

## NON RUMINANT NUTRITION

# Effects of dietary soluble or insoluble fiber intake in late gestation on litter performance, milk composition, immune function, and redox status of sows around parturition

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## Abstract

The objective of this study was to investigate the effects of dietary soluble fiber (SF) or insoluble fiber (ISF) intake in late gestation on litter performance, milk composition, immune function, and redox status of sows around parturition. A total of 60 Yorkshire sows were randomly assigned into three dietary treatments: normal level of dietary fiber (CON, 16.16% dietary fiber with 1.78% soluble fiber and 14.38% insoluble fiber), high insoluble fiber (ISF, 30.12% dietary fiber with 2.97% soluble fiber and 27.15% insoluble fiber), and high soluble fiber (SF, 30.15% dietary fiber with 4.57% soluble fiber and 25.58% insoluble fiber). Digestible energy and crude protein intake were comparable among treatments via adjusting feed intake from day 90 of gestation to parturition. After parturition, all sows were fed the same lactation diet. Results showed that litter performance of sows was not markedly affected by maternal fiber intake. However, sows fed ISF or SF diet had increased concentration of plasma immunoglobulin G at day 107 ( $P < 0.05$ ) and parturition ( $P < 0.01$ ), and the SF diet had a tendency to increase fat content in both colostrum and milk relative to the CON diet. Furthermore, sows fed ISF diet had increased glutathione peroxidase activity ( $P < 0.05$ ) at day 107, but decreased the plasma level of malondialdehyde at parturition ( $P < 0.05$ ). High maternal SF intake tended to decrease the number of weaned piglets due to the increased preweaning mortality, as compared with sows fed the ISF diet. In conclusion, high fiber intake in late gestation may improve immune function and redox status, but differentially influenced the milk composition and preweaning mortality.

**Key words:** antioxidant, colostrum, dietary fiber, immunology, lactation, swine

## Abbreviations

ADFI	average daily feed intake
ADG	average daily gain
ALB	albumin
CAT	catalase
CI	colostrum intake
C-RP	C-reactive protein
GLU	glucose
GSH-Px	glutathione peroxidase
LAC	lactose
LBW	low birth weight
MDA	malondialdehyde
SCFA	short-chain fatty acid
TDF	total dietary fiber
T-SOD	total superoxide dismutase

## Introduction

It has been demonstrated that fiber addition in the gestation diet may increase litter size through one or several reproductive cycles (Veum et al., 2009; Che et al., 2011). In addition, fiber-rich diet during gestation improved feed intake of sows and piglets growth rate during lactation due to a carryover effect on feed intake capacity (Guillemet et al., 2007; Li et al., 2019). Other positive effects of dietary fiber on embryo survival rate, piglet colostrum intake (CI), stillbirth rate, and intestinal microbiota composition of sows have also been reported (Theil et al., 2014; Feyera et al., 2017; Pan et al., 2017).

During pregnancy, fetal development is largely influenced by the uterine environment and umbilical supply of nutrients (Vallet et al., 2014), which determines the birth weight and litter uniformity (Wang et al., 2017). In addition, the inflammatory response and oxidative stress occurred during the perinatal period (Berchieri-Ronchi et al., 2011; Newbern and Freemark, 2011), which may impair fetal development by decreasing fetal protein deposition and skeletal formation (Prater et al., 2008). In contrast, dietary fiber has been shown to improve immune response and redox status during the perinatal period (Wang et al., 2016).

To our knowledge, however, it is rarely reported about the effects of dietary fiber sources on reproductive performance and sow physiology. In this study, therefore, we aimed to investigate the effects of high soluble or insoluble fiber intake in late gestation on litter performance, milk composition, immune function, and redox status of sows around parturition. High ISF inclusion in diet was obtained by including soybean hulls and wheat bran as main fiber ingredients with ISF/SF ratio of 9.14, which is a typical value of gestating diet in China (Sun et al., 2014; Tan et al., 2018). The high SF diet was obtained by replacing part of these ingredients with sugar beet pulp with ISF/SF ratio of 5.60, which closes to the typical value of gestating diet in European countries (Guillemet et al., 2007; Quesnel et al., 2009). To a great extent, the beneficial function of fiber depends on its fermentation and water-holding capabilities. It is widely believed that soluble fibers are fermented faster, producing higher amounts of short-chain fatty acids (SCFA) than insoluble fibers and favoring proliferation of beneficial microbiota (Jha and Berrococo, 2015). Based on this, we hypothesized that high SF or high ISF intake in late gestation may differentially affect litter performance, milk composition, immune function, and redox status of sows.

## Materials and Methods

The study was conducted at Tianfu Sow Farm, Giastar Group, Chengdu, China. The experiment followed the actual law of animal protection and was approved by the Animal Care and Use Committee of the Sichuan Agricultural University (DKY-B20121602) and was performed in accordance with the National Research Council's Guideline for the Care and Use of Laboratory Animals.

### Animals and diets

A total of 60 Yorkshire sows (20 per treatment) were included and randomly allocated into three dietary treatments, based on parity (4-6) and body weight ( $267.8 \pm 22.6$  kg, means  $\pm$  SD). Three diets were formulated based on corn-soybean meal to meet or exceed the recommendation of NRC (2012) as presented in Table 1: normal dietary fiber diet (CON, 16.2 % total dietary

**Table 1.** Ingredients and composition of gestation diets and lactation diet<sup>1</sup>

Ingredients, %	Gestation diets			Lactation diet
	CON	ISF	SF	
Corn (CP 8.2%)	73.50	53.30	49.83	59.86
Soybean meal (CP 46%)	16.80	10.40	11.30	17.68
Wheat bran	2.90	16.40	12.00	—
Soybean hull	2.90	16.40	12.00	5.00
Sugar beet pulp	0.00	0.00	11.40	—
Fish meal	—	—	—	2.00
Extruded soybean	—	—	—	6.00
Wheat	—	—	—	3.59
Soybean oil	—	—	—	2.00
Lysine-HCl (70%)	0.02	0.01	0.00	0.25
DL-Methionine (98.5%)	0.01	0.04	0.04	0.05
L-Threonine (98.5%)	0.00	0.03	0.04	0.09
CaCO <sub>3</sub>	1.08	0.86	0.67	0.87
CaHPO <sub>4</sub>	1.70	1.56	1.63	0.93
Sodium chloride	0.40	0.40	0.40	0.40
Potassium chloride	—	—	—	0.50
Choline chloride (50%)	0.14	0.14	0.14	0.15
Vitamin and mineral premix <sup>2</sup>	0.55	0.55	0.55	0.63
Calculated nutrient levels				
Digestible energy, MJ/kg	13.31	12.39	12.47	—
Crude protein, %	14.23	13.29	13.29	—
NDF, %	10.11	21.15	21.93	—
SF, %	1.78	2.97	4.57	—
ISF, %	14.38	27.15	25.58	—
ISF/SF	8.08	9.14	5.60	—
Dietary fiber, %	16.15	30.11	30.14	—
Analyzed nutrient levels				
Digestible energy, MJ/kg	13.80	13.22	13.16	14.27
Crude protein, %	13.59	12.57	12.48	17.20
NDF, %	13.25	26.84	26.47	11.00
SF, %	1.92	3.22	5.06	3.80
ISF, %	15.55	29.68	28.44	12.15
ISF/SF	8.10	9.22	5.62	3.20
Dietary fiber, %	17.47	32.90	33.50	15.95

<sup>1</sup>CON, control fiber; CP, crude protein; ISF, high insoluble fiber; NDF, neutral detergent fiber; SF, high soluble fiber.

<sup>2</sup>Provided per kg of diet: Zn 100 mg, Cu 6 mg, Fe 100 mg; Mn 10 mg, I 0.14 mg, Se 0.25 mg, VA 14 mg, VB6 14 mg, VE 30 mg, VC 100 mg, biotin 0.1 mg, folic acid 2.5 mg, carnitine 46 mg, and organic chromium 0.3 mg.

fiber [TDF]), high insoluble fiber diet (ISF, 30.1% total dietary fiber), and high soluble fiber diet (SF, 30.1% total dietary fiber). The average parity was 4.74, 4.75, and 4.89 for CON, ISF, and SF groups, respectively. In this study, all sows were used for recording reproductive performance, but only sows in parities 4 and 5 were used for milk and blood sampling. The ISF and SF diets had similar TDF, but the SF diet had a higher amount of soluble fiber than the ISF diet (4.57% in SF vs. 2.97% in ISF, respectively) from sugar beet pulp. In addition to dietary fiber, other nutrients such as digestible energy and crude protein intake were comparable via adjusting feed intake (3.0 kg/d in CON and 3.2 kg/d in either ISF or SF group) from day 90 of gestation to parturition. The daily dietary fiber intake of ISF and SF groups was about twice as much as the CON group (485g/d in CON and 964g/d in either ISF or SF group). During day 90 to 110 of gestation, the diet was supplied once a day (0800 hours). On day 111 of gestation, sows were moved to the farrowing room and feeding frequency turned to twice a day (0800 and 1500 hours) until parturition, but the total feeding supply did not change. Within 48 h after parturition, cross-fostering was carried out within dietary treatment to standardize the litter size to 11 to 12 piglets. On the day of parturition, no feed was supplied to sows. After parturition, all sows were fed a commercial lactation diet until day 21 of lactation and feed intake was increased by 0.5 kg/d from day 2 to 7 of lactation. From day 8 of lactation, ad libitum feeding was applied. The healthcare and immunization procedures of sows and piglets followed the regulation of Tianfu Sow Farm. During the entire experimental period, sows and piglets were given free access to drinking water.

### Data collection and sampling

The number of total born, born alive, low birth weight (LBW) piglets (birth weight < 0.8 kg), mummies, and stillborn were recorded at parturition. Expelled placentas were collected and weighed. The placental efficiency was calculated as the ratio of the total litter weight to the placental weight. Piglets were weighed at birth and 48 h after birth, before cross-fostering, then days 7, 14, and 21 after cross-fostering to determine average daily gain (ADG). The average daily feed intake (ADFI) of sows after cross-fostering was recorded by weighing daily feed refusals.

Blood samples (10 mL,  $n = 10$ ) from ear vein of sows were collected into sodium heparinized tubes 4 h after providing the morning meal on day 107 of gestation and on 1 h after the first piglet born. Plasma was obtained by centrifuging at  $3,000 \times g$  for 15 min and stored immediately at  $-20^\circ\text{C}$  for later analysis.

Colostrum samples (20 mL,  $n = 10$ ) were collected on 1 h after the first piglet born. Milk samples (20 mL,  $n = 10$ ) were collected on day 7 of lactation after an intravenous injection of 20 IU of oxytocin (Qilu Animal Health Products Co., Ltd, Shandong, China). Both colostrum and milk samples were manually collected from all functional teats, then stored at  $-20^\circ\text{C}$  for later analysis.

### CI and milk composition

#### CI and colostrum yield

A total of 24 sows were included for estimating CI, including 258 piglets. Ten sows (five sows in parity 4, two sows in parity 5, and three sows in parity 6), five sows (three sows in parity 4, one sow in parity 5, and one sow in parity 6), and nine sows (three sows in parity 4, five sows in parity 5, and one sow in parity 6) were used for detecting CI for CON, ISF, and SF groups, respectively. CI

by individual piglet during the 24-h period after the first piglet born was estimated using the following equation developed by Theil et al. (2014):

$$\text{CI (g)} = -106 + 2.26 \times \text{WG} + 200 \times \text{BW}_b + 0.111 \times \text{D} - 1414 \times \text{WG/D} + 0.0182 \times \text{WG/BW}_b,$$

where WG is piglet weight gain between birth and 24 h after the first piglet born (g),  $\text{BW}_b$  is BW at birth (kg), and D is the duration of colostrum suckling, that is the time difference (min) from birth to 24 h after the birth of the first piglet. Piglets from these 24 sows were weighed not only at birth but also 24 h after the first piglet born for the calculation of WG. Colostrum yield was the sum of CI for all piglets in the same litter.

#### Composition of colostrum and milk

Frozen colostrum and milk samples were thawed at  $4^\circ\text{C}$ , and then 10 mL of each sample was used for composition analysis. The fat, protein, lactose (LAC), dry matter, and urea nitrogen content of colostrum and milk were measured using a milk composition analyzer (Milkoscan FT2, Denmark).

#### Plasma metabolites and redox status

The plasma concentrations of glucose (GLU), LAC, triglyceride, urea, total protein, albumin (ALB), nonesterified fatty acid, total bile acids, immunoglobulin G (IgG), immunoglobulin M, complement 4, and C-reactive protein (C-RP) were determined using automatic biochemical analyzer (Model 7020, Hitachi, Tokyo, Japan). There was less than 5% variation of intra-assay and inter-assay coefficients for each assay.

Glutathione peroxidase (GSH-Px), malondialdehyde (MDA), total superoxide dismutase (T-SOD), and catalase (CAT) enzyme activities were determined as described by Wang et al. (2016), who have validated the kits (Nanjing Jiancheng Bioengineering Institute, Nanjing, China) used for determination. There was less than 5% variation of intra-assay and inter-assay coefficients for each assay.

### Statistical analysis

Sows were regarded as the experimental unit and piglet data were reported as a mean for the litter. The data were considered as outlier when the student residue was greater than 3. The GLIMMIX and univariate procedures of SAS (SAS Institute Inc., Cary, NC, USA) were used to analyze the variance homogeneity and normality, respectively. Reproductive performance, milk composition, and blood biochemistry were analyzed using the MIXED procedure of SAS with the diet as a fixed factor and parity as a random factor, using the following statistical model:

$$Y = \alpha + S_i + B_j + \varepsilon_{ij}$$

where Y is the parameter to be tested,  $\alpha$  is the mean,  $S_i$  is the effect of the diet ( $i = 1, 2, 3$ ),  $B_j$  is the random effect of the parity ( $j = 1, 2$ ), and  $\varepsilon_{ij}$  is the error term. Means were separated using the Tukey method with a significance level of 0.05, and a tendency was considered when probability values were less than 0.10. The results were expressed as the mean and SEM.

## Results

### Litter performance

The results pertaining to the litter performance of sows are presented in Table 2. No significant effects of dietary fiber for

**Table 2.** Effect of high ISF or SF intake in late gestation on litter performance of sows<sup>1,2</sup>

	CON	ISF	SF	P-value
Piglets per litter, no.				
Total born	15.31 ± 0.61	16.13 ± 0.56	15.39 ± 0.63	0.59
Born alive	13.75 ± 0.70	14.25 ± 0.55	13.22 ± 0.65	0.52
Stillborn	1.25 ± 0.43	1.31 ± 0.43	1.72 ± 0.36	0.66
Mummies	0.31 ± 0.15	0.56 ± 0.20	0.44 ± 0.27	0.73
LBW piglets <sup>3</sup>	0.94 ± 0.22	0.69 ± 0.30	1.11 ± 0.27	0.52
Placental weight	3.51 ± 0.35	3.55 ± 0.35	3.34 ± 0.28	0.89
Placental efficiency <sup>4</sup>	5.36 ± 0.76	5.84 ± 0.95	5.92 ± 0.43	0.62
CV <sup>5</sup> , %	21.50 ± 1.60	20.43 ± 1.56	21.46 ± 1.06	0.83
Total born, kg				
Litter birth weight	19.28 ± 0.75	20.36 ± 0.72	19.47 ± 1.09	0.67
Piglet birth weight	1.27 ± 0.05	1.27 ± 0.03	1.27 ± 0.06	0.99
Born alive, kg				
Litter birth weight	17.67 ± 0.84	18.59 ± 0.85	17.31 ± 1.25	0.66
Piglet birth weight	1.31 ± 0.05	1.30 ± 0.03	1.30 ± 0.05	0.99

<sup>1</sup>n = 20.<sup>2</sup>CON, control fiber; ISF, high insoluble fiber; SF, high soluble fiber.<sup>3</sup>LBW piglets refer to piglets with birth weight less than 0.8 kg.<sup>4</sup>Placental efficiency, the ratio of total litter weight to placental weight.<sup>5</sup>CV, coefficient of variation within-litter birth weight.

number of total born, born alive, LBW piglets, mummy and stillborn, litter birth weight, born alive litter weight, placental efficiency, and CV (coefficient of variation within-litter birth weight) ( $P > 0.05$ ).

### CI and milk composition

The results of CI of piglets and milk composition of sows are presented in Table 3. Feeding ISF or SF diet did not markedly affect CI of piglets and colostrum yield ( $P > 0.05$ ). Sows fed the ISF diet tended to increase the concentration of urea nitrogen in colostrum when compared with sows fed the CON diet ( $P = 0.08$ ). Also, sows fed ISF and SF diets tended to increase fat content in colostrum when compared with sows fed CON diet ( $P = 0.07$ ). At day 7 of lactation, sows fed SF diet tended to have a higher milk fat content as compared with sows fed CON and ISF diets ( $P = 0.08$ ).

### Lactation performance

As presented in Table 4, ADG of piglets and ADFI of sows in lactation were not different across the three dietary treatments ( $P > 0.05$ ). The litter size ( $P = 0.06$ ) and litter weight ( $P = 0.05$ ) at weaning tended to be lower, while preweaning mortality ( $P = 0.06$ ) tended to be greater in sows fed SF diet.

### Metabolic and immunological parameters

The results pertaining to the metabolic and immunological parameters of sows are presented in Table 5. Sows fed SF had markedly increased ALB concentration in the plasma on day 107 as compared with sows fed ISF and CON diets ( $P < 0.05$ ). Moreover, sows fed either ISF or SF diet had higher IgG concentration in the plasma than sows fed CON diet on both day 107 ( $P < 0.05$ ) and parturition ( $P < 0.01$ ). Compared with sows fed the CON diet, sows fed SF tended to have a lower C-RP concentration in plasma on day 107 of gestation ( $P = 0.08$ ).

### Redox status

Compared with sows fed the CON diet, sows fed the ISF diet had higher activity of GSH-Px ( $P < 0.05$ ) on day 107 (Figure 1A).

**Table 3.** Effects of high SF or ISF intake in late gestation on milk composition of sows and CI of piglets<sup>1</sup>

	CON	ISF	SF	P-value
CI, g				
Colostrum yield, kg	3.42 ± 0.31	4.12 ± 0.59	3.54 ± 0.43	0.54
Colostrum				
Fat, %	3.74 ± 0.25	4.58 ± 0.39	4.68 ± 0.15	0.07
Protein, %	15.64 ± 0.62	16.70 ± 0.82	15.34 ± 0.90	0.45
LAC, %	2.96 ± 0.16	3.09 ± 0.12	3.36 ± 0.12	0.11
Dry matter, %	25.36 ± 0.71	26.35 ± 0.94	25.47 ± 0.91	0.67
Urea nitrogen, mg/dL	61.20 ± 2.45	68.22 ± 2.33	63.90 ± 2.18	0.09
Milk, 7 d				
Fat, %	8.02 ± 0.34	8.32 ± 0.31	9.11 ± 0.36	0.08
Protein, %	5.86 ± 0.08	6.21 ± 0.25	6.16 ± 0.16	0.37
LAC, %	5.88 ± 0.09	5.86 ± 0.09	5.66 ± 0.14	0.33
Dry matter, %	21.22 ± 0.34	21.77 ± 0.49	22.37 ± 0.51	0.23
Urea nitrogen, mg/dL	66.20 ± 2.67	68.22 ± 1.03	65.10 ± 1.82	0.56

<sup>1</sup>CON, control fiber; ISF, high insoluble fiber; SF, high soluble fiber.**Table 4.** Effects of high SF or ISF intake in late gestation on lactation performance of sows<sup>1</sup>

	CON	ISF	SF	P-value
Litter size, no.				
Cross-foster	11.42 ± 0.15	11.64 ± 0.15	11.42 ± 0.15	0.96
Weaning	10.72 ± 0.23	11.38 ± 0.35	10.05 ± 0.26	0.06
Piglet weight, kg				
Cross-foster	1.80 ± 0.14	1.79 ± 0.10	1.84 ± 0.14	0.83
Weaning	6.85 ± 0.35	6.76 ± 0.25	6.35 ± 0.32	0.34
ADG of piglet, g/d				
Day 1 to 7	165.19 ± 13.93	171.90 ± 8.74	149.03 ± 11.96	0.53
Day 8 to 14	271.46 ± 11.97	266.54 ± 12.99	241.02 ± 11.70	0.30
Day 15 to 21	281.33 ± 10.48	272.22 ± 12.50	255.37 ± 10.00	0.26
Day 1 to 21	240.07 ± 12.06	236.65 ± 10.39	215.15 ± 10.79	0.33
ADFI of sows, kg/d				
Day 1 to 7	1.50 ± 0.01	1.46 ± 0.03	1.50 ± 0.01	0.95
Day 8 to 14	6.02 ± 0.16	5.85 ± 0.19	5.73 ± 0.22	0.76
Day 15 to 21	7.04 ± 0.11	6.68 ± 0.19	6.88 ± 0.17	0.78
Day 1 to 21	4.85 ± 0.08	4.66 ± 0.10	4.70 ± 0.11	0.69
Litter weight at weaning, kg	73.10 ± 5.12	76.96 ± 2.66	64.75 ± 3.32	0.05
Preweaning mortality, %	6.13	2.23	12.00	0.06

<sup>1</sup>CON, control fiber; ISF, high insoluble fiber; SF, high soluble fiber.

Moreover, plasma MDA level in sows fed SF diet was lower than for sows fed ISF or CON diets on day 107 of gestation ( $P < 0.05$ ). In addition, sows fed ISF diet had decreased plasma level of MDA at parturition ( $P < 0.05$ ) when compared with sows fed the CON diet (Figure 1B). The T-SOD and CAT activities in the plasma were not affected by dietary treatment (Figure 1C–D;  $P > 0.05$ ).

## Discussion

### Litter performance

Several studies reported that high fiber intake during gestation improved the litter size of sows (Veum et al., 2009; Che et al., 2011). In this study, however, we did not observe increased litter size or increased litter weights by feeding high fiber diet, which



**Table 5.** Effect of high ISF or SF intake in late gestation on metabolic and immunological parameters of sows<sup>1</sup>

	CON	ISF	SF	P-value
GLU, mmol/L				
Day 107	3.72 ± 0.18	3.76 ± 0.34	3.87 ± 0.20	0.91
Parturition	3.88 ± 0.19	3.90 ± 0.22	3.73 ± 0.30	0.89
Lactic acid, mmol/L				
Day 107	2.23 ± 0.12	2.20 ± 0.21	2.29 ± 0.12	0.93
Parturition	2.77 ± 0.17	2.40 ± 0.15	2.52 ± 0.08	0.19
Triglyceride, mmol/L				
Day 107	0.46 ± 0.04	0.50 ± 0.08	0.54 ± 0.02	0.52
Parturition	0.19 ± 0.03	0.19 ± 0.01	0.17 ± 0.02	0.75
Urea, mmol/L				
Day 107	4.20 ± 0.18	4.51 ± 0.27	4.32 ± 0.15	0.57
Parturition	3.55 ± 0.27	3.83 ± 0.22	3.55 ± 0.22	0.93
Total protein, g/L				
Day 107	77.81 ± 1.79	76.29 ± 1.39	79.99 ± 1.15	0.20
Parturition	69.29 ± 1.82	65.88 ± 1.11	67.53 ± 1.32	0.29
ALB, g/L				
Day 107	34.67 ± 0.44 <sup>b</sup>	35.64 ± 0.55 <sup>b</sup>	38.46 ± 0.54 <sup>a</sup>	<0.01
Parturition	34.33 ± 0.70	34.19 ± 0.51	34.46 ± 0.43	0.95
Nonesterified fatty acid, μmol/L				
Day 107	94.90 ± 6.15	91.22 ± 6.45	99.67 ± 7.74	0.69
Parturition	633.70 ± 132.14	605.50 ± 78.07	560.10 ± 93.38	0.88
Total bile acid, μmol/L				
Day 107	101.56 ± 12.11	104.35 ± 4.27	110.18 ± 11.35	0.84
Parturition	85.10 ± 13.53	98.53 ± 10.38	86.04 ± 4.12	0.98
Immunoglobulin G, g/L				
Day 107	2.39 ± 0.27 <sup>b</sup>	3.29 ± 0.18 <sup>a</sup>	3.14 ± 0.15 <sup>a</sup>	0.01
Parturition	2.79 ± 0.18 <sup>b</sup>	3.70 ± 0.12 <sup>a</sup>	3.39 ± 0.12 <sup>a</sup>	<0.01
Immunoglobulin M, g/L				
Day 107	0.29 ± 0.05	0.21 ± 0.03	0.30 ± 0.05	0.23
Parturition	0.39 ± 0.02	0.36 ± 0.02	0.37 ± 0.04	0.80
Complement C4, mg/L				
Day 107	14.70 ± 1.22	13.60 ± 0.83	15.56 ± 1.61	0.55
Parturition	6.80 ± 1.04	5.90 ± 0.94	8.22 ± 1.14	0.31
C-RP, mg/L				
Day 107	3.17 ± 0.42	2.36 ± 0.21	2.23 ± 0.23	0.08
Parturition	3.58 ± 0.86	2.83 ± 0.55	2.53 ± 0.53	0.52

<sup>1</sup>CON, control fiber; ISF, high insoluble fiber; SF, high soluble fiber.

<sup>a,b</sup>Mean values within a row with unlike superscript letters were significantly different ( $P < 0.05$ ).  $n = 10$ .

may be related to the intervention period, as sows in the present study were provided dietary treatments only in late gestation. It is a noneffective period to change litter size in late gestation (Krogh et al., 2015; Feyera et al., 2017) as the litter size is already determined in early gestation partly (Durrant et al., 1980). In this study, moreover, dietary fiber may not be able to provide sufficient energy to influence litter weights, though dietary fiber could be fermented to produce SCFAs (Michael, 2015).

### Performance during the colostrum period and lactation

In this study, maternal fiber intake at 964 g/d with ISF/SF ratio either at 9.14 or 5.60 tended to increase the fat concentration of colostrum. High fiber intake may increase the retention of fat in the mammary glands prior to parturition, which then is secreted into early colostrum (Krogh et al., 2017; Feyera et al., 2018). No evidence of increased colostrum production due to fiber inclusion in this study, which is in contrast to Theil et al. (2014), but in line with Krogh et al. (2015).

Although SCFAs, produced by high fiber intake, could be used as substrate for the synthesis of milk fat (Loisel et al.,

2013), the reasons for the increased milk fat observed at day 7 of lactation for sows fed SF are unknown. Surprisingly, higher SF intake in late gestation tended to decrease the number of weaning piglets and litter weight at weaning, because the preweaning mortality was 12% in SF while it was as low as 2% in the ISF group. It is noteworthy that the amount of CI is far more important than the composition for the growth of piglet during lactation (Quesnel et al., 2012). Previous studies showed that piglet body weight gain increased concomitantly with CI during the first 24 h after birth (Devillers et al., 2011). Besides, Dyck and Swierstra (1987) reported that the preweaning mortality has been negatively associated with CI. In this study, we did find that the CI in sows fed the SF diet was numerically lower (11.6% decrease, 290 vs. 328 g on average), when compared with sows fed the CON diet. The lower amount of CI by the SF group may be partly responsible for the decreased number of weaning piglets. Supportively, Theil et al. (2014) found that sows fed pectin residue containing high insoluble fiber had markedly higher yield (approximately 1.56 kg increase) of colostrum than sows fed potato pulp containing high soluble fiber.

It is not known which specific mechanism may account for the negative effects of maternal SF intake on the survival rate of preweaning piglets. Previous studies have shown that fiber intake at 13% to 23% (16% on average) improved the piglets growth rate and intestinal function associated with the gut microbiome of neonates (Cheng et al., 2018; Li et al., 2019). In this study, however, the excessive intake of soluble fiber may not be positive on the intestinal function of the offspring. Vestergaard and Danielsen (1998) reported that both mean piglet weight and total mean litter weight at birth markedly decreased by receiving 500 g sugar beet pulp per kilogram diet. Likewise, long-term consumption of fermentable fiber leads to dysbiosis and hepatocellular carcinoma in a mice model (Singh et al., 2018).

### Immunology

The markedly changed physiology occurs around parturition, such as inflammatory response, changes of endocrine and metabolism (Quesnel et al., 2009), and transferring of maternal IgG to sow colostrum (Feyera et al., 2018). High fiber intake has been shown to influence immunology by changing intestinal microbiota or fermentation metabolites (Maslowski et al., 2009). In this study, maternal high ISF or SF intake increased IgG, but decreased C-RP concentration of plasma around parturition, indicating that farrowing stress may be alleviated by high fiber intake. As a biomarker for inflammation, the lower systematic level of C-RP in sows with high fiber intake suggests that inflammatory response was alleviated, which has been shown to influence colostrum composition (Aring et al., 1999). Consistently, systematic levels of IgG were higher when sows had higher fiber intake (Kim et al., 2016), and the immune-regulatory effect of dietary fiber has been mainly ascribed to its fermentation metabolites-SCFA, which would induce maturation of B cells, through upregulating genes for promoting the differentiation of naive B cells into B cells (Kim et al., 2014; Kim and Chang, 2017). Moreover, SCFA has been shown to enhance antibody production by activating cell-surface receptors (GPR41, GPR43, and GPR109A), histone deacetylase inhibition, and metabolic integration (Licciardi et al., 2011; Ganapathy et al., 2013).

### Redox status

The increased demands of energy and oxygen for the placenta of sows in late gestation lead to excessive oxidative stress,

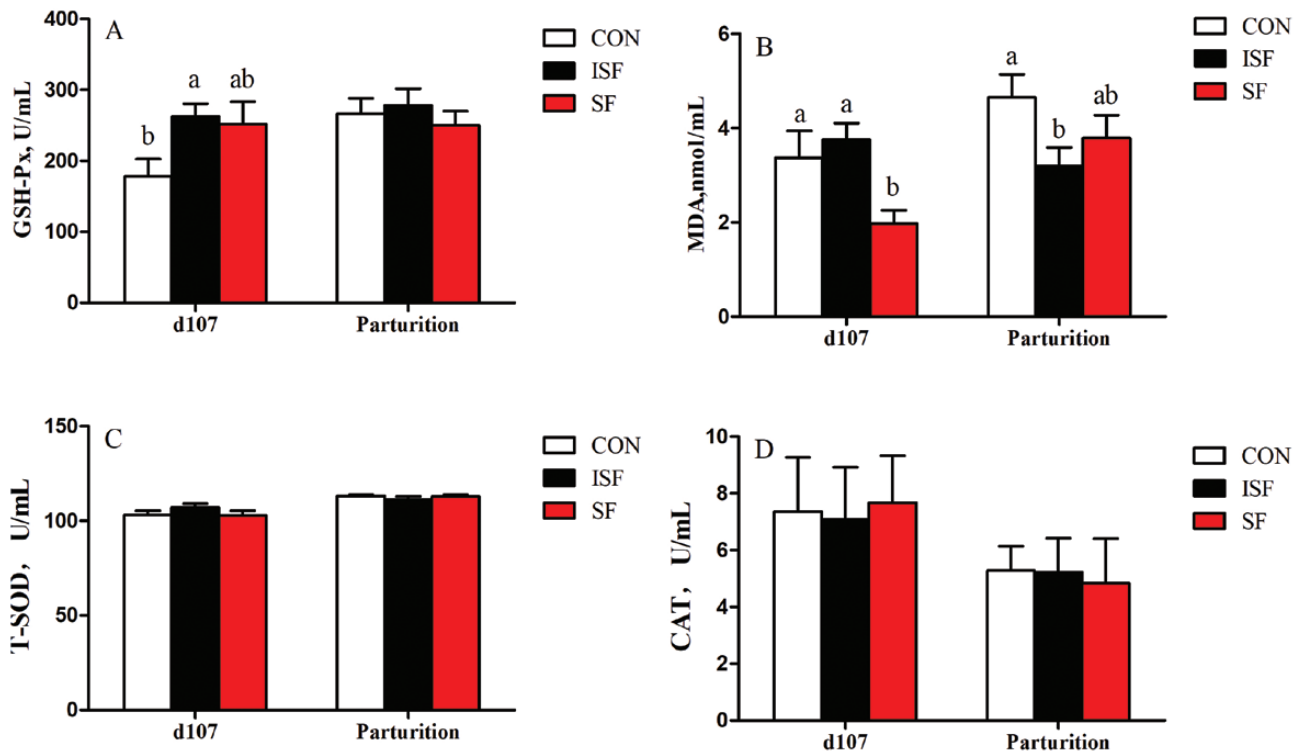


Figure 1. Effects of high SF or ISF intake in late gestation on redox status of sows around parturition. Plasma GSH-Px activity (A), MDA concentration (B), T-SOD activity (C), and CAT activity (D) were determined on day 107 and at parturition. Values are means, with their standard errors represented by vertical bars. <sup>a,b</sup>Mean values with unlike letters were significantly different ( $P < 0.05$ ).  $n = 10$ .

which impairs the litter performance of sows (Mueller et al., 2005). As a marker for oxidative stress, MDA is resulting from lipid peroxidation of polyunsaturated fatty acids (Che et al., 2019), and the lower MDA concentration may indicate relatively less energy supply from fatty acids, but more energy from GLU was available during farrowing. In line with Wang et al. (2016), in this study, maternal high fiber intake decreased the MDA level of plasma on day 107 of gestation or parturition and increased GSH-Px activity on day 107 of gestation, supporting the antioxidant effect of high fiber intake in sows around parturition.

## Conclusions

In this study, high ISF or high SF intake in late gestation did not markedly influence litter performance, but increased fat concentration of colostrum and milk and improved immune function and redox status around parturition. Unexpectedly, however, piglets from sows fed high SF diet had higher preweaning mortality in lactation and the underlying mechanism needs further research.

## Acknowledgments

This work was supported by the National Key Research and Development Program of China (2018YDF05001002), Overseas Expertise Introduction Project for Discipline Innovation (111 Project), and the National Natural Science Foundation of China (31872372).

## Conflict of interest statement

There is no conflict of interest for any of the authors of this manuscript.

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