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Nano selenium and plant extracts supplementation enhanced reproductive performance of parity-2 sows

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To investigate the effects of nano selenium (nano-Se), curcumin (CUR), and glycyrrhiza extracts (GE) on reproductive performance, antioxidant and immune functions of primiparous sows and parity-2 sows, 54 primiparous sows (Landrace × Yorkshire) were randomly divided into three groups (18 sows per group): (1) CON group, basal diet (0.30 mg·kg^{-1} Se, sodium selenite); (2) CUR group, basal diet + 0.20 mg·kg^{-1} Se (nano-Se) + 300 mg·kg^{-1} CUR; (3) GE group, basal diet + 0.20 mg·kg^{-1} Se (nano-Se) + 500 mg·kg^{-1} GE. The trial lasted for approximately 180 days from day 90 of gestation of primiparous sows to parity-2 sows. There were no significant differences in reproductive performance among three groups ($p > 0.05$), but the litter weight gain of piglets from primiparous sows in the GE group was 16.49% higher than that in the CON group ($p < 0.05$). Compared with the CON group, the serum SOD and GSH-Px levels of primiparous sows in the GE group were significantly increased, and the MDA content was extremely decreased. The concentrations of serum IL-6 and IL-1β ($p < 0.05$) of primiparous sows in the GE group were significantly lower than those in the CON group, and the serum IL-10 and TNF-α concentrations ($p < 0.05$) was significantly higher. The combination of nano-Se and CUR decreased the serum IL-1β level and increased the TNF-α concentration ($p < 0.05$). In conclusion, the addition of nano-Se along with CUR or GE in the diet of primiparous sows significantly increased the antioxidant and immune levels in the serum of primiparous sows at parturition, enhanced their stress resistance, and thus improved growth performance of offspring piglets and reproductive performance of parity-2 sows.

Keywords Nano-selenium, Curcumin, Glycyrrhiza extract, Sow, Immune function

Selenium (Se) is an essential trace element in human and animal life[1]. Nano-Se, as a natural antioxidant with high biological activity, has low toxicity compared to both organic and inorganic Se[2]. Not only can it be absorbed and utilized by human body, but also it can exert the unique antioxidant and immune regulatory functions of organic and inorganic Se[2]. Se can reduce oxidized low-density lipoprotein, reduce lipid deposition on arterial walls, increase the activity of glutathione peroxidase in platelets, and inhibit platelet aggregation[3]. Se also participates in cellular oxidative phosphorylation and energy metabolism, eliminating free radicals while undergoing lipid peroxidation, thereby enhancing the antioxidant capacity of animals[4].

Curcumin (CUR) is a natural substance extracted from plants in the ginger family and is the main active ingredient in turmeric, which has various biological functions such as antibacterial, anti-inflammatory, antioxidant, liver protection, and anti-tumor[5]. It can promote pig growth and improve pork quality. CUR has antibacterial and anti-inflammatory functions, and its main mechanism of action is to inhibit inflammatory factors by inhibiting biological activity related signaling pathways. CUR combines with intracellular free radicals to produce stable phenolic compounds, clearing intracellular free radicals, reducing malondialdehyde content, inhibiting lipid metabolism and oxidation, and improving pork quality[5]. Research has found that CUR can regulate the innate immune system and digestive function of pigs[6]. Adding 200 mg·kg^{-1}CUR to the diet of intrauterine growth retardation (IUGR) piglets may enhance the antioxidant function of live IUGR pigs and alleviate oxidative stress through the Nrf2 signaling pathway[7]. Glycyrrhizic acid (GA) is isolated from the roots

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and rhizomes of licorice and has antiviral, anti-inflammatory, and hepatoprotective effects[8]. GA can maintain the balance of gut microbiota and improve metabolic disorders, promoting healthy growth of piglets.

With the aggravation of metabolic process of sows in the later stage of pregnancy, the reactive oxygen species (ROS) produced in metabolic process is excessive and antioxidant capacity is decreased, resulting in oxidative stress[9]. IUGR piglets usually refer to newborn mammals whose fetal or postpartum growth and development are impaired due to intrauterine dysfunction[10]. Due to the congenital lack of antioxidant system in newborn animals, the physiological oxidative stress occurring during the delivery of mother is easy to be transmitted to offspring, resulting in offspring piglets suffering from more serious oxidative stress[11], thus bearing serious pressure[12]. Previous study found that it could improve the survival ability of IUGR piglets and promote the growth of piglets by improving maternal dietary nutrition[13,14]. Another study also found that the antiviral effect of GA enhanced body's immunity[15], the addition of nano-Se to the mother diet improved the newborn litter weight of offspring piglets[16], and the combination of nano-Se and macleaya cordata extract (MCE) in the sow's diet also enhanced the resistance of newborn IUGR piglets[17]. However, there is a lack of research on whether the combination of maternal nano-Se and CUR or glycyrrhiza extract (GE) can promote the reproductive performance of sows and the growth of offspring piglets, or it have a continuation effect on next birth.

Therefore, the aim of this study is to investigate the effects of the combination of nano Se and CUR or GE in the diet of primiparous sows on the reproductive performance of first and second litter sows, in order to determine whether the addition of nano Se and CUR or GE to the diet of primiparous sows has a sustained effect on the reproductive performance of next parity.

Materials and methods

All animal procedures were approved by the Institutional Animal Care and Use Committee of Yibin University (2023036) and the experiment was complied with Laboratory animal—Guideline for ethical review of animal welfare (GB/T 35892 – 2018). Also, all the experiments in the manuscript follows the recommendations in the Animal Research Reporting in Vivo Experiments (ARRIVE) guidelines.

Sources of nano-Se, CUR and GE

Nano-Se (> 99%, 30–70 nm particle size, and 45 nm average particle size) was provided by Sichuan Jilongda Group, China. CUR (> 98%) was purchased from a biotechnology company in Guangdong Province, China. GE (> 95%) was purchased from Natural Products Research Lab, Southwest University of Science and Technology, Mianyang, China.

Experimental design

The farm lies in Weining City of Guizhou Province, China. A total of 54 primiparous sows (Landrace × Yorkshire) were randomly divided into three groups (18 sows per group): (1) CON group, basal diet (0.30 mg·kg^{-1} Se, sodium selenite); (2) CUR group, basal diet + 0.20 mg·kg^{-1} Se (nano-Se) + 300 mg·kg^{-1} CUR; (3) GE group, basal diet + 0.20 mg·kg^{-1} Se (nano-Se) + 500 mg·kg^{-1} GE. The trial lasted for approximately 180 days from day 90 of gestation of primiparous sows to next birth.

Feeding management

The animal experiment was conducted in the breeding pig farm from April to October 2023, amounting to approximately 180 days. Sows were raised separately in the pregnancy house (2.0 × 0.6 m) from d 90 to d 107 of pregnancy. At d 7 before delivery, sows were transferred to the delivery room. The delivery bed was made of cast iron leakage plate with an area of 2.1 × 3.6 m, and the piglet incubator area was 55 cm × 105 cm. The temperature in the sow delivery room was in the range of 25–30 ℃, and the humidity was 40–60%. After piglets were weaned at 25 days of age, sows were moved to the limit bar of the pregnancy house (2.0 × 0.6 m). Sows drank freely during the whole experiment. The immunization and disinfection measures were carried out according to the farm regulation. The basic diet for lactating sows referred to Liu et al.[18], while the basal diet for pregnant sows was same as commercial feed purchased from the breeding farm. CUR and GE were added in the form of nutrient packs (diluted to 2 kg with glucose and the daily intake for each sow was calculated, then were added along with the feed). The basal diet of sows was shown in Table 1, and the feeding procedure of sows was shown in Table 2.

Sow and piglet performance

At birth, the number of total piglets, live piglets, healthy piglets, live stillborn, and IUGR piglets (the birth weight of live piglets was less than 0.80 kg) were recorded. The birth interval between the first piglet and the last piglet was recorded, and the farrowing duration (FD) were calculated. Each piglet was weighed at birth. The feed intake of each sow was recorded daily, and the average daily feed intake (ADFI) during lactation was also calculated. The ADFI is equal to the daily feeding amount minus the remaining amount and the amount of wasted feed.

Sample preparation and analysis

At farrowing, blood samples were randomly collected from the limbal vein of eight sows in each group with vacuum collection vessels containing no anticoagulant, centrifuged at 3,500 r/min for 10 min. Then the serum was separated and stored at – 80 ℃ until further analysis. The levels of superoxide dismutase (SOD), glutathione peroxidase (GSH-Px), malondialdehyde (MDA), interleukin 6 (IL-6), interleukin 10 (IL-10), interleukin 1β (IL-1β), and tumor necrosis factor α (TNF-α) were analyzed using commercial kits (Nanjing Jiancheng Bioengineering Institute, Nanjing, China).

Ingredients	Count, %	Nutrient levels	Count, %
Corn	45.00	DE/(MJ kg^{-1}) ③	13.62
Wheat	10.00	CP, %②	17.88
Wheat bran	10.00	DM, %②	88.68
Soybean meal (CP 43%)	22.00	Ca, %②	0.92
Soybean oil	2.00	P, %②	0.69
Glucose	1.00	Lys, %③	1.01
Fermented soybean meal	5.00	Met + Cys, %③	0.56
Calcium monophosphate	1.50	Tyr, %③	0.66
Calcium carbonate	1.10	Trp, %③	0.19
Premix①	2.00	-	-
NaCl	0.40	-	-
Total	100.00	-	-

Table 1. The basal diet composition and nutrient levels of Sow diets (DM basis). ①The premix provided the following per kg of the diet: Zn 100 mg, Mn 40 mg, Fe 100 mg, Cu 25 mg, Se 0.30 mg, I 0.40 mg; VA 12 000 IU, VD_3 2 000 IU, VE 48 IU, VK_3 0.50 mg, VB_6 2.50 mg, VB_{12} 0.02 mg, VB_1 10 mg, VB_2 5 mg, choline chloride 1000 mg, niacin 25 mg, pantothenic acid 15 mg, folic acid 1.80 mg, riboflavin 6.00 mg, thiamine 1.00 mg, biotin 0.25 mg. ②Nutrient levels were measured values. *DM*, dry matter; *CP*, crude protein;. ③Nutrient levels was calculated values. *DE*, digestive energy.

Pregnancy days	ADFI of diets
d 1 to d 28	2.5–2.8 kg
d 29 to d 89	2.8–3.0 kg
d 90 to d 107	3.0–3.5 kg
d 107 to d 111	3.2–3.5 kg
d 112 to farrowing	decreased by 0.5 kg
Lactation period (d 1-d 25)	Free feeding

Table 2. The feeding procedures of sows during pregnancy and lactation. *ADFI*, average daily feed intake.

Statistical analyses
Statistical analyses were conducted using GLM of SPSS (SPSS, version 23.0, Inc., Chicago, Illinois, USA). Differences among treatment means were determined using the ANOVA test. Variability in the data was expressed as SEM. A probable level of $p < 0.05$ indicated statistical significance.

Results
Reproductive performance of primiparous sows
There were no significant differences on the reproductive performance of primiparous sows among the three groups ($p > 0.05$, Table 3), but the live and healthy piglets in the GE group were 0.83 piglet and 1.17 piglet higher than those in the CON group, respectively. The FDs in the CUR and GE groups were reduced by 33 min and 44 min compared with the CON group, respectively ($p > 0.05$, Table 3).

Reproductive performance of next birth (parity 2)
There were no significant differences on the reproductive performance of next parity among the three groups ($p > 0.05$, Table 4), but the live and healthy piglets in the GE group were 1.14 piglet and 0.68 piglet higher than that in the CON group, respectively. The FDs in the CUR and GE groups were reduced by 25 min and 32 min compared with the CON group, respectively ($p > 0.05$, Table 4).

The growth performance of piglets during lactation
The litter weight and litter weight gain of piglets of primiparous sows during lactation in the GE group were 9.28 kg higher than those in the CON group ($p < 0.05$, Table 5).

The antioxidant capacity in the sow serum
Compared with the CON group, the SOD and GSH-Px levels in the sow serum from the GE group were significantly increased, and the serum MDA content was significantly decreased ($p < 0.05$, Table 6). The combination of nano-Se and CUR increased significantly the serum GSH-Px level in the sow at delivery and decreased significantly the serum MDA content compared with the CON group ($p < 0.05$, Table 6).

Items	CON group	CUR group	GE group	SEM	*p*-value
n	18	18	18	-	-
Total No. of piglets born per litter	11.67	11.61	12.22	0.39	0.780
No. of live piglets born per litter	11.06	11.11	11.89	0.38	0.609
No. of healthy piglets born per litter	9.89	10.44	11.06	0.36	0.415
No. of live stillbirths born per litter	0.50	0.44	0.22	0.14	0.695
No. of old stillbirths born per litter	0.06	0.00	0.00	0.02	0.375
No. of mummy piglets per litter	0.06	0.06	0.11	0.04	0.774
No. of malformation piglets per litter	0.00	0.00	0.00	0.00	-
No. of IUGR piglets born per litter	1.17	0.67	0.83	0.21	0.633
FD (min)	196	163	152	11.64	0.280
Weaning-estrus interval	6.19	6.08	5.75	0.12	0.309

Table 3. The reproductive performance of primiparous sows. *CON group*: basal diet (0.30 $mg{\cdot}kg^{-1}$ Se, sodium selenite); *CUR group*: basal diet + 0.20 $mg{\cdot}kg^{-1}$ Se (nano-Se) + 300 $mg{\cdot}kg^{-1}$ CUR; *GE group*: basal diet + 0.20 $mg{\cdot}kg^{-1}$ Se (nano-Se) + 500 $mg{\cdot}kg^{-1}$ GE. *FD*, farrowing duration. Values within a row with different superscripts differ significantly at $p < 0.05$.

Items	CON group	CUR group	GE group	SEM	*p*-value
n	16	18	18	-	-
Total No. of piglets born per litter	12.75	12.78	14.11	0.46	0.387
No. of live piglets born per litter	11.75	11.78	12.89	0.44	0.486
No. of healthy piglets born per litter	11.38	11.00	12.06	0.38	0.519
No. of live stillbirths born per litter	0.75	0.56	0.78	0.14	0.770
No. of old stillbirths born per litter	0.06	0.06	0.00	0.03	0.589
No. of mummy piglets per litter	0.19	0.39	0.22	0.09	0.610
No. of malformation piglets per litter	0.00	0.00	0.22	0.08	0.397
No. of IUGR piglets born per litter	0.38	0.78	0.83	0.13	0.333
FD (min)	175	150	143	9.55	0.379

Table 4. The reproductive performance of the sows (parity 2). *CON group*: basal diet (0.30 $mg{\cdot}kg^{-1}$ Se, sodium selenite); *CUR group*: basal diet + 0.20 $mg{\cdot}kg^{-1}$ added Se (nano-Se) + 300 $mg{\cdot}kg^{-1}$ CUR; *GE group*: basal diet + 0.20 $mg{\cdot}kg^{-1}$ Se (nano-Se) + 500 $mg{\cdot}kg^{-1}$ GE. *FD*, farrowing duration. Values within a row with different superscripts differ significantly at $p < 0.05$.

Items	CON group	CUR group	GE group	SEM	*p*-value
n (live piglets born per litter)	11.06	11.11	11.89	0.38	0.609
The litter weight of newborn live piglets (kg)	15.78	16.81	16.38	0.58	0.771
The average weight of newborn live piglets (kg)	1.59	1.58	1.44	0.08	0.683
n (weaning piglets born per litter)	9.50	10.22	10.89	0.33	0.226
The litter weight of weaning piglets (kg)	72.06^{b}	77.44^{ab}	81.94^{a}	1.58	0.035
The average weight of weaning piglets (kg)	7.92	7.75	7.85	0.20	0.938
The litter weight gain of piglets during lactation(kg)	56.28^{b}	60.63^{ab}	65.56^{a}	1.54	0.044

Table 5. The growth performance of offspring piglets (parity 1, day 25). *CON group*: basal diet (0.30 $mg{\cdot}kg^{-1}$ Se, sodium selenite); *CUR group*: basal diet + 0.20 $mg{\cdot}kg^{-1}$ Se (nano-Se) + 300 $mg{\cdot}kg^{-1}$ CUR; *GE group*: basal diet + 0.20 $mg{\cdot}kg^{-1}$ Se (nano-Se) + 500 $mg{\cdot}kg^{-1}$ GE. Values within a row with different superscripts differ significantly at $p < 0.05$.

The immune functions in the sow serum

GE in combination with nano-Se decreased significantly the IL-6 and IL-1β levels of the serum in the primiparous sow at delivery, and increased the IL-10 and TNF-α levels in the sow serum ($p < 0.05$, Table 7). CUR in combination with nano-Se decreased significantly the IL-1β level and increased significantly the serum TNF-α level ($p < 0.05$, Table 7).

Items	CON group	CUR group	GE group	SEM	*p*-value
n	8	8	8	-	-
SOD (IU mL^{-1})	383.76[b]	398.85[b]	431.17[a]	7.82	0.020
GSH-Px (IU mL^{-1})	312.62[b]	485.65[a]	496.06[a]	26.16	< 0.001
MDA (nmol mL^{-1})	9.11[a]	7.92[b]	7.64[b]	0.22	0.002

Table 6. The antioxidant function in the serum of primiparous sows at parturition. *CON group*: basal diet (0.30 mg·kg^{-1} Se, sodium selenite); *CUR group*: basal diet + 0.20 mg·kg^{-1} Se (nano-Se) + 300 mg·kg^{-1} CUR; *GE group*: basal diet + 0.20 mg·kg^{-1} Se (nano-Se) + 500 mg·kg^{-1} GE. *SOD*, superoxide dismutase; *GSH-Px*, glutathione peroxide; *MDA*, malondialdehyde. Values within a row with different superscripts differ significantly at $p < 0.05$.

Items	CON group	CUR group	GE group	SEM	*p*-value
n	8	8	8	-	-
IL-6 (mg L^{-1})	55.23[a]	51.44[ab]	49.25[b]	1.20	0.109
IL-10 (mg L^{-1})	354.84[b]	374.78[b]	476.62[a]	18.82	0.003
IL-1β (mg L^{-1})	38.42[a]	31.89[b]	28.35[b]	1.39	0.001
TNF-α (ng L^{-1})	76.52[c]	89.76[b]	101.47[a]	3.29	< 0.001

Table 7. The immune function in the serum of primiparous sows at parturition. *CON group*: basal diet (0.30 mg·kg^{-1} Se, sodium selenite); *CUR group*: basal diet + 0.20 mg·kg^{-1} Se (nano-Se) + 300 mg·kg^{-1} CUR; *GE group*: basal diet + 0.20 mg·kg^{-1} Se (nano-Se) + 500 mg·kg^{-1} GE. *IL-6*, interleukin 6; *IL-10*, interleukin 10; *IL-1β*, interleukin 1β; *TNF-α*, tumor necrosis factor α. Values within a row with different superscripts differ significantly at $p < 0.05$.

Discussion

Reproduction performance of primiparous sows and next birth

Adding an appropriate dose of minerals in the diet is conducive to promoting animal growth and reproduction[11,19]. Se can improve the fertility of female animals and promote the uterus of female animals to be in the best state[20]. In the later stage of pregnancy, females are supplemented with Se, then Se can enter the piglets through the placental barrier or milk, improve the antioxidant capacity of piglets, and thus promote the growth of piglets[13]. Lin et al.[16] found that nano-Se (0.7 mg·kg^{-1} Se) added in the sow diet during late pregnancy and lactation increased significantly the birth weight of piglets. Li et al.[17]found that the combination of nano-Se and MCE in the sow diet during late pregnancy shortened significantly the sow labor process. Liu M[21]. observed that the addition of nano- Se (0.3 mg·kg^{-1} Se) to sow diets increased the weaning litter weight and lactation litter weight gain of piglets. In this experiment, the combination of nano-Se and GE shortened the FDs of sows and increased significantly the litter weight gain of piglets during lactation, indicating that the combination of nano-Se and GE might reduce the oxidative stress of sows during farrowing by improving the resistance of sows, so as to promote the growth of offspring piglets. Adding nano-Se and GE to sows' diets during late pregnancy also significantly improved the litter weight gain of offspring piglets during lactation, which further indicated that nano-Se and GE also had a synergistic effect on piglets. However, the combination of nano-Se and GE in the sow diet during late pregnancy had no significant effect on the reproductive performance of sows, but can enhance the number of live and healthy piglets of primiparous sows and parity-2 sows.

The antioxidant capacity of the sow serum

The antioxidant system of animals is usually in dynamic equilibrium. When the animal body is stimulated and damaged by the external factors, the balance between the body's oxidation system and antioxidant system is out of balance, leading to oxidative stress in animals[22]. Oxidative stress is mainly caused by oxidative reduction dysfunction induced by ROS and reactive nitrogen species (RNS), leading to lipid and protein oxidation, as well as DNA and cell damage[23]. There is evidence to suggest that sow delivery can lead to fetal oxidative stress, which may be related to an imbalance between free radical accumulation and cellular adaptive antioxidant capacity. Antioxidant enzymes are proteins present in the cellular environment that can eliminate free radicals in the body by regulating the activity and quantity of antioxidant enzymes. GSH itself contains thiol groups that are prone to oxidation, and it can quickly and effectively eliminate excessive free radicals in the body. As an important indicator for evaluating the body's oxidative stress status, it is an important factor in measuring the body's antioxidant capacity. MDA is an important indicator reflecting endogenous lipid peroxidation in the body. SOD and GSH-Px activities, as well as MDA content, can reflex the level of antioxidant capacity and the degree of cell damage[24,25]. In vivo, SOD and GSH-Px can remove superoxide anion[26], H_2O_2[27], and free radicals[28,29], so as to reduce cell damages.

As an essential trace element for animals, Se is a key element to maintain the normal life activities of organisms, such as reproductive process[30–32]. In addition, Se can also reduce lipid peroxides and hydrogen peroxides, thereby avoiding oxidative damages[33–35]. Nano-Se can specifically inhibit the production of free radicals, maintain the normal morphology of cell membrane, and ensure the normal operation of cells[36]. Research has found that Se can improve the reproductive capacity of female animals and promote their uterus to be in optimal condition[37]. Therefore, Se is commonly used as a nutritional additive for breeding livestock. Natural plant extracts have been widely used in sow production due to their biological functions such as antibacterial activity, immunomodulatory function, antioxidant propety, and growth-promoting effect. CUR is a commonly used traditional Chinese medicine, and as a plant pigment extracted from turmeric, CUR has effects such as promoting growth, antagonizing inflammatory reactions, and antioxidant properties[38]. Adding 750 $mg \cdot kg^{-1}$extracts of lonicera japonica and scutellaria baicalensis extracts to the feed of sows (parity 3–4) increased significantly the number of live and healthy piglets and reduced significantly the number of stillbirths[39].

Nano-Se and CUR or GE have strong antioxidant and free radical scavenging abilities, and can protect cells from damage by inhibiting the production of free radicals[17]. For breeding animals, compared with inorganic Se, organic Se is easier to deposit in the fetus through the animal placenta or milk, which may enhance the immune function of piglets[40]. The previous study showed that the addition of 50–250 $mg \cdot kg^{-1}$GE to the diet of weaned piglets improved the antioxidant capacity of piglets and promoted significantly the animal growth[41]. Supplemental nano-Se increased expression profiles of antioxidant enzymes in the liver and spleen of weanling pigs[42]. Li et al.[17] found that the newborn litter weight of offspring piglets was significantly higher than that from the CON group when nano-Se was used in the feed of sows in the late pregnancy period or in combination with MCE. This study indicated that the addition of nano-Se and GE to the sow's diet during late pregnancy increased significantly the serum SOD and GSH-Px levels, and decreased significantly the MDA content of sows at delivery. Nano-Se and GE might indirectly improve the antioxidant capacity of sows by reducing oxidative stress during delivery, so as to enhance the resistance of offspring piglets. The result was consistent with the increase of litter weight of offspring piglets during lactation, which further indicated that nano-Se and GE improved the growth performance of offspring piglets by improving the ability of sows to resist the oxidative stress.

The immune function of the Sow serum

Infected by foreign pathogens or viruses, inflammation occurs in the body, and the level of pro-inflammatory factor IL-6 in the serum decreases, while anti-inflammatory factors IL-10 and TNF-α levels will slightly increase[43]. Due to the congenital lack of immune antibodies, newborn piglets have a very weak ability to resist external adverse pressure and disease invasion[44]. Inflammation in piglets can cause diarrhea or death, which in turn affects their growth performance and can cause significant economic losses to pig farmers[45]. Due to the immature development of their own immune system, suckling piglets are easily infected by exogenous pathogenic microorganisms, which can cause slow growth or death. The immune level of lactating piglets during lactation is mainly provided by their mother. Therefore, it is particularly important to enhance the resistance of offspring by increasing the immune level of sows. Previous study showed that nano-Se and MCE reduced the level of proinflammatory factors in weaned piglets and improve the immune function of animals[17]. Organic Se can increase the level of endogenous antioxidant enzymes in the mice and increase the levels of immune factors[46]. Adding CUR to the feed of lactating sows can significantly improve the growth performance of piglets and improve their immune functions[47]. Maternal MCE and nano-Se can improve the immune function of IUGR piglets[39]. GE can treat rotavirus-induced enteritis by coordinating antiviral and anti-inflammatory effects[48]. CUR or GE may partially block the release of TNF-α, reduce ROS production, and inhibit the necrotic apoptosis pathway, thereby further reducing inflammation and oxidative damage[49,50]. In this study, the combination of nano-Se and GE or CUR decreased significantly the IL-10 and IL-1β levels in sow's serum, and increased significantly the IL-6 and TNF-α levels in sow's serum. The changes of immune factors in the sow serum indicated that the maternal immune function was improved and transmitted to offspring through milk or blood, thus indirectly improving the immune function, inflammatory response, and the resistance of offspring piglets.

Conclusion

In this study, it was concluded that dietary supplemented with nano-Se and GE in primiparous sow exerted a synergistic effect. This effect was achieved by enhancing the antioxidant function and immune defense of sows, thereby promoting the growth of offspring piglets and improving the reproductive performance of sows in their subsequent litters.

Data availability

The data supporting the conclusions of this article are included within the article.

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Declarations

Competing interests
The authors declare no competing interests.

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