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# Effects of dietary grape seed polyphenols supplementation during late gestation and lactation on antioxidant status in serum and immunoglobulin content in colostrum of multiparous sows<sup>1</sup>

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**ABSTRACT:** The aim of this study was to determine the effects of dietary grape seed polyphenols (GSP) supplementation during the late gestation and lactation period on reproductive performance, antioxidative status in serum, nutrient composition, and Ig content in colostrum of multiparous sows. On day 80 of gestation, a total of 64 sows with similar body condition were allocated to a completely randomized block design with 4 dietary treatments ( $n = 16$  sows per treatment): 1) basal diet (CON, control group); 2) basal diet supplemented with 200 IU/kg vitamin E (200VE, positive control group); 3) basal diet supplemented with 200 mg/kg GSP (200GSP); and 4) basal diet supplemented with 300 mg/kg GSP (300GSP). The trial lasted 56 d until the piglets were weaned on day 21 of lactation. Reproductive performance, parameters of antioxidative status, and levels of progesterone (P4) and estradiol (E2) in serum, nutrient composition, and Ig content in colostrum of sows were determined. The number of dead fetuses was reduced, and farrowing survival was significantly

improved in the litters from 300GSP-fed ( $P < 0.05$ ). Preweaning survivability significantly increased in the litters from sows fed 200GSP and 200VE ( $P < 0.05$ ). The activity of superoxide dismutase and glutathione peroxidase (GSH-Px) in the serum was significantly increased in sows fed 200GSP and 300GSP ( $P < 0.05$ ). The activity of GSH-Px in the serum also significantly increased in sows fed 200VE ( $P < 0.05$ ). Sows fed 300GSP had the greatest levels of P4 and E2 in the serum, which was significantly greater than sows fed 200VE and CON ( $P < 0.05$ ). No significant differences were found among treatments for the content of solids-not-fat, fat, protein, and lactose in colostrum ( $P > 0.05$ ). However, sows fed GSP had greater IgM and IgG content in colostrum compared with sows fed 200VE and CON ( $P < 0.05$ ). In conclusion, dietary GSP supplementation during late gestation and lactation improved the farrowing survival and preweaning survivability, enhanced the antioxidant status and hormone levels in serum, and increased the IgM and IgG content in colostrum of sows.

**Key words:** antioxidant status, grape seed polyphenols, hormone levels, immunoglobulin, reproductive performance, sow

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## INTRODUCTION

Gestation is characterized by dynamic changes in several tissues and organs that lead to increased basal oxygen consumption and metabolic status modifications in both the sow and the fetus (Berchieri-ronchi et al., 2015). Gestation is a state of high oxidative stress in animals, which is harmful to embryonic, fetal, and placental development (Al-Gubory et al., 2010; Yin et al., 2014). Reactive oxygen species (ROS), such as superoxide, hydrogen peroxide, and hydroxyl radical, are some of the most important factors for oxidative stress and lead to significant oxidative damage. An imbalance between ROS and antioxidants is considered responsible for affecting female reproductive processes (Mou et al., 2018). Reactive oxygen species are eliminated or detoxified by different components of enzymatic defense system, such as superoxide dismutase (SOD), glutathione peroxidase (GSH-Px), catalase (CAT), and glutathione reductase, and nonenzymatic antioxidant defense system, such as carotenoids, retinoids, vitamin C, vitamin E, albumin, uric acid, bilirubin, and transferrin (Čolak et al., 2017). Dietary antioxidants have been recognized as important contributors to the total antioxidant capacity of cells and plasma, which have the ability to neutralize ROS and other free radicals produced by oxidative stress (Oliveira et al., 2017). It has been reported that vitamin E supplementation in the sows diet increases milk  $\alpha$ -tocopherol levels, prevents vitamin E deficiency in young piglets, improves the weight of piglets at weaning, and enhances the antioxidant activity of sows and piglets (Mahan, 1991, 1994; Shelton et al., 2014; Wang et al., 2017). As a commonly used antioxidant, besides vitamin E, a great number of secondary plant metabolites may be most promising due to their well-established antioxidative and gene regulatory properties (Aguirre et al., 2014; Gessner et al., 2017).

Polyphenols, as well-known natural antioxidants and chemopreventive agents, are one of the most common groups of substances in plants and their derived foods and beverages, as well as in flowers, vegetables, fruits, essential oil, and tea (Zhang and Tsao, 2016). Epidemiological, clinical, and nutritional studies have shown that polyphenols have a wide range of biological activities, include antioxidant (Gessner et al., 2017; Zou et al., 2018), anticancer (Fantini et al., 2015; Niedzwiecki et al., 2016; Colomer et al., 2017), and anti-inflammatory (Joseph et al., 2016; Zhang and Tsao, 2016) properties. Their antioxidant capacity is comparable

to vitamin E, which is generally considered to be the main biological antioxidants and minimize the negative consequences of oxidative stress (Iqbal et al., 2015). Grape seed polyphenols (GSP) have been widely used as a human food supplement for health promotion and disease prevention. The polyphenols in grape pomace can increase the total antioxidant status and decrease lipid peroxidation in duodenum and colon, and increase SOD activity in duodenum and CAT and GSH-Px activity in the colon of piglets (Chedea et al., 2018). Feeding polyphenol-rich plant products (grape seed or grape pomace meal extract) has been shown to decrease expression of various proinflammatory genes in duodenum, ileum, and colon of growing pigs (Fiesel et al., 2014). However, the effects of dietary GSP supplementation on reproductive performance and antioxidative status of sows has been less investigated so far. Therefore, our objective is to investigate the reproductive performance, parameters of antioxidative status and hormone levels in serum, and Ig content in colostrum of sows that received GSP during late gestation and lactation.

## MATERIALS AND METHODS

The experimental design and procedures of this study were reviewed and approved by the Institutional Animal Care and Use Committee of Hunan Agricultural University, China.

### *Animals, Diets, and Experimental Design*

Grape seed polyphenols (total polyphenolic  $\geq 501.3$  mg/g dry weight) were extracted from grape seed and purchased from Hunan PERFLY Biotechnology Co. Ltd (Changsha, China). Sixty-four multiparous crossbred sows (Large White  $\times$  Landrace, parity 4 and 5) with similar body condition on day 80 of gestation were allocated to 4 dietary treatments ( $n = 16$  sows per treatment) in completely randomized block design and then maintained until the piglets were weaned on day 21 of lactation. The total feeding trial lasted for 56 d. The 4 experimental treatments were defined as follows: 1) basal diet (CON, control group); 2) basal diet supplemented with 200 IU/kg vitamin E (200VE, positive control group); 3) basal diet supplemented with 200 mg/kg GSP (200GSP); and 4) basal diet supplemented with 300 mg/kg GSP (300GSP). The basal diet was formulated to meet or exceed all the nutrient requirements of lactating sows according to National Research Council (NRC, 2012) and contained 50 IU/kg vitamin E. Since an additional

200 IU/kg vitamin E (DL- $\alpha$ -tocopherol acetate, Zhejiang NHU company LTD, Zhejiang, China) was supplemented to 200VE diet, the total vitamin E content of 200VE was 250 IU/kg. The ingredient composition and nutrient levels of the basal diet are shown in Table 1. The levels of vitamin E used in 200VE treatment based on Chen et al. (2016) and Wang et al. (2017). The levels of GSP used based on Meng et al. (2018) and Chedea et al. (2018).

The sows in gestation were kept in crates with half-slatted floors until the day 110 of pregnancy, then moved into the farrowing building in farrowing pens with crates. All sows were fed 2.60 kg/d individually, twice daily (at 08:00 and 15:00 h) in 2 equal meals from day 80 of gestation until farrowing, and provided ad libitum after parturition. Water was available ad libitum via nipple drinkers throughout the whole trial period. Cross-fostering was performed between sows in the same treatment and was completed within 24 to 48 h after birth. Litter size was equalized within treatment to achieve 9 to 11 pigs per sow. Relevant parameters of reproductive performance were recorded and calculated as described by Young et al. (2016). The number of total born piglet, born alive, dead fetuses, and mummies per sow were recorded at farrowing. Farrowing survival was calculated as the percent born alive out of the total number farrowed (born alive + dead fetuses + mummies). Preweaning survivability was calculated as the percentage of piglets weaned out of the number of piglets birthed by the sow regardless of whether she nursed them or not. Individual weights were measured at birth for all born alive piglets and at weaning for all weaning piglets.

Total live piglet birth weight, average live piglet birth weight, average weight of weaned piglet, and average weight gain of piglet were calculated based on all piglets born to a sow regardless of whether she nursed them or not.

### Sampling and Assay

On day 110 of pregnancy, 8 sows were randomly chosen from each treatment for blood sampling. Approximately 10 mL of blood was drawn into vacuum tube by puncture of the sow's auricular vein and directly centrifuged at  $2,000 \times g$  for 10 min under 4 °C. Then supernatant serum of each sample was divided into 2 subsamples and stored at -20 °C until analysis. One subsample was used for determining the activities of SOD and GSH-Px, the levels of malondialdehyde (MDA), and total antioxidant capacity (T-AOC) in serum with an ELISA detection kit. The other subsample was used to determine the concentrations of progesterone (P4) and estradiol (E2) in serum by commercial ELISA Kit respectively. SOD kit, GSH-Px kit, MDA kit, and T-AOC kit were all purchased from Nanjing Jiancheng Bioengineering Institute (Nanjing, China). P4 and E2 ELISA Kit were obtained from Wuhan ColorfulGene Biological Technology Co., LTD (Wuhan, China).

Approximately 20 mL of colostrum from 6 sows per treatment was collected from the functional mammary glands after the last piglet was born. The definition of the last piglet born was when the contractions had stopped and after the expulsion of placenta (Kielland et al., 2015). Piglets were not separated from sows before and during colostrum

**Table 1.** Ingredients composition and nutrient levels of the basal diet<sup>1</sup> (air dry basis)

Ingredients	Composition, %	Items, unit	Nutrient level <sup>2</sup>
Corn, 7.8% CP	65.0	CP, %	17.2
Soybean meal, 43% CP	22.0	DE, Mcal/kg	3.30
Wheat bran	5.0	DM, %	87.5
Fish meal, 65% CP	2.0	Ether extract, %	5.27
Soybean oil	2.5	Linoleic acid, %	2.69
Calcium phosphate	1.1	Calcium, %	0.70
Limestone	0.8	Total phosphorus, %	0.61
Salt	0.3	Available phosphorus, %	0.37
L-Lysine, 98%	0.2	Lysine, %	1.10
Threonine, 98%	0.1	Threonine, %	0.68
Vitamin and mineral premix <sup>3</sup>	1.0	Crude fiber, %	2.35
Total	100		

<sup>1</sup>The basal diet was used throughout the trial period (from day 80 gestation until the piglets were weaned on day 21 of lactation).

<sup>2</sup>CP was an analyzed value, whereas the other nutrient levels were calculated.

<sup>3</sup>The vitamin and mineral premix supplied per kilogram of complete diet: 100 mg Zn (ZnSO<sub>4</sub>·H<sub>2</sub>O), 80 mg Fe (FeSO<sub>4</sub>·H<sub>2</sub>O), 22 mg Mn (MnSO<sub>4</sub>·H<sub>2</sub>O), 25 mg Cu (CuSO<sub>4</sub>·5H<sub>2</sub>O), 0.4 mg I (CaI<sub>2</sub>O<sub>6</sub>), 0.3 mg Se (Na<sub>2</sub>SeO<sub>3</sub>), 14,000 IU vitamin A, 4000 IU vitamin D<sub>3</sub>, 50 IU vitamin E, 124 mg vitamin K<sub>3</sub>, 4 mg vitamin B<sub>1</sub>, 10 mg vitamin B<sub>2</sub>, 0.04 mg vitamin B<sub>12</sub>, 4.8 mg vitamin B<sub>6</sub>, 40 mg niacin, 20 mg D-pantothenate, 2 mg folic acid, and 0.16 mg D-biotin.

collection. The colostrum sample from each individual was divided into 2 equal portions and stored at  $-20^{\circ}\text{C}$  until further analysis. One colostrum sample was diluted with 3 times its own quantity of purified water and assayed using a fully automated milk analyzer (UL120BC, Hangzhou Ultrasun Technologies Co., Ltd., Hangzhou, China) for nutrient composition (total solids-not-fat, fat, protein, and lactose). The other colostrum sample was used to quantify the content of IgG, IgA, and IgM. Colostral Ig proteins (IgG, IgA, and IgM) were measured with a swine ELISA kit (Wuhan Cusabio Biotech Co., Wuhan, China), and the final values of IgG, IgA, and IgM were expressed in grams per liter.

All of the laboratory analysis procedures followed the manufacturer's instructions and included 2 duplicates in the same sample. The mean of the duplicates was used for data.

### Statistical Analyses

All statistical analysis was performed using the SPSS Statistics 25.0 software (IBM SPSS, Chicago, IL). The differences between treatments were analyzed by one-way analysis of variance, and Duncan's multiple comparisons tests were used to isolate means that differed. Results are given as mean values and a pooled SEM. A value of  $P < 0.05$  was used to indicate statistical significance.

## RESULTS

### Reproductive Performance

Sow's reproductive performance in response to dietary GSP supplementation is described in

**Table 2.** No significant differences in the number of total born piglets, born alive piglets, and mummies were observed among treatments. Compared with the litters from sows fed CON, the number of dead fetuses was reduced ( $P < 0.05$ ) and farrowing survival was significantly improved ( $P < 0.05$ ) in the litters from 300GSP-fed. But there was no significant difference between the litters from sows fed 200VE and 200GSP ( $P > 0.05$ ). Total live piglet birth weight, average live piglet birth weight, average weight of weaned piglet, average weight gain of piglet, and number weaned piglet of sow were not affected by dietary treatment ( $P > 0.05$ ). However, the preweaning survivability was significantly increased in litters from 200VE- and 200GSP-fed sows compared with litters from CON-fed sows ( $P < 0.05$ ).

### Antioxidant Status and Hormone Levels in Serum

To investigate the effects of dietary supplementation with GSP during late gestation and lactation on antioxidant status, T-AOC, SOD, GSH-Px, and MDA in serum of sows were analyzed, and the results are presented in **Table 3**. The activity of T-AOC and the content of MDA in the serum of sows were not significantly different among treatments ( $P > 0.05$ ). There was no significant difference in the activity of SOD in the serum of 200VE-fed sows, compared with the CON-fed sows ( $P > 0.05$ ), but the activity of SOD in the serum of 200GSP- and 300GSP-fed sows increased significantly ( $P < 0.05$ ). The activity of GSH-Px in the serum of sows fed 200VE, 200GSP, and 300GSP was significantly increased ( $P < 0.05$ ). Compared with the positive control (sows fed 200VE), there was no significant

**Table 2.** Effects of dietary GSP supplementation on reproductive performance of sows

Item ( $n = 16$ )	CON <sup>1</sup>	200VE <sup>1</sup>	200GSP <sup>1</sup>	300GSP <sup>1</sup>	SEM	<i>P</i> -value
Days of pregnancy, d	116.01	115.29	114.43	115.20	0.20	0.688
Total born, no.	12.00	11.81	11.50	11.88	0.29	0.245
Number of born alive, no.	9.75	10.00	10.00	10.50	0.25	0.164
Number of dead fetuses, no.	1.19 <sup>a</sup>	1.13 <sup>ab</sup>	0.75 <sup>ab</sup>	0.63 <sup>b</sup>	0.09	0.031
Number of mummies, no.	1.06	0.69	0.75	0.75	0.09	0.472
Farrowing survival, %	81.47 <sup>b</sup>	85.43 <sup>ab</sup>	87.53 <sup>ab</sup>	89.32 <sup>a</sup>	1.06	0.009
Total live piglet birth weight, kg	12.45	13.36	12.64	12.44	0.48	0.898
Average live piglet birth weight, kg	1.19	1.38	1.39	1.29	0.06	0.823
Average weight of weaned piglet, kg	5.87	6.19	6.24	6.06	0.12	0.299
Average weight gain of piglet, kg	4.69	4.85	4.84	4.78	0.16	0.347
Number weaned piglet by sow, no.	8.94	9.63	9.69	10.13	0.56	0.462
Weaning weight by sow, kg	52.48	59.56	60.46	61.38	1.68	0.536
Preweaning survivability, %	91.85 <sup>b</sup>	96.29 <sup>a</sup>	96.99 <sup>a</sup>	95.23 <sup>ab</sup>	0.76	0.016

<sup>a,b</sup>Means values within a row with different letters superscripts means significantly different ( $P < 0.05$ ).

<sup>1</sup>GSP = grape seed polyphenols; CON = basal diet; 200VE = basal diet + 200 IU/kg vitamin E; 200GSP = basal diet + 200 mg/kg GSP; 300GSP = basal diet + 300 mg/kg GSP.

difference in the activity of GSH-Px in serum of sows fed 200GSP and 300GSP ( $P > 0.05$ ).

The effects of dietary GSP supplementation during late gestation on the levels of P4 and E2 in the serum of sows are shown in Fig. 1. Sows fed 300GSP had the greatest levels of P4 and E2 in serum, significantly greater than sows fed CON and 200VE, but the difference was not significant compared with sows fed 200GSP ( $P > 0.05$ ).

### Nutrient Composition and Ig Content of Colostrum

The effects of dietary GSP supplementation during late gestation and lactation on the nutrient composition in colostrum of sows are given in Table 4. No significant differences among treatments were found in colostrum nutrient content (solids-not-fat, fat, protein, and lactose;  $P > 0.05$ ). Figure 2 shows the effects of dietary GSP supplementation during late gestation and lactation on the Ig content in colostrum of sows. There was no significant difference in the concentrations of IgA in colostrum among treatments ( $P > 0.05$ ). However, sows fed 200GSP and 300GSP had greater content of IgM and IgG in colostrum compared with sows fed 200VE and CON ( $P < 0.05$ ).

## DISCUSSION

Reproductive performance of sows is one of the critical factors influencing the efficiency of swine production (Koketsu et al., 2017; Małopolska et al., 2018). The increase of oxidative stress during gestation, farrowing, and lactation of sows are responsible for the impaired reproductive performance of sows (Kim et al., 2013), which is a difficult problem to be faced in the swine industry. Although in the feed industry, vitamin E is often supplemented to the diet of farm animals to maintain the optimal health, highly productive and reproductive performance (Surai, 2014), previous studies have not been consistent on whether dietary supplementation with a high concentration of vitamin E resulted in a better reproductive performance of sows. Pinelli-Saavedra and Scaife (2005) reported that piglet growth performance and sow reproductive performance were unaffected by the dietary addition of vitamin E (200 and 400 mg/kg). Similarly, Sosnowska et al. (2011) did not observe any significant differences in reproductive performance of sows on the applied addition of 60, 200 mg/kg vitamin E during the last stage of gestation (day 90) and lactation. On the contrary, Wang et al.

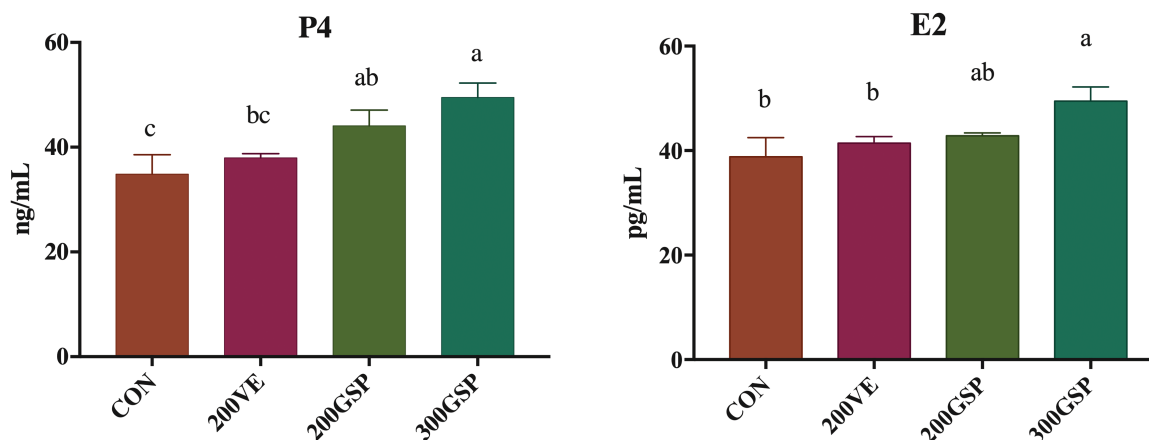
**Table 3.** Effects of dietary GSP supplementation on the antioxidant status in serum of sow

Items <sup>1</sup> (n = 8)	CON <sup>2</sup>	200VE <sup>2</sup>	200GSP <sup>2</sup>	300GSP <sup>2</sup>	SEM	P
T-AOC, IU/mL	29.14	26.83	32.14	41.43	4.37	0.700
SOD, IU/mL	37.51 <sup>b</sup>	42.08 <sup>b</sup>	61.81 <sup>a</sup>	66.21 <sup>a</sup>	3.26	<0.001
GSH-Px, IU/mL	417.83 <sup>b</sup>	586.30 <sup>a</sup>	562.24 <sup>a</sup>	620.33 <sup>a</sup>	23.71	0.002
MDA, nmol/mL	4.13	2.94	2.56	2.33	0.37	0.339

<sup>a,b</sup>Means values within a row with different letters superscripts means significantly different ( $P < 0.05$ ).

<sup>1</sup>T-AOC = total antioxidant capacity; SOD = superoxide dismutase; GSH-Px = glutathione peroxidase; GSH = glutathione; MDA = malonaldehyde.

<sup>2</sup>GSP = grape seed polyphenols; CON = basal diet; 200VE = basal diet + 200 IU/kg vitamin E; 200GSP = basal diet + 200 mg/kg GSP; 300GSP = basal diet + 300 mg/kg GSP.

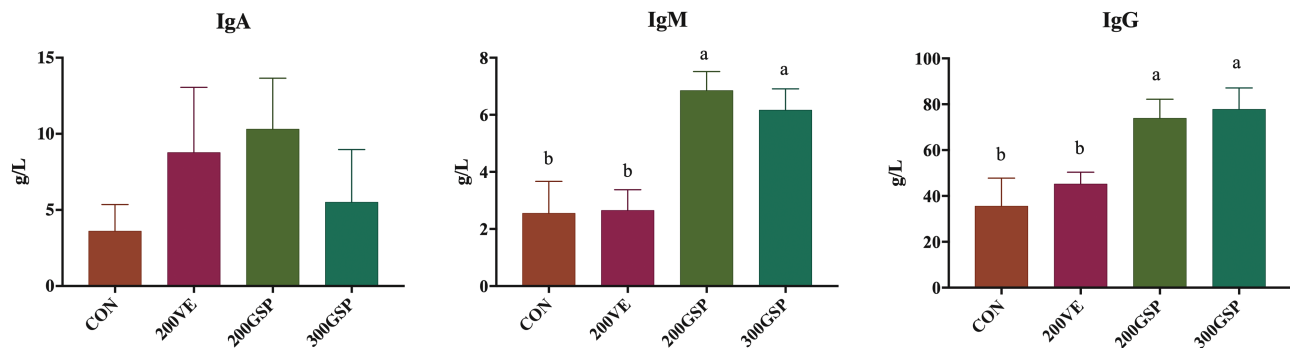


**Figure 1.** Effect of dietary GSP supplementation on the levels of P4 and E2 in serum of sows. GSP = grape seed polyphenols; CON = basal diet; 200VE = basal diet + 200 IU/kg vitamin E; 200GSP = basal diet + 200 mg/kg GSP; 300GSP = basal diet + 300 mg/kg GSP. P4 = Progesterone; E2 = estradiol. Data are mean  $\pm$  SEM. <sup>a,b,c</sup>Means values within a bar with different letters superscripts means significantly different ( $P < 0.05$ ).

**Table 4.** Effect of dietary GSP supplementation on the composition in colostrum of sows

Item, g/kg	CON <sup>1</sup>	200VE <sup>1</sup>	200GSP <sup>1</sup>	300GSP <sup>1</sup>	SEM	<i>P</i>
Solids-not-fat	215	219	225	218	2.43	0.248
Fat	45.5	41.0	40.1	45.8	1.64	0.285
Protein	91.8	86.5	93.0	87.0	1.18	0.059
Lactose	114	115	120	119	1.15	0.093

<sup>1</sup>GSP = grape seed polyphenols; CON = basal diet; 200VE = basal diet + 200 IU/kg vitamin E; 200GSP = basal diet + 200 mg/kg GSP; 300GSP = basal diet + 300 mg/kg GSP.



**Figure 2.** Effects of dietary GSP supplementation on Ig in colostrum of sows. GSP = grape seed polyphenols; CON = basal diet; 200VE = basal diet + 200 IU/kg vitamin E; 200GSP = basal diet + 200 mg/kg GSP; 300GSP = basal diet + 300 mg/kg GSP. Data are mean  $\pm$  SEM. <sup>a,b</sup>Means values within a bar with different letters superscripts means significantly different ( $P < 0.05$ ).

(2017) demonstrated that the addition of vitamin E to the diet of sows at high concentration (250 IU/kg) improved the weight of piglets at weaning. In the present study, the preweaning survivability was significantly increased in litters from 200VE-fed sows compared with litters from control-fed sows. There are many different reasons that might cause such a phenomenon, and further research is warranted. In addition, we also found that the number of dead fetuses was reduced, farrowing survival was improved with sows fed 300GSP, and the preweaning survivability was significantly increased in litters from 200GSP-fed sows during late gestation and lactation.

Polyphenols are characterized by high antioxidant activity due to their complex chemical structure and minimize the negative consequences of oxidative stress (Lipiński et al., 2017). It has been suggested that polyphenols could be more effective than traditional biological antioxidants, such as vitamin E and C (Surai, 2014). In addition, polyphenols exert nonspecific effects on cell metabolism and deliver health benefits to humans and animals (Petti and Scully, 2009; Kamboh et al., 2015). Garbetta et al. (2018) studied the influences of grape skin polyphenols on the modulation of ROS and GSH levels in basal and in stressed conditions on human intestinal cells (HT-29) and found that grape skin polyphenols exerted antioxidant effects up to  $1.3 \times 10^{-6}$   $\mu\text{g/g}$  and restored the stress-related GSH reduction in stressed conditions. The

results are consistent with that of Goutzourelas et al. (2015), who reported that polyphenolic composition of grape stem extracts at low concentrations increased the redox status of endothelial (EA.hy926) and muscle (C2c12) cells. In contrast to the potential antioxidative and anti-inflammatory effects of polyphenols that are well established in model animal and humans, the effects have been less investigated in sows so far (Gessner et al., 2017). Zhao et al. (2018) reported that the activities of T-AOC, glutathione peroxidase 4, and SOD in *longissimus dorsi* muscle were increased when lambs were fed diet containing 10% wine grape pomace. In addition, several studies developed in pigs have reported a significant increase in the serum antioxidant capacity of weaned piglets or sows that offered diets supplemented with grape seed procyanidins (Hao et al., 2015) or with catechins, which belongs to plant polyphenolic constituents (Fan et al., 2015). Our results demonstrate that dietary GSP supplementation during late gestation exerts a beneficial role in the antioxidant defense capacity of sows, that is achieved by increasing the activity of SOD and GSH-Px in serum in agreement with those in the literature mentioned above. The results of our study also further suggest that the oxidative stress in the process of sow farrowing was reduced by dietary GSP supplementation during late gestation.

Previous studies have shown that P4 plays an important role in establishing and maintaining pregnancy, and E2 is mainly secreted by the fetus,

and increases accompanied with the normal development of the fetus, as a communication signal between sow and fetus during gestation (Perry et al., 1973; Wang et al., 2015). In the present study, the levels of P4 in the serum of pregnant sows (110 d) were significantly increased by dietary GSP supplementation during late gestation and the levels of E2 in the serum were also significantly increased in 300GSP-fed sows. According to these results, another hypothesis can be derived, namely, the addition of GSP in the diet of sows in early gestation has a positive impact on the levels of P4 and E2 in serum, thus playing a role in reducing embryo loss and promoting fetal development. In addition, P4 may play an active role in the IgG transfer from plasma to colostrum (Devillers et al., 2004). Jackson et al. (1995) showed that higher colostral IgG content in sows treated with P4 and farrowing at 116 d of gestation instead of 114 d. In this study, sows fed GSP had greater levels of P4 in serum at 110 d of gestation and greater IgG content in colostrum after farrowing. These results are consistent with those of previous studies.

Sow's colostrum and milk are very important to the growth and development of piglets during and after lactation (Hurley, 2015). In particular, colostrum has been found to have several advantages over formula. In addition to providing energy and critical nutrients for growth and heat production for newborn piglets, it also has the potential to provide antioxidant protection and maternal immunity to piglets (Berchieri-ronchi et al., 2015), which is a key to the survival of newborn piglets. This study did not find a significant difference in nutrient composition (solids-not-fat, fat, protein, and lactose) in colostrum between sows fed GSP with sows fed CON. These results are consistent with those data obtained in dairy cows by Chedea et al. (2017), using 15% dried grape pomace in the diets, and the milk of cows fed with a grape pomace diet preserves the normal levels of fat, protein, and caseins.

Both IgG and IgM could be absorbed over the gastrointestinal tract during the first 24 to 48 h after birth; therefore, it is considered to be clinically important Ig during the first weeks of life (Sjaastad et al., 2010; Tan et al., 2017). The serum content of IgG in piglet is dependent on several factors, which is strongly associated with the IgG content of colostrum and the amount of colostrum ingested (Rooke and Bland, 2002). In addition, the Igs (IgA, IgG, and IgM) in colostrum are rapidly taken up by nonspecific pinocytosis into the enterocytes of the small intestine of the newborn piglet

and localized in vacuoles (Rooke and Bland, 2002). Therefore, the increased IgG content of colostrum will improve the levels of IgG in piglets and potentially improve the survival rate of piglets (Kielland et al., 2015). In the present study, we found that the contents of IgM and IgG in colostrum of sows fed GSP were significantly increased compared with sows fed 200VE or CON. The preweaning survivability of piglets was significantly increased by dietary GSP supplementation of sows during late gestation and lactation. This might be related to the significant increase in IgG and IgM content in colostrum, which may improve the passive immunity and health status of piglets after birth.

## CONCLUSIONS

Dietary GSP supplementation of multiparous sows during late gestation and lactation enhanced the antioxidant status and the levels of P4 and E2 in serum. In addition, it increased IgM and IgG content in colostrum of sows, which is potentially beneficial to increase the preweaning survivability of piglets. Overall, our study indicated the potential beneficial effects of dietary GSP supplementation in improving the reproduction performance of sows and suggested that GSP could be useful feed supplements in sow nutrition.

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