but had no significant effects on serum hormone levels in weaned piglets (P>0.05). (3) Significant interactions between selenium source and vitamin E level were observed for thymus index in neonatal piglets and serum T4 levels in weaned piglets (P<0.05). These findings indicate that different selenium sources and vitamin E levels in sow diets during gestation and lactation affect visceral organ development in neonatal and weaned piglets. Moreover, SY supplementation enhances serum IGF-1, Ins, and T3 levels in neonatal piglets compared with SS, and SY and vitamin E interact to promote the conversion of T4 to T3 in weaned piglets.

Keywords: selenium source; vitamin E level; sow; piglet; organ index; hormone level

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Selenium and vitamin E are essential nutritional factors for animals, exhibiting synergistic, complementary, and potentiating effects on growth, immunity, and antioxidant capacity [1]. Vitamin E scavenges free radicals in cells, while selenium-containing glutathione peroxidase eliminates peroxides, jointly protecting cell membranes from damage [2]. Previous research indicates that as sow parity increases, maternal reserves of selenium and vitamin E gradually decrease, leading to reduced selenium and -tocopherol concentrations in milk [3]. Modern production practices involving early weaning further exacerbate this situation by reducing colostrum and milk intake. Maternal selenium is transferred to piglets primarily through the placenta and mammary gland [4]. Different selenium sources exhibit varying transfer efficiencies; organic selenium demonstrates higher placental transfer efficiency than inorganic selenium, resulting in higher selenium levels in developing fetuses and neonatal piglets [5] and increased fetal body length, weight, and protein content [6]. Organic selenium also shows higher transfer efficiency via lactation [7]. Anan et al. [7] demonstrated through rat studies that organic selenium is more readily transferred to milk than inorganic selenium, and Zhan et al. [8] found that organic selenium increased selenium content in sow colostrum and milk, thereby elevating selenium levels in serum, liver, kidney, pancreas, thymus, thyroid, and muscle of weaned piglets. Sow milk and nursing piglet blood vitamin E concentrations are also influenced by

dietary vitamin E levels [9]. Mahan [10] reported that increasing dietary vitamin E levels (22, 44, and 66 IU/kg) in sow diets elevated -tocopherol content in sow milk and weaned piglet serum. Our research group has previously reported effects of dietary selenium sources and vitamin E levels on sow reproductive performance and antioxidant capacity [11] and on progeny antioxidant status [12]. However, whether these effects relate to the role of different selenium sources and vitamin E levels in piglet organ development and hormonal regulation remains unreported. Therefore, this experiment investigated the effects of dietary selenium sources and vitamin E levels and their interactions on organ indices and serum hormone levels in sow progeny throughout one reproductive cycle.

1.1 Experimental Materials

The selenium yeast used in this experiment was provided by Alltech Inc. (USA) with a guaranteed analysis of 2,000–2,600 mg/kg selenium and 98% organic selenium. Vitamin E was purchased from Zhejiang Xinweipu Additive Co., Ltd., with a guaranteed analysis of 50% DL- -tocopheryl acetate.

1.2 Experimental Design and Management

A 2×2 factorial design was employed with two selenium sources [sodium selenite (SS) and selenium yeast (SY)] both supplemented at 0.30 mg/kg and two vitamin E levels (30 and 90 IU/kg). A total of 296 Landrace × Yorkshire multiparous sows (parity 3–8, average parity 5.13±0.22) were randomly allocated to 4 groups according to parity, body condition, and expected farrowing date: Group 1 (0.30 mg/kg SS + 30 IU/kg vitamin E), Group 2 (0.30 mg/kg SS + 90 IU/kg vitamin E), Group 3 (0.30 mg/kg SY + 30 IU/kg vitamin E), and Group 4 (0.30 mg/kg SY + 90 IU/kg vitamin E). Each group comprised 74 replicates with one sow per replicate.

The feeding trial was conducted at Taishan Wencun Farm of Guangdong Changjiang Food Group from June to December 2013. The farm facilities were complete, and management followed routine farm procedures and conventional immunization protocols. The experimental period spanned from day 1 of gestation to weaning at 21 days postpartum. During early gestation (days 1–50), each sow was fed 2.5 kg/d; during mid-gestation (days 51–84) and late gestation (days 85–112), feed allowance was 2.5–3.5 kg/d (adjusted according to body condition). Sows were transferred to farrowing crates 2 days before parturition and were not fed on the day of farrowing. Feed allowance increased by 1 kg daily thereafter, with ad libitum feeding from day 5 postpartum. Water was available ad libitum throughout the experiment. Within 48 h after birth, cross-fostering was conducted within each group to standardize litter size to 10±1 piglets. Nursing piglets were not provided creep feed.

1.3 Experimental Diets

The basal diets were corn-soybean meal-based and formulated for early gestation, mid-gestation, and late gestation-lactation (day 85 of gestation to day 21 of lactation). All nutrient levels met the requirements for gestating and lactating sows (NRC, 1998). Diet composition and nutrient levels are presented in Table 1 .

Table 1 Composition and nutrient levels of basal diets (air-dry basis)

Items	Early stage of gestation	Mid stage of gestation	Late stage of gestation and lactation
Ingredients, %			
Corn	46.00	46.00	45.00
Wheat bran	26.00	26.00	25.00
Rice bran and hull	10.00	10.00	10.00
Soybean meal	12.50	12.50	15.00
Fish meal	1.00	1.00	1.00
Palm oil	1.00	1.00	1.00
$CaHPO_4$	1.50	1.50	1.50
Limestone	1.20	1.20	1.20
$NaHCO_3$	0.30	0.30	0.30
Anhydrous sodium sulfate	0.20	0.20	0.20
NaCl	0.30	0.30	0.30
Choline chloride (50%)	0.20	0.20	0.20
Vitamin C (95%)	0.05	0.05	0.05
L-Lys · HCl	0.05	0.05	0.05

Items	Early stage of gestation	Mid stage of gestation	Late stage of gestation and lactation
L-Thr	0.02	0.02	0.02
Premix[1]	1.00	1.00	1.00
Total	**100.00**	**100.00**	**100.00**
Nutrient levels[2]			
DE, MJ/kg	12.80	12.80	13.00
Crude protein, %	14.00	14.00	15.00
Ash, %	5.20	5.20	5.30
Ether extract, %	2.80	2.80	3.00
Total P, %	0.70	0.70	0.70
Available P, %	0.45	0.45	0.45
Digestible Lys, %	0.65	0.65	0.70
Digestible Met + Cys, %	0.38	0.38	0.40
Digestible Trp, %	0.14	0.14	0.15
Digestible Thr, %	0.45	0.45	0.48
Vitamin E, IU/kg[3]	30 (90)	30 (90)	30 (90)
Se, mg/kg	0.30	0.30	0.30

[1]The premix provided the following per kg of diet: VA 13,000 IU, VE (30 IU in groups 1 and 3, and 90 IU in groups 2 and 4), VD 4,000 IU, VK 4 mg, VB 4 mg, VB 10 mg, VB 4.8 mg, VB 0.034 mg, nicotinic acid 40 mg, D-pantothenic acid 20 mg, folic acid 2 mg, D-biotin 0.16 mg, Fe (as ferrous sulfate) 80 mg, Cu (as copper sulfate) 5 mg, Zn (as zinc sulfate) 50 mg, Mn (as manganese sulfate) 20 mg, I (as potassium iodide) 0.14 mg, Se 0.30 mg (sodium selenite in groups 1 and 2, and selenium yeast in groups 3 and 4).

[2]Nutrient levels were calculated values.

[3]The calculated vitamin E value outside or inside brackets refers to 30 or 90 IU/kg VE supplemental diet, respectively.

1.4 Measurements

1.4.1 Reproductive Performance Lactation feed intake, total piglets born, piglets born alive, litter birth weight, number weaned, and litter weaning weight were recorded for each group.

1.4.2 Organ Index Determination To assess organ development, eight piglets per group (one per litter, with body weight close to the litter average and balanced for sex) were selected at farrowing and at 21 days postpartum. After weighing, whole blood was collected, and piglets were slaughtered to separate the heart, liver, spleen, kidney, pancreas, thymus, and thyroid. Each organ was weighed, and organ indices were calculated using the formula: Organ index (%) = 100 × fresh organ weight / live body weight before slaughter.

1.4.3 Serum Hormone Level Determination Serum levels of insulin (Ins), glucagon (Glu), triiodothyronine (T3), and thyroxine (T4) in neonatal and 21-day-old weaned piglets were determined by radioimmunoassay (RIA) using kits from Tianjin Jiuding Medical Bioengineering Co., Ltd. and a Keda Zhongjia GC-1200 radioimmunoassay counter. Insulin-like growth factor-1 (IGF-1) levels were measured by enzyme-linked immunosorbent assay (ELISA) using kits from Shanghai Lanji Biotechnology Co., Ltd.

1.5 Statistical Analysis

Data were analyzed using the GLM procedure of SPSS 19.0 software for 2×2 factorial ANOVA. When significant differences were detected, LSD tests were used for multiple comparisons among the four selenium source × vitamin E level combinations. Significance was set at $P<0.05$, with $P<0.01$ considered extremely significant and $P<0.10$ indicating a trend. Data are presented as means ± standard error.

2 Results

2.1 Sow Reproductive Performance

Sow lactation feed intake was not affected by dietary treatments (P>0.10). Compared with inorganic selenium, organic selenium supplementation tended to increase piglets born alive (P=0.082), significantly increased litter birth weight (P=0.023), and tended to increase number weaned (P=0.051). Sow reproductive performance was not significantly affected by dietary vitamin E level or the interaction between selenium source and vitamin E level (P>0.10) (data not shown, see reference [11]).

2.2 Effects of Dietary Selenium Source and Vitamin E Level on Organ Indices of Progeny

As shown in Table 2 , selenium source had no significant effect on heart, liver, spleen, kidney, pancreas, or thymus indices in neonatal piglets (P>0.05). High-level vitamin E supplementation significantly increased pancreas and thymus indices in neonatal piglets (P<0.05). A significant interaction between selenium source and vitamin E level was observed for thymus index in neonatal piglets (P<0.05), with groups 3 and 4 showing significantly higher thymus indices than group 1 (P<0.05).

Table 3 shows that compared with SS, SY supplementation significantly increased thyroid index (P<0.05) and extremely significantly decreased thymus index (P<0.01) in weaned piglets. High-level vitamin E supplementation significantly increased spleen index (P<0.05) and tended to increase pancreas index (P=0.056) in weaned piglets. A trend toward significant interaction between selenium source and vitamin E level was observed for spleen index in weaned piglets (P=0.052).

2.3 Effects of Dietary Selenium Source and Vitamin E Level on Serum Hormone Levels of Progeny

Table 4 demonstrates that compared with SS, SY supplementation significantly increased serum Ins and T3 levels (P<0.05) and tended to increase IGF-1 levels (P=0.086) in neonatal piglets, while extremely significantly decreasing serum Glu and T4 levels (P<0.01). High-level vitamin E supplementation significantly decreased serum Glu levels in neonatal piglets (P<0.05) but had no significant effects on serum IGF-1, Ins, T3, or T4 levels (P>0.05). No significant interaction between selenium source and vitamin E level was observed for serum hormone levels in neonatal piglets (P>0.05).

As shown in Table 5 , SY supplementation compared with SS significantly decreased serum T4 levels in weaned piglets (P<0.05) but had no significant effects on serum IGF-1, Ins, Glu, or T3 levels (P>0.05). Dietary vitamin E level had no significant effect on serum hormone levels in 21-day-old weaned piglets (P>0.05). A significant interaction between selenium source and vitamin E level was ob-

served for serum T4 levels in weaned piglets ($P<0.05$), with group 4 showing significantly lower serum T4 levels than group 1 ($P<0.05$).

3 Discussion

3.1 Effects on Organ Indices

Maternal nutrition during gestation is critical for placental and fetal development. Micronutrient nutrition in pregnant animals affects fetal growth and survival, and deficiencies in growth-required trace elements can impact relative growth and morphological development of fetal and neonatal piglet organs [13]. Organ indices reflect organ development and functional status to some extent and can be used alongside production performance to evaluate the effects of different selenium sources and vitamin E levels. Peng [14] reported that high selenium levels significantly affected the thymus in chicks, with higher selenium levels showing more pronounced inhibitory effects on thymus development in a dose-dependent manner. Li [15] found that supplementing different selenium sources during late gestation and lactation did not significantly affect liver, kidney, pancreas, spleen, or thyroid indices in 28-day-old weaned piglets, but DL-selenomethionine increased thymus index by 36.37% compared with SS. In the current study, different selenium sources had no significant effect on organ indices in neonatal piglets or on heart, liver, spleen, kidney, or pancreas indices in weaned piglets. However, SY significantly increased thyroid index while decreasing thymus index in weaned piglets compared with SS, which partially contradicts Li [15]. This discrepancy may be attributed to the longer experimental period (from day 1 of gestation to day 21 postpartum), as organic selenium has higher transfer efficiency to fetuses via the placenta [6] and to progeny via milk [7] than inorganic selenium. Our previous study found that SY supplementation increased selenium concentrations in colostrum and milk, with thymus selenium content in weaned piglets being 20% higher than in the SS group [12], suggesting that high selenium accumulation in the thymus inhibited its development. Farnworth et al. [16] reported that increasing dietary vitamin E levels tended to decrease fetal kidney weight at day 90 of gestation, consistent with our finding of a decreasing trend in kidney index in neonatal piglets from high vitamin E groups ($P=0.065$). Gao et al. [17] found that vitamin E significantly affected mouse spleen weight, and our results align with this, showing that 90 IU/kg vitamin E significantly increased spleen index in weaned piglets, promoting spleen development. High-level vitamin E also significantly increased pancreas and thymus indices in neonatal piglets, contributing to digestive and immune system maturation. The significant interaction between selenium source and vitamin E level for thymus index in neonatal piglets indicates that either SY or high-level vitamin E supplementation can significantly improve thymus development, thereby increasing piglets born alive in this study.

3.2 Effects on Serum Hormone Levels

Selenium and vitamin E enhance antioxidant capacity, protecting IGF-1-secreting cells from damage and promoting IGF-1 secretion [18]. Gunter et al. [19] reported no significant difference in serum IGF-1 levels between SY and inorganic selenium groups in neonatal and nursing calves, which is consistent with our results. This may be because serum IGF-1 levels are influenced not only by dietary selenium but also by experimental duration, animal age, sex, activity, stress level, nutritional status, and disease [14].

Selenium affects pancreatic endocrine function, with Ins and Glu being major pancreatic hormones. Pancreatic islets are sensitive to oxidative stress due to low superoxide dismutase (SOD) content and abundant endoplasmic reticulum structures. Zhang et al. [20] found that selenium protects islet endocrine cells by preserving endoplasmic reticulum integrity; selenium deficiency impairs islet B and D cell function, reducing serum Ins, C-peptide, and somatostatin levels, which can be alleviated by selenium supplementation. Our results show that SY supplementation significantly increased serum Ins and extremely significantly decreased serum Glu levels in neonatal piglets. This may be because SY has higher placental transfer efficiency [5], and our previous study found that SY supplementation increased pancreatic selenium content by 32.2% and 17.9% in neonatal and weaned piglets, respectively [12], thereby protecting endoplasmic reticulum integrity, promoting Ins secretion, and inhibiting Glu secretion. This facilitates glycogen, fat, and protein synthesis in fetuses, promoting piglet development and increasing litter birth and weaning weights.

Selenium is a crucial component of the deiodinase active center, which converts T4 to T3. Triiodothyronine is the biologically active thyroid hormone, with 5-8 times the activity of T4. Selenium deficiency reduces deiodinase activity, decreasing T3 production and impairing metabolism and growth. Li [15] reported that organic selenium increased serum T3 and decreased T4 levels in weaned piglets compared with inorganic selenium. Our study found that SY significantly increased serum T3 and extremely significantly decreased T4 levels in neonatal piglets, and also significantly decreased T4 levels in weaned piglets, consistent with previous research. The mechanism may involve higher placental [5] and mammary [7] transfer efficiency of SY compared with SS. Our previous study found that SY supplementation significantly increased thyroid selenium content in weaned piglets [12], enhancing pituitary deiodinase activity and promoting conversion of low-activity T4 to high-activity T3, thereby facilitating piglet growth and development.

Dietary vitamin E level had no significant effect on serum IGF-1, Ins, or T3 levels in progeny, possibly because placental transfer of vitamin E to fetuses is limited, and as a fat-soluble vitamin, it is easily stored in piglet tissues, making low levels sufficient for hormone secretion. High-level vitamin E decreased serum Glu levels in neonatal piglets, though the mechanism requires further investigation. The significant interaction between selenium source and vitamin

E level for serum T4 levels in weaned piglets suggests that SY and high-level vitamin E synergistically promote conversion of T4 to T3, jointly enhancing piglet development and increasing number weaned and litter weaning weight in this study.

4 Conclusion

Supplementation of SY and high-level vitamin E in sow diets during gestation and lactation affects visceral organ development in neonatal and weaned piglets. Compared with SS, SY supplementation increases serum IGF-1, Ins, and T3 levels in neonatal piglets. Furthermore, SY and vitamin E interact to promote conversion of T4 to T3 in weaned piglets.

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