Effects of Dietary Pyrroloquinoline Quinone Supplementation on Reproductive Performance and Antioxidant Function in Peripartum Sows: Postprint

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Abstract

This experiment was conducted to compare the effects of pyrroloquinoline quinone (PQQ), vitamin E, and organic selenium on the reproductive performance and antioxidant function of peripartum sows. Forty Large White sows in their third parity with similar body weight and backfat thickness at 90 days of gestation were randomly allocated into 2 groups (n = 20 per group). The control group was supplemented with 60 mg/kg vitamin E and 0.20 mg/kg organic selenium in the basal diet, while the experimental group was supplemented with 1 mg/kg PQQ in the basal diet. The experimental period lasted from day 90 of gestation to day 7 postpartum. The results showed that, compared with the control group, dietary PQQ supplementation had no significant effects on farrowing duration, litter size, number of piglets born alive, litter birth weight, average birth weight of piglets, or average daily gain of piglets at 7 days postpartum ($P > 0.05$), but these parameters were numerically increased. Dietary PQQ supplementation significantly increased serum total superoxide dismutase and glutathione peroxidase activities and reduced glutathione content in newborn piglets and sows ($P < 0.05$), and significantly decreased serum malondialdehyde content ($P < 0.05$), while having no significant effects on serum catalase activity, total antioxidant capacity, or oxidized glutathione content ($P > 0.05$). In conclusion, dietary PQQ supplementation during the peripartum period slightly improved sow reproductive performance compared with vitamin E and organic selenium, and significantly enhanced the serum antioxidant function of peripartum sows and newborn piglets.

Full Text

Effects of Dietary Pyrroloquinoline Quinone Supplementation on Reproductive Performance and Antioxidant Function of Sows in the Perinatal Period

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Abstract: This study was conducted to compare the effects of dietary pyrroloquinoline quinone (PQQ) supplementation versus vitamin E and organic selenium on the reproductive performance and antioxidant function of sows during the perinatal period. Forty Yorkshire sows at 90 days of gestation, all in their third parity with similar body weight and backfat thickness, were randomly allocated into two groups of 20 sows each. The control group received a basal diet supplemented with 60 mg/kg vitamin E and 0.20 mg/kg organic selenium, while the experimental group received the basal diet supplemented with 1 mg/kg PQQ. The trial period spanned from day 90 of gestation to day 7 post-farrowing. The results demonstrated that compared with the control group, dietary PQQ supplementation had no significant effects on sow labor duration, total born number, number of live-born piglets, litter birth weight, average piglet birth weight, or average daily gain of piglets during the first 7 days postpartum ($P > 0.05$), although numerical improvements were observed. However, PQQ supplementation significantly elevated serum total superoxide dismutase (T-SOD) and glutathione peroxidase (GSH-Px) activities as well as reduced glutathione (GSH) content in both newborn piglets and sows ($P < 0.05$), while significantly decreasing serum malondialdehyde (MDA) content ($P < 0.05$). No significant effects were observed on serum catalase (CAT) activity, total antioxidant capacity (T-AOC), or oxidized glutathione (GSSG) content ($P > 0.05$). In conclusion, dietary supplementation with PQQ during the perinatal period, compared to the combination of vitamin E and organic selenium, slightly improved sow reproductive performance and significantly enhanced serum antioxidant function in both sows and their newborn offspring.

Keywords: pyrroloquinoline quinone; perinatal period; sows; reproductive performance; antioxidant function

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Metabolic rates in both the maternal body and fetus accelerate during late gestation, leading to increased production of free radicals [1]. This can cause lipid and protein peroxidation in the mother and impair normal endothelial

cell function [2], subsequently affecting placental function [3], hindering fetal intrauterine development, triggering miscarriage [4,5], and reducing sow longevity [6]. Vitamin E is an essential nutrient with antioxidant functions that works synergistically with selenium [7]. Previous studies have reported that dietary vitamin E supplementation in pregnant sows can improve reproductive efficiency [8] and enhance antioxidant capacity [9]. As a lipid-soluble antioxidant, vitamin E primarily reacts with reactive oxygen species (ROS) radicals and fatty acid peroxidation radicals on biological membranes, generating stable tocopheroxyl radicals and blocking peroxide formation in biomembranes to exert its antioxidant effects [10]. Pyrroloquinoline quinone (PQQ), discovered in the 1970s as a redox enzyme cofactor, possesses multiple physiological functions including growth promotion, antioxidant activity, and immune activation [11], with particularly notable antioxidant properties. PQQ can directly scavenge oxygen and hydroxyl radicals in vivo, demonstrating 50-100 times greater free radical scavenging capacity than ascorbic acid, while also enhancing antioxidant enzyme activities [12]. Additionally, PQQ prevents lipid and protein peroxidation damage caused by mitochondrial oxidative stress [12,13]. Studies by Killgore et al. [14] and Smidt et al. [15] found that PQQ also improves reproductive performance in mammals, as female mice fed PQQ-deficient diets exhibited reduced reproductive capacity. Current research on PQQ has primarily focused on microorganisms, rodents, chickens, and in vitro experiments, with no reported applications in sows. This trial compares the effects of PQQ versus vitamin E and organic selenium on reproductive performance and antioxidant function in perinatal sows to provide reference data for nutritional strategies during this critical period.

1.1 Experimental Materials

PQQ was produced through microbial fermentation with a purity 99.9%, provided by the Shanghai Medical Life Science Research Center. Vitamin E (DL- -tocopheryl acetate, powder form, 50% content) was supplied by DSM (Netherlands), and organic selenium (selenium yeast, 0.2% selenium content) was provided by Alltech (USA).

1.2 Experimental Design and Diets

The experiment was conducted at the breeding farm of Fujian Aonong Modern Agricultural Development Co., Ltd. in Zhangzhou City. Forty Yorkshire sows in their third parity at 90 days of gestation, with similar body weight [(300±15) kg], were randomly divided into two groups: a control group and an experimental group, each comprising 20 sows. Sows were housed in individual gestation stalls.

The basal diet was a corn-soybean meal-based formulation designed according to NRC (2012) [16] standards. The composition and nutrient levels of the basal diet are presented in Table 1 . The control diet consisted of the basal diet supplemented with 60 mg/kg vitamin E (effective content) and 0.20 mg/kg selenium yeast (selenium content). The experimental diet consisted of the basal

diet supplemented with 1 mg/kg PQQ. The trial period extended from day 90 of gestation to day 7 post-farrowing.

During the experimental period, sows were fed at 07:30 and 15:00 daily, with 3 kg of feed per sow and ad libitum access to water. Sows were moved to farrowing crates three days before expected parturition. Both the sow area and piglet activity area featured slatted floors with piglet heating boxes provided. Feed intake was adjusted as follows: 2.0 kg on days 1-2 prepartum, no feed on farrowing day, 0.5 kg on day 1 postpartum, 3.0 kg on day 2, 4.0 kg on day 3, and 4.5 kg from days 4-7 postpartum. Management and disease prevention protocols strictly followed standard commercial sow production procedures.

1.3 Sample Collection

On the day of farrowing, umbilical cord blood was collected from nine piglets per sow. Blood from three piglets with similar birth times was pooled as one sample, yielding three samples per sow (10 mL per piglet, 30 mL per sample). On day 8 postpartum at 09:00, 10 mL of blood was collected from the jugular vein of fasting experimental sows. All blood samples were allowed to clot at 4°C for 30 minutes, then centrifuged at 3,500 rpm for 15 minutes. The resulting serum was collected, aliquoted into 1.5 mL centrifuge tubes, and stored at -20°C until analysis.

1.4 Reproductive Performance Measurements

On the day of farrowing, the total number of piglets born, number of live-born piglets, and labor duration (time interval from first piglet to placenta expulsion) were recorded for each sow. Litter birth weight and average piglet birth weight were measured, and litter weight was recorded on day 8 postpartum to calculate average daily gain of piglets during the first 7 days postpartum.

1.5 Serum Antioxidant Function Assays

Serum total antioxidant capacity (T-AOC), total superoxide dismutase (T-SOD), glutathione peroxidase (GSH-Px), and catalase (CAT) activities, as well as reduced glutathione (GSH), oxidized glutathione (GSSG), and malondialdehyde (MDA) contents were determined using commercial assay kits (Nanjing Jiancheng Bioengineering Institute) according to the manufacturer' s instructions.

1.6 Statistical Analysis

Experimental data are expressed as means ± standard deviation. Intergroup differences were analyzed using Student' s t-test in SPSS 19.0 software, with $P < 0.05$ considered statistically significant.

2.1 Effects of Dietary PQQ Supplementation on Reproductive Performance of Perinatal Sows

As shown in Table 2 , PQQ supplementation had no significant effects on labor duration, total born number, live-born number, litter birth weight, average piglet birth weight, or average daily gain of piglets during the first 7 days postpartum ($P > 0.05$). However, compared with the control group, numerical improvements were observed: total born number increased by 4.5%, live-born number by 1.4%, litter birth weight by 6.14%, average piglet birth weight by 3.62%, and average daily gain during the first 7 days by 21.42%.

2.2 Effects of Dietary PQQ Supplementation on Serum Antioxidant Function in Newborn Piglets and Perinatal Sows

Tables 3 and 4 demonstrate that compared with the control group, dietary PQQ supplementation during the perinatal period significantly increased serum T-SOD and GSH-Px activities and GSH content in both newborn piglets and sows ($P < 0.05$), while significantly decreasing serum MDA content ($P < 0.05$). No significant effects were observed on serum CAT activity, T-AOC, or GSSG content in either newborn piglets or sows ($P > 0.05$).

Due to experimental constraints, this study did not include a blank control group without PQQ, vitamin E, or organic selenium. Instead, the control diet was formulated at conventional commercial sow diet levels with vitamin E and organic selenium supplementation, while the experimental diet contained PQQ. The comparison between these two treatments provides valuable reference for practical production applications. The combination of vitamin E and organic selenium exhibits synergistic antioxidant effects [17] and represents essential nutrients for mammalian growth and development. Vitamin E enhances immunity [18], maintains placental biomembrane integrity, promotes ovarian function, increases follicular luteal cell numbers, and improves reproductive performance [19]. PQQ, currently recognized as the most potent antioxidant substance [12], demonstrated superior advantages in sow production when supplemented at 1 mg/kg compared to the combination of vitamin E (60 mg/kg) and organic selenium (0.20 mg/kg). Further investigation into the application value and optimal supplementation level of PQQ in sow production would be beneficial for improving reproductive performance.

Antioxidant function serves as a crucial indicator of animal health status. Under normal physiological conditions, free radical generation and scavenging maintain dynamic equilibrium. During late gestation, accelerated mammary gland development and fetal growth increase metabolic rates. Reports indicate that DNA oxidative damage in sows at day 110 of gestation is significantly higher than at day 30, while plasma -carotene and -tocopherol concentrations are lower [20], suggesting that oxidative stress levels during late gestation far exceed those in early pregnancy. Therefore, this study utilized multiparous sows in late gestation to evaluate whether PQQ as an antioxidant could provide comparable

efficacy to the vitamin E and organic selenium combination. The results showed that PQQ supplementation significantly increased serum T-SOD and GSH-Px activities and GSH content while decreasing MDA content in both sows and newborn piglets, indicating that PQQ may possess superior antioxidant efficiency in vivo.

Superoxide dismutase (SOD) and GSH-Px are the primary antioxidant enzymes in the body. This study demonstrated that dietary PQQ supplementation not only enhanced the activities of these two antioxidant enzymes but also reduced the oxidative product MDA, consistent with findings from Xu et al. [13], Sun et al. [21], and Zhao [22]. The antioxidant mechanism of PQQ likely involves reducing intracellular oxidative stress, activating mitochondrial synthesis and repair pathways, increasing mitochondrial biogenesis, and maintaining stable mitochondrial function. Zhao [22] and Barhwal et al. [23] reported that PQQ can increase peroxisome proliferator-activated receptor coactivator-1 (PGC-1) gene expression, directly scavenge ROS, and promote nuclear respiratory factor-1 (NRF-1) and nuclear respiratory factor-2 (NRF-2) gene expression. These factors bind to antioxidant response elements (ARE) to promote transcription and expression of antioxidant enzymes including SOD, CAT, and GSH-Px, thereby achieving antioxidant functions. Additionally, Taira et al. [24] reported that PQQ enhances cellular regulatory capacity and increases synthesis of Parkinson' s disease protein 7 (DJ-1) to strengthen mitochondrial repair function. PQQ activates NRF-2 to promote expression of related antioxidant enzymes for ROS clearance and prevention of oxidative damage [25,26]. Unlike vitamin E, which reacts with ROS radicals and fatty acid peroxidation radicals on biomembranes to generate stable tocopheroxyl radicals and block peroxide formation [10], PQQ not only directly scavenges free radicals in biomembranes to prevent lipid peroxidation but also regulates a series of enzymes and factors involved in antioxidant responses to prevent intracellular oxidative damage. This may explain why PQQ' s antioxidant function surpasses that of the vitamin E and organic selenium combination.

The fetus and mother exchange nutrients, metabolites, and bioactive substances through the placenta, which meets fetal growth and development requirements via blood circulation [27]. Therefore, antioxidant function in umbilical cord blood reflects the antioxidant status of newborn piglets to some extent. Vitamin E transfer from sow to fetus through the placenta is very limited, and newborn piglets must rely on colostrum and milk to meet their vitamin E requirements [28]. In this study, changes in serum antioxidant function in PQQ group piglets mirrored those observed in sows, suggesting that the improved antioxidant status in sows mediated by PQQ could be transmitted to piglets. This may represent another difference in how PQQ exerts antioxidant effects compared to vitamin E and organic selenium. Guo et al. [29] reported that dietary ginger powder supplementation in pregnant sows tended to increase serum GSH content in both sows and newborn piglets. Long et al. [30] found that chitosan oligosaccharide supplementation in late gestation improved antioxidant function in both sows and newborn piglets. These findings indicate that nutri-

tional regulation during gestation can provide newborn piglets with a healthy start, offering insights for integrated sow-piglet nutritional strategies.

In summary, dietary supplementation with 1 mg/kg PQQ during the perinatal period, compared to the combination of vitamin E (60 mg/kg) and organic selenium (0.20 mg/kg), did not significantly affect sow reproductive performance but showed slight improvements while significantly enhancing serum antioxidant function in both sows and newborn piglets.

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