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Original Research Article

Combined yeast culture and organic selenium supplementation during late gestation and lactation improve preweaning piglet performance by enhancing the antioxidant capacity and milk content in nutrient-restricted sows

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A B S T R A C T

This study was conducted to investigate the effects of dietary supplementation with yeast culture (YC) and organic selenium (Se) during late gestation and lactation on reproductive performance, milk quality, piglet preweaning performance, antioxidant capacity, and secretion of immunoglobulin in multiparous sows. A total of 160 healthy cross-bred sows (Landrace × Yorkshire, mean parity 4.1 ± 0.3) were randomly assigned to 4 groups as follows: 1) high nutrient (HN), 3,420 kcal/kg digestible energy (DE) and 18.0% crude protein (CP); 2) low nutrient (LN), 3,240 kcal/kg DE and 16.0% CP; 3) LN + YC, LN diet + 10 g/kg YC; 4) LN + YC + Se, LN diet + 10 g/kg YC + organic Se (1 mg/kg Se). Feeding trials of sows started from d 85 of pregnancy to d 35 of lactation. Compared with sows in the LN group, sows fed the LN + YC + Se diet had greater litter weaning weight, average litter gain, and milk fat content (14-d and 25-d milk) ($P < 0.05$). The content of malonaldehyde (MDA) (colostrum and 14-d milk) was lesser, and the activity of glutathione peroxidase (GSH-Px) (colostrum and 25-d milk) was greater when sows were fed the LN + YC + Se diet, compared with sows fed the LN diet ($P < 0.05$). Supplementation of YC and organic Se in the nutrient-restricted diet improved sows' reproductive performance and pig weaning body weight by enhancing the antioxidant capacity and fat content in milk.

1. Introduction

Yeast culture (YC) is a dried fermented product containing a small amount of active yeast cells and various metabolites. Current studies suggest that YC is a promising alternative to antimicrobial growth promoter (AGP), because of β-glucan and mannan oligosaccharides existing in its cell wall (Ganner and Schatzmayr, 2012). Supplementation of YC has been shown to improve growth performance, increase milk production, and stimulate immune systems in pigs (Van Heugten, Funderburke & Dorton, 2003) and ruminants (Nocek et al., 2011). Furthermore, dietary supplementation of YC has also been shown to improve the digestibility of dry matter, gross energy, and crude protein (CP) in pigs, indicating YC supplementation could improve the dietary feed conversion ratio (Shen et al., 2009). Recently, more attention has been focused on the function of YC in diets of sows. Some studies have reported that yeast products supplementation in gestation and lactation diets of sows increased the litter weight and litter weight gain of weaned

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piglets (Shen et al., 2011), which might be the result of higher amounts of total solids, CP, and γ-globulin in milk of sows supplemented with yeast products (Jurgens et al., 1997).

Selenium (Se) is an important trace nutrient for many different animal species, as it is an essential component of selenoproteins, such as the antioxidative enzyme glutathione peroxidase (GSH-Px) (Brown and Arthur, 2001). Besides playing a vital role in cell antioxidant defense, Se also participates in the reduction of inflammation and immune regulation. In the past few years, several reports highlighted the function of high dose Se supplementation in animals (higher than the up-limit level of selenium [0.5 mg/kg] in Food and Drug Administration [FDA] in USA and standards in China). This level is greater than that required for optimal expression of selenoproteins, but less than maximum tolerable level. In ruminants, feeding Se at supranutritional levels to pregnant or lactating females alleviated heat-induced oxidative stress (Chauhan et al., 2014c), down-regulated inflammatory genes (Chauhan et al., 2014b), and altered colostrum volume and composition including immunoglobulin G (IgG) (Stewart et al., 2013b). Providing Se to the females during gestation and lactation is an effective way to transfer Se to the infants and newborns, because Se can cross the placental barrier and is excreted in colostrum and milk (Stewart et al., 2013b).

Generally, feed cost accounts for approximately 70% of the total cost of animal husbandry. Reasonable reduction of dietary nutrient levels with an increase in nutrient digestibility is a strategy to reduce expenditure and decrease environmental pollution. As mentioned above, YC is a functional feed additive with the ability to increase the digestibility of nutrients in pigs. However, it is unknown if the effects of feeding sows nutrient-limited diets could be ameliorated by supplementation with YC. Furthermore, oxidative stress during gestation and lactation have a strong negative influence on reproductive performance, which might require a stronger antioxidant defense system (like GSH-Px) to protect females from oxidative stress. Therefore, the objective of this study was to determine whether supplementation of dietary YC and Se in nutrient-limited diets during late gestation and lactation could regulate piglet performance, reproductive performance, milk quality, antioxidant capacity, and secretion of immunoglobulin in multiparous sows.

2. Materials and methods

The animal use and care protocol was approved by the South China Agricultural University Animal Care and Use Committee.

2.1. Experimental design

This experiment was conducted as a completely randomized design. A total of 160 multiparous sows (Landrace × Yorkshire, mean parity 4.1 ± 0.3) were allocated equally by parity and body condition to one of 4 groups (40 replicates per group and one sow per replicate) as follows: 1) high nutrient (HN) group, a corn-soybean meal basal diet containing 3,420 kcal/kg digestible energy (DE) and 18.0% CP; 2) low nutrient (LN) group, a corn-soybean meal basal diet containing 3,240 kcal/kg DE and 16.0% CP; 3) LN + YC group, LN diet supplemented with 10 g/kg YC (*saccharomyces cerevisiae*); 4) LN + YC + Se group, LN diet supplemented with 10 g/kg YC (*saccharomyces cerevisiae*) and 1 mg/kg Se (SelenoSource AFTM2000, 2,000 mg/kg, 98% of total Se are organic Se). Yeast culture and Se were supplemented on top of basal formula. Sows were fed the experimental diets from d 85 post-coitus until d 35 postpartum (piglets were weaned at 28 d of age).

2.2. Diets and management

In the HN group, a corn-soybean meal based diet was used and formulated to meet or exceed the nutrient requirements of gestating and lactating sows (NRC, 2012). Compared with the HN group, DE and CP in LN groups were decreased by 180 kcal/kg and 2%, respectively. The composition and nutrient content of basal diets are presented in Table 1. After breeding, sows were housed individually in gestation crates and allowed *ad libitum* access to water. The total daily rations per sow were 3.5 kg from d 85 post-coitus until 112 d post-coitus. At 112 d post-coitus, sows were moved into an environmentally controlled farrowing house, with feed restricted (3.5 kg) until 5 d postpartum. From 5 d postpartum to the end of this experiment (35 d postpartum), sows had *ad libitum* access to experimental diets and water. Creep feed was provided to the piglets from 7 d postpartum. Sows experiencing abnormal health conditions (abortion, severe lameness, metritis, respiratory disease, death, etc.) during the experiment were culled with numbers listed in Table 2. The average temperatures in the farrowing house and the gestation room were 30.8 and 27.2 °C, and the humidity averages were 82.78% and 77.89%, respectively.

2.3. Data and sample collection

Six sows per treatment were randomly selected and 10 mL blood was sampled via ear venipuncture at 85 d post-coitus, and 1, 14 and 25 d postpartum. The same subset of sows was bled at each

Table 1
Ingredients and nutrient content of basal diets (as-fed basis, %).

Item	High nutrient diet	Low nutrient diet
Ingredients		
Maize	58.70	64.42
Soybean meal (42% crude protein)	23.70	19.58
Wheat bran	8.00	8.00
Fish meal (65% crude protein)	2.00	2.00
Palm oil	4.00	2.00
Limestone	1.35	1.35
Dicalcium phosphate	0.75	0.83
Vitamin premix[1]	0.10	0.10
Mineral premix[2]	0.04	0.04
Salt	0.33	0.33
L-Lys·HCl	0.10	0.21
Vitamin E (50%)	0.01	0.01
Biotin (2%)	0.005	0.005
Folic acid (98%)	0.005	0.005
Choline chloride (50%)	0.30	0.30
Phytase	0.02	0.02
Fungicide	0.05	0.05
Antioxidant (ethoxyquin >6.5%, butylated hydroxytoluene > 2.5%)	0.04	0.04
Carrier	0.50	0.71
Total	100.00	100.00
Nutrient content (calculated)		
Digestible energy, kcal/kg	3,420	3,240
Crude protein	18.00	16.00
Calcium	1.02	1.02
Total phosphorus	0.79	0.79
Available phosphorus	0.48	0.49
NaCl	0.41	0.41
Lys	0.96	0.96
Met + Cys	0.58	0.59
Thr	0.62	0.63
Trp	0.21	0.21

[1] Provided the following per kilogram of diet: Fe, 80 mg; Cu, 5 mg; Zn, 51 mg; Mn, 20.5 mg; I, 0.14 mg; Se, 0.15 mg.
[2] Provided the following per kilogram of diet: vitamin A, 13,000 IU; vitamin D_3, 4,000 IU; vitamin E, 60 mg; vitamin K_3, 4 mg; vitamin B_1, 4 mg; vitamin B_2, 10 mg; vitamin B_6, 4.8 mg; vitamin B_{12}, 0.034 mg; niacin, 40 mg; pantothenic acid, 20 mg; folacin, 2 mg; biotin, 0.16 mg.

Table 2
Sample size before and after exclusions from trial.

Item	Groups[1]			
	HN	LN	LN + YC	LN + YC + Se
No. of initial sows	40	40	40	40
Diseases[2]	2	6	6	1
Sows for analysis	38	34	34	39

[1] High nutrient (HN) group: 3,420 kcal/kg digestible energy (DE) and 18.0% crude protein (CP); low nutrient (LN) group: 3,240 kcal/kg DE and 16.0% CP; LN + yeast culture (YC) group: LN diet + 10 g/kg YC; LN + YC + selenium (Se) group: LN diet + 10 g/kg YC + 1 mg/kg Se.
[2] Diseases refer to lameness, metritis, poor health, etc.

time period. The blood was collected in sterile vacutainer tubes and remained at room temperature for 1 h to allow clotting. Samples were centrifuged in a clinical centrifuge at 3,000$\times g$ for 10 min, and the serum was pipetted into micro-tubes. All the serum samples were immediately frozen at −20 °C until subsequent chemical analysis.

After intramuscular injection of 20 IU of oxytocin, samples of colostrum, 14-d milk, and 25-d milk were collected from anterior, middle and posterior teats of the same subset of sows for blood sample collection. Colostrum was sampled within 12 h postpartum. Milk samples were collected into 30 mL tubes and stored at −20 °C until analysis.

The number of piglets born (total, stillborns, live, weak [body weight < 0.8 kg], qualified [number of live piglets minus number of weak piglets]), litter weight at birth, and individual weight at birth were recorded at farrowing. The number of pigs weaned, litter weight and individual pig weight were all recorded at weaning.

2.4. Milk composition

Colostrum and milk samples were analyzed for solids-not-fat, fat, protein, and lactose using a fully automated milk composition analyzer (MilkoScan® FT + Analyzer, Foss, Hillerød, Denmark).

2.5. Immunoglobulin

The concentrations of IgG, immunoglobulin A (IgA) and immunoglobulin M (IgM) IgM were analyzed by turbidimetric inhibition immunoassay in the laboratory of Anda Clinical Inspection Center, Sun Yat-Sen University, using a Hitachi 7600 automatic biochemical analyzer (Hitachi Co., Tokyo, Japan).

2.6. Determination of redox status of serum and milk

Total antioxidant capability (T-AOC), and the activities of superoxide dismutase (SOD), GSH-Px, glutathione (GSH) and malonaldehyde (MDA) in serum and milk were estimated using commercial kits (Nanjing Jiancheng Bioengineering Institute, Nanjing, China), according to the manufacturer's protocols with a V1600 Split Beam Visible Spectrophotometer (Meipuda Co., Shanghai, China). The results were expressed as units per milliliter serum or milk.

2.7. Statistical analysis

Statistical analyses were performed using the General Linear Model procedure of SPSS 17.0 software (SPSS, INC., Chicago, IL, USA) in a completely randomize design. The individual sow and its litter were used as an experimental unit for the analysis of sow and litter performance. Milk composition and redox status in serum and milk were analyzed as repeated measures. Pair-wise tests of hypotheses were done using LSD multiple range analysis. Probabilities less than 0.05 were used for determination of significant differences and probabilities less than 0.10 were considered to represent tendencies among treatments.

3. Results

3.1. Sow reproductive performance

Sow reproductive performance is presented in Table 3. There was little evidence of differences among the 4 groups in the number of pigs born in total, live pigs born, stillbirths, and qualified pigs (P > 0.10). Similarly, treatment differences in pig weight at birth, litter weight at birth, and number of pigs weaned were small and not important (P > 0.10). Compared with pigs from sows in the LN group, there was a trend for individual weaning weights of pigs from sows fed LN + YC diet to be greater (P < 0.10); and litters from sows fed LN + YC + Se diet were greater in litter weaning weight (P < 0.01), pig weaning weight (P < 0.01), average litter gain (P < 0.05) and average daily gain per piglet (P < 0.05) compared to pigs from sows fed the LN diet. Compared with pigs from sows fed HN diet, pigs from sows fed LN + YC + Se diet had greater pig weaning body weight (P < 0.01) and tended to have greater average litter gain (P < 0.10) and average daily pig weight gain (P < 0.10).

3.2. Milk components

The effect of dietary supplementation of YC and organic Se on the composition of colostrum, 14-d milk, and 25-d milk is shown in Fig. 1 Compared with sows in the HN group, sows fed LN and LN + YC diets tended to have less concentrations of protein (9.19% vs. 8.24% and 8.29%, P < 0.10), lactose (12.90% vs. 11.80% and 11.81%, P < 0.10) and solids-not-fat (24.07% vs. 21.80% and 21.87%, P < 0.10) in colostrum. Sows fed LN + YC + Se diet had greater concentrations of milk fat in 14-d (6.88% vs. 7.71%, P < 0.05) and 25-d (5.54% vs. 6.80%, P < 0.05) milk, compared with sows fed LN diet. The concentration of solids-non-fat from 25-d milk in the HN group were greater than that in the LN group (6.18% vs. 5.54%, P < 0.05) and the LN + YC group (6.18% vs. 5.69%, P < 0.10).

3.3. Antioxidant status in colostrum and milk

Fig. 2 shows the effect of yeast culture and organic Se on antioxidant status in colostrum and milk. Compared with sows fed the HN diet, sows fed the LN diet had a trend for decreased activity of SOD in colostrum (356 vs. 326 U/mL, P < 0.10). Compared to sows in the LN group, sows in the LN + YC group had comparatively lower MDA content in colostrum (13.59 vs. 10.98 nmol/mL, P < 0.05) and greater activity of GSH-Px in 25-d milk (79.47 vs. 64.34 U/mL, P < 0.05). Additionally, sows in the LN + YC group tended to have increased activity of SOD in colostrum (326.27 vs. 350.28 U/mL, P < 0.10), compared with the sows in the LN group. Compared with sows in the LN group, the MDA content was less in colostrum (13.59 vs. 9.63 nmol/mL, P < 0.05) and 14-d milk (8.41 vs. 7.01 nmol/mL, P < 0.05) in LN + YC + Se group. When sows were fed LN + YC + Se diet, the activity of GSH-Px was greater in colostrum (146.59 vs. 181.23 U/mL, P < 0.05) and 25-d milk (64.43 vs. 79.47 U/mL, P < 0.05) compared to sows fed the LN diet. Additionally, sows fed the LN + YC + Se diet tended to have decreased MDA content in colostrum (12.30 vs. 9.63 nmol/mL, P < 0.10) compared with sows fed the HN diet.

Table 3
Effects of yeast culture (YC) and supranutritional organic selenium (Se) supplementation during late gestation and lactation on the reproductive performance of sows.

Item	Groups[1]				Pooled SEM	*P* value
	HN	LN	LN + YC	LN + YC + Se		
Parturition						
Total No. of pigs born per litter	11.13	11.21	11.06	10.90	0.21	0.92
No. of live pigs born per litter	10.42	10.47	10.18	10.08	0.19	0.82
No. of stillbirths per litter	0.71	0.74	0.88	0.82	0.08	0.69
No. of qualified piglets	10.30	10.00	9.82	9.64	0.19	0.84
No. of weak pigs per litter	0.26	0.29	0.21	0.31	0.02	0.80
Pig weight at birth, kg	1.57	1.50	1.47	1.55	0.02	0.30
Litter weight at birth, kg	16.29	15.36	14.91	15.24	0.27	0.58
Weaning (21 d of age)						
No. of pigs weaned per litter	8.63	8.38	8.47	8.53	0.16	0.73
Litter weight, kg	50.84^{ab}	47.16^{b}	52.11^{ab}	54.53^{a}	1.22	<0.01
Pig weight, kg	5.86^{b}	5.65^{b}	6.14^{ab}	6.47^{a}	0.09	<0.01
Average litter gain, kg	29.36^{ab}	27.21^{b}	29.72^{ab}	34.17^{a}	1.40	0.03
Average daily gain per piglet, g	150^{ab}	145^{b}	155^{ab}	167^{a}	3.04	0.02

[ab] Means in the same row with different superscripts differ (P < 0.05).
[1] High nutrient (HN) group: 3,420 kcal/kg digestible energy (DE) and 18.0% crude protein (CP); low nutrient (LN) group: 3,240 kcal/kg DE and 16.0% CP; LN + yeast culture (YC) group: LN diet + 10 g/kg YC; LN + YC + selenium (Se) group: LN diet + 10 g/kg YC + 1 mg/kg Se.

3.4. Antioxidant status in serum of sows

The effect of YC and organic Se on antioxidant status in serum of sows is presented in Fig. 3. Sows fed the LN diet had a trend for lower activity of serum GSH-Px at 25 d postpartum (948 vs. 885 U/mL, $P < 0.10$) than sows fed the HN diet. Compared to the sows in the LN group, sows fed the LN + YC diet showed a trend for greater activity of serum SOD at 1 d postpartum (174 vs. 195 U/mL, $P < 0.10$), but there was little evidence of differences in other serum indexes. When compared with the sows in the LN group, sows in the LN + YC + Se group tended to exhibit greater activity of T-AOC at 1 d postpartum (1.57 vs. 2.18 U/mL, $P < 0.10$) and 25 d postpartum (0.99 vs. 1.35 U/mL, $P < 0.10$). Sows in the LN + YC + Se group had trends for comparatively greater GSH concentration at 1 d postpartum (5.80 vs. 6.65 μmol/L, $P < 0.10$) and greater activity of GSH-Px at 25 d postpartum (885.35 vs. 911.61 U/mL, $P < 0.10$) than sows in the LN group. Additionally, compared to sows in the LN group, sows in the LN + YC + Se group had greater SOD activity at 1 d postpartum (174 vs. 198 U/mL, $P < 0.05$) and a trend at 14 d postpartum (141 vs. 154 U/mL, $P < 0.10$).

3.5. Concentrations of immunoglobulin in serum and colostrum

The concentrations of immunoglobulins in serum and colostrum are shown in Fig. 4. There was little evidence of differences in serum IgG concentration among the 4 groups ($P > 0.10$). On d 85 of gestation and d 1, 14, and 25 of lactation, there was little evidence of differences in concentrations of IgG, IgA and IgM in sow colostrum among the groups ($P > 0.10$).

4. Discussion

The performance of breeding sows affects the entire productivity of pig operations. Deficiency in either protein or energy during gestation can have negative effects on sow reproductive performance. It has been demonstrated that sows fed an adequate-energy diet during gestation gained more weight from the start of the experiment to weaning and farrowed heavier pigs than those fed energy-restricted diet (Clawson et al., 1963; Frobish et al., 1966). Furthermore, milk yield in sows is depressed by a deficiency of protein or energy during gestation and lactation and this would be reflected in lower litter weights (Pond, 1973). Similarly, in this study, sows fed the nutrient-limited diet had lower litter weight, which might be caused by the decrease in fat, protein, lactose, and non-fat-milk content in milk. Although we did not measure milk yield, it is reasonable to assume that lower milk yield in the nutrient-limited sows was also a contributing factor. Our research also demonstrated that feeding sows with a nutrient-limited diet had adverse effects on the protein, lactose and solids-not-fat concentrations in colostrum but not in 14-d milk and 25-d milk (except

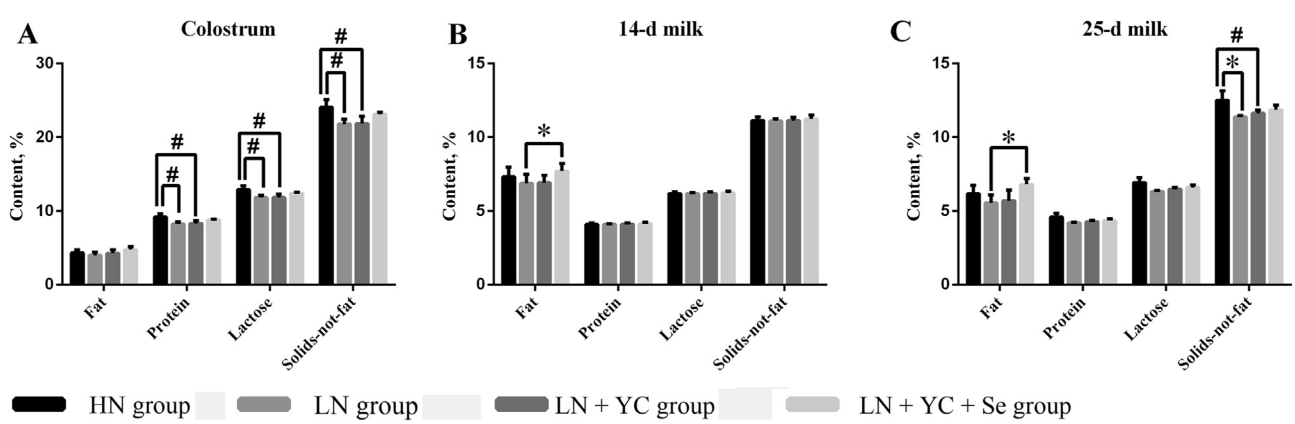

Fig. 1. Effects of dietary supplementation of yeast culture (YC) and supranutritional organic selenium (Se) on the composition of colostrum (A), 14-d milk (B), and 25-d milk (C). High nutrient (HN) group: 3,420 kcal/kg digestible energy (DE) and 18.0% crude protein (CP); low nutrient (LN) group: 3,240 kcal/kg DE and 16.0% CP; LN + YC group: LN diet + 10 g/kg YC; LN + YC + Se group: LN diet + 10 g/kg YC + 1 mg/kg Se. The asterisk (*) indicates that there are significant differences ($P < 0.05$) between 2 groups. Pound sign (#) represents tendencies between 2 groups ($P < 0.10$).

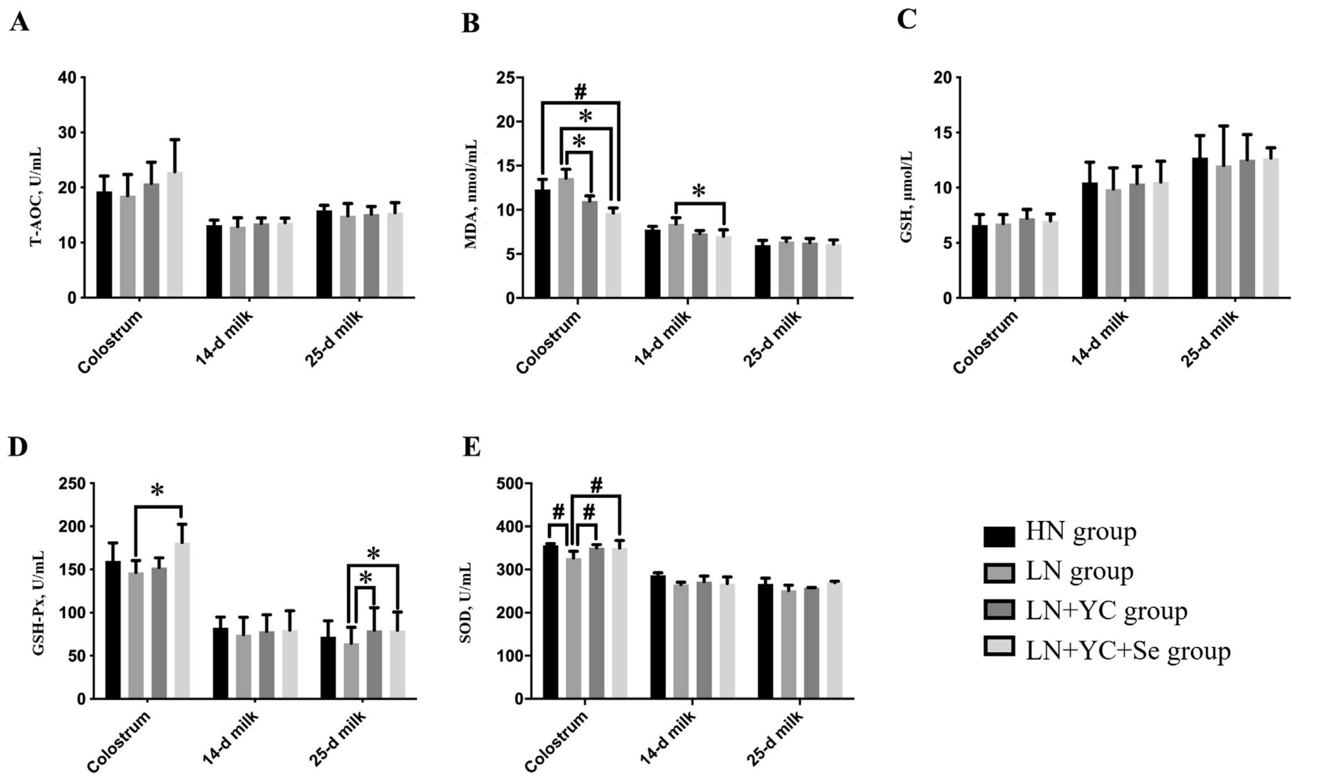

Fig. 2. Effects of dietary supplementation of yeast culture (YC) and supranutritional organic selenium (Se) on T-AOC (A), MDA (B), GSH (C), GSH-Px (D), and SOD (E) in colostrum and milk. T-AOC = total antioxidant capability; MDA = malonaldehyde; GSH = glutathione; GSH-Px = glutathione peroxidase; SOD = superoxide dismutase. High nutrient (HN) group: 3,420 kcal/kg digestible energy (DE) and 18.0% crude protein (CP); low nutrient (LN) group: 3,240 kcal/kg DE and 16.0% CP; LN + YC group: LN diet + 10 g/kg YC; LN + YC + Se group: LN diet + 10 g/kg YC + 1 mg/kg Se. The asterisk (*) indicates that there are significant differences between 2 groups ($P < 0.05$). Pound sign (#) represents tendencies between 2 groups ($P < 0.10$).

the solids-not-fat content in 25-d milk). This might be related to the early limited feed intake of sows (3.5 kg from d 85 post-coitus to 5 d postpartum, ad libitum thereafter). Colostrum was sampled under limited intake, and 14-d milk and 25-d milk were collected during *ad libitum* feeding. Sows appear to maintain the output of energy and protein in milk and protect the offspring against nutritional protein and energy deficiency by mobilizing their own reserves to allow pig survival, unless undergoing severe deficiencies in either class of nutrients (Pond, 1973; Noblet and Etienne, 1986). Thus, the sufficient feed intake after 5 d postpartum might allow sows to mobilize more energy and maintain the nutrient content in 14-d milk and 25-d milk.

Reports in the literature of the effect of YC supplementation on growth performance are inconsistent. Some studies reported supplementation of live yeast or YC improved post-weaning performance (Van Heugten, Funderburke & Dorton, 2003; Shen et al., 2009), whereas one report observed no benefits of YC supplementation (Kornegay et al., 1995). Others reported that yeast product supplementation in gestation and lactation diets of sows increased the litter weight and litter weight gain of weaned piglets (Sungwoo et al., 2008). In this study, YC supplementation in nutrient-limited diet numerically increased the litter weight, pig weight, average litter gain and average daily gain for the piglet. Yeast culture supplementation has resulted in higher contents of total solids, CP, and γ-globulin in milk (Jurgens et al., 1997), which might be partly caused by the increase of nutrient digestibility in the sow. The results from our study agreed with the hypothesis that supplementation of YC in gestation and lactation diets of sows significantly increased the digestibility of ether extract, dry matter, organic matter, and gross energy (unpublished data).

Sufficient Se must be provided to prevent Se-related diseases in animals. High dose organic Se was selected to supplement the sow diet during late gestation and lactation in this trial. Commonly, organic forms of Se have higher bioavailability and antioxidant properties and are more friendly to the environment than inorganic forms of it (Kim and Mahan, 2001). Supplementation of Se at high levels has resulted in an improvement in animal performance and immune function in ruminants (Rooke et al., 2004), which might have been caused by increases of ruminal fermentation and nutrient digestibility (Xun et al., 2012). Maternal nutrition during gestation and lactation plays an important role in neonatal health as it regulates both colostrum volume and composition, which is required for offspring in an early stage (Lilja et al., 1991). High dose of Se has been reported to result in a greater milk yield and higher butterfat, solids-not-fat, lactose and protein content in colostrum (Meyer et al., 2011), which is consist with our results that supplementation of a high dose Se numerically increased solids-not-fat, lactose and protein content in colostrum, and fat content in 14-d milk and 25-d milk.

Supranutritional supplementation has been shown to enhance humoral immune function and increase IgG absorption (Kamada et al., 2007). Stewart et al. (2013a) found supranutritional Se supplementation in diets of ewes and cows during pregnancy increased IgG concentrations in colostrum and promoted IgG transfer from mother to offspring. Additionally, supranutritional Se status has been shown to influence the vascularity of the mammary gland and enhance nutrient content level in milk (Vonnahme et al., 2011). However, in this study, no difference was observed in concentrations of IgG, IgA and IgM in colostrum and sow serum when supranutritional Se was supplemented in the diet. Species

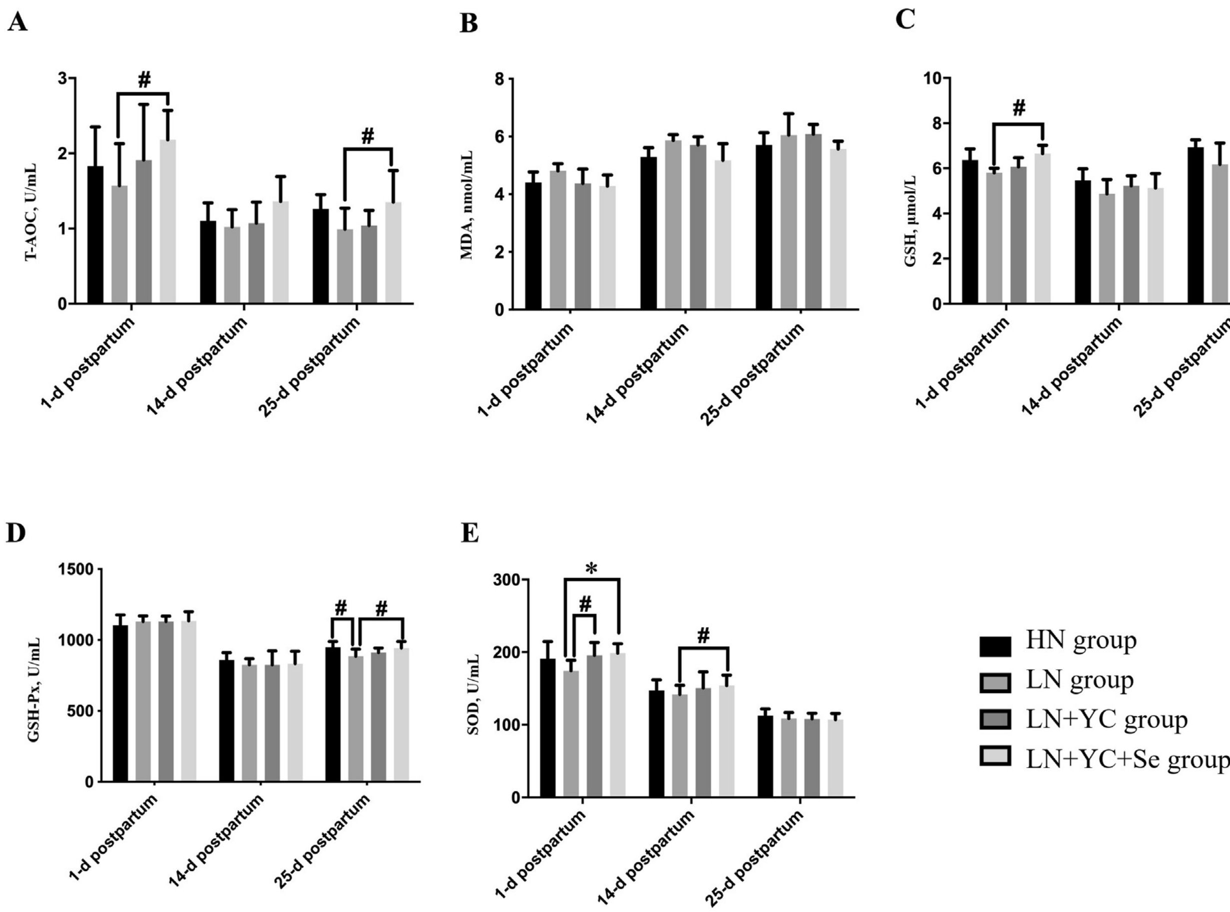

Fig. 3. Effects of dietary supplementation of yeast culture (YC) and supranutritional organic selenium (Se) on T-AOC (A), MDA (B), GSH (C), GSH-Px (D), and SOD (E) in serum of sows. T-AOC = total antioxidant capability; MDA = malonaldehyde; GSH = glutathione; GSH-Px = glutathione peroxidase; SOD = superoxide dismutase. High nutrient (HN) group: 3,420 kcal/kg digestible energy (DE) and 18.0% crude protein (CP); low nutrient (LN) group: 3,240 kcal/kg DE and 16.0% CP; LN + YC group: LN diet + 10 g/kg YC; LN + YC + Se group: LN diet + 10 g/kg YC + 1 mg/kg Se. The asterisk (*) indicates that there are significant differences between 2 groups ($P < 0.05$). Pound sign (#) represents tendencies between 2 groups ($P < 0.10$).

differences in effects of supranutritional Se on immunoglobulin secretion and transportation might lead to these differences between ruminants and non-ruminants. More studies are needed to fully elucidate species differences in response to supranutritional Se supplementation.

The current nutrient requirements of swine (NRC, 2012) recommend 0.15 mg/kg Se for sows during gestation and lactation. Some scientists hypothesized that pigs are more sensitive to insulin than ruminants, and supranutritional Se supplementation might interfere with insulin homeostasis with the result of negative effects on pig performance (Pinto et al., 2012). However, in our experiment, when the dose of Se was increased to 1 mg/kg, supranutritional Se supplementation significantly enhanced piglet performance (litter weight, pig weight, average litter gain and average daily gain) and had no apparent adverse effects.

Pregnancy is considered as a state of oxidative stress. Metabolic burdens on sows can increase lipid and protein oxidation and

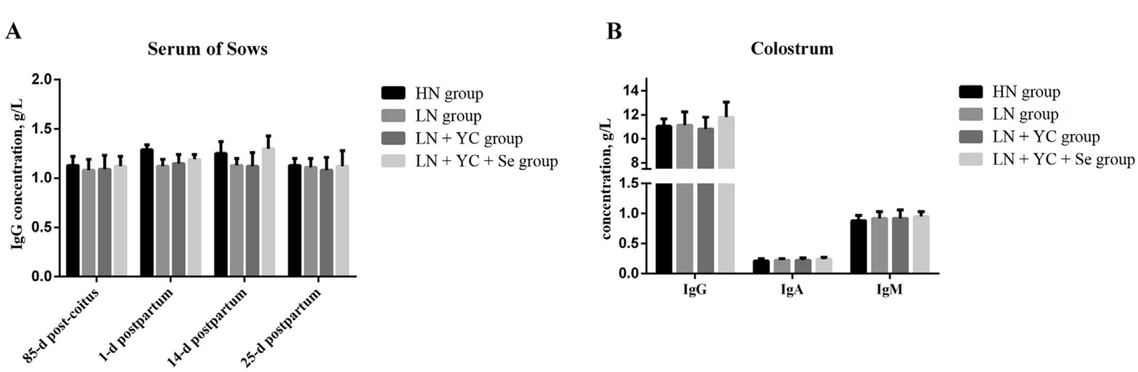

Fig. 4. Effects of dietary supplementation of yeast culture (YC) and supranutritional organic selenium (Se) on serum IgG concentrations of sows (A) and concentrations of IgG, IgA and IgM in colostrum (B). IgG = immunoglobulin G; IgA = immunoglobulin A; IgM = immunoglobulin M. High nutrient (HN) group: 3,420 kcal/kg digestible energy (DE) and 18.0% crude protein (CP); low nutrient (LN) group: 3,240 kcal/kg DE and 16.0% CP; LN + YC group: LN diet + 10 g/kg YC; LN + YC + Se group: LN diet + 10 g/kg YC + 1 mg/kg Se.

impair normal cell functions during late gestation and lactation. In recent years, more attention has been focused on the potential influence of maternal nutrition on the nutritional status and antioxidant system of their offspring. Total antioxidant capability, SOD, GSH, GSH-Px, and MDA were used for determination of redox status of serum and milk in sows in this experiment. Total antioxidant capability is a crucial integrative index to reflect the total antioxidant capacity of the animal, and SOD enzymes play an important role in catalyzing the disproportionation of superoxide to H_2O_2 and water (Fridovich, 1986). The major role of GSH is to act as a reductant in oxidation-reduction processes, and GSH-Px is considered as an antioxidant enzyme to catalyze the reduction of hydrogen peroxide in the presence of GSH. Furthermore, MDA is a product of lipid peroxidation caused by the reaction of lipid oxidation induced by oxygen-free radicals.

In this research, YC supplementation increased the activity of SOD (1 d postpartum serum and colostrum) and GSH-Px (25-d milk), and decreased the MDA content (colostrum) of sows. Similarly, effects of YC supplementation on antioxidant capacity are also observed in finishing pigs (Sauerwein et al., 2007) and weaning pigs (Yang et al., 2016). Currently, the underlying mechanism of the effects of YC supplementation is still poorly understood. It is possible that various metabolites in YC, including minerals like Se, Cu, and Zn, may be involved. Eukaryotes have 2 intracellular SOD as follows: a copper- and zinc-containing enzyme (SOD1) located in the cytosol and a manganese-containing enzyme (SOD2) located in the mitochondrial matrix (Crapo et al., 1992). Selenium is a vital component of selenoprotein enzyme GSH-Px in animals (Arthur, 2001). Therefore, supplementation of YC provides mineral substrates for antioxidant enzyme synthesis, which might increase the activity of those enzymes.

Supranutritional organic Se supplementation has been reported to improve the antioxidant status and immune response, which is attributed to the selenoproteins that are involved in oxidative stress and inflammation regulation (Mattmiller et al., 2014). Chauhan et al. (2014a) demonstrated that supplementation of sheep diets with supranutritional doses of vitamin E and Se successfully scavenged heat stress-induced reactive oxygen species generation, resulting in a decrease in oxidative stress. Hall et al. (2014) conducted an experiment in cows and observed similar results, which are supranutritional doses of Se improved antioxidant status in early lactation. In this study, we observed similar results, i.e., a high dose of Se supplementation increased the activity of GSH-Px (25 d postpartum) and SOD (1 d and 14 d postpartum), with a higher concentration of GSH (1 d postpartum) and T-AOC (1 d and 25 d postpartum) in sow serum. Also, MDA content (colostrum and 14-d milk) was less, and the activity of GSH-Px (colostrum and 25-d milk) greater in sow milk.

5. Conclusion

Combined of YC and organic Se supplementation in nutrient-restricted sows during late gestation and lactation appears beneficial in improving piglet preweaning performance by enhancing antioxidant capacity in serum and milk and improving milk fat content.

Conflict of interest

We declare that we have no financial and personal relationships with other people or organizations that can inappropriately influence our work, there is no professional or other personal interest of any nature or kind in any product, service and/or company that could be construed as influencing the content of this paper.

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