Dietary supplement rich in fiber fed to late gestating sows during transition reduces rate of stillborn piglets[1]

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ABSTRACT: The beneficial effects of dietary fiber (DF) from a behavioral and welfare perspective have been thoroughly studied. However, data on the effects of DF on reproductive performance are scarce. Therefore, the aim of this study was to investigate the impact of increased DF supply during the last 2 wk of gestation on stillbirth rate, preweaning mortality, and total piglet mortality. A total of 644 sows were selected for the experiment from a commercial farm, and the sows were inseminated in weekly batches. Sows in the control group ($n = 310$) were fed according to the normal feeding strategy of the farm with a gestation diet until 1 wk before expected farrowing, then a transition diet until d 5 of lactation, and then a lactation diet until weaning. Sows in the treatment group ($n = 334$) were fed as the control group except that 280 g/d of the gestation diet (from d 102 to 108 of gestation) and 570 g/d of the transition diet (from d 109 of gestation until farrowing) was daily replaced with 350 and 700 g/d, respectively, of a DF-rich supplement. Both groups received isocaloric diets on a NE basis. The numbers of live-born and stillborn piglets as well as mortality of live-born piglets with presumed causes of death were recorded. The supplemented DF reduced the proportion of stillborn piglets from 8.8 to 6.6% ($P < 0.001$) and mortality of total born piglets from 22.3 to 19.9% ($P = 0.004$) but had no impact on preweaning mortality of the piglets ($P = 0.21$). Moreover, supplemented DF reduced the proportion of death due to poor viability ($P < 0.001$; 2.8 vs. 1.5% in the control and treatment groups, respectively) and prevalence of piglet diarrhea ($P = 0.004$; 0.7 vs. 0.3% in the control and treatment groups, respectively). Crushing, low birth weight, and poor viability were the top 3 contributors to preweaning mortality of live-born piglets, in descending order. In conclusion, the supplemented DF reduced the proportion of stillborn piglets and total piglet mortality as well as mortality due to poor viability and piglet diarrhea in lactation.

Key words: dietary fiber, late gestation, piglets, preweaning, stillbirth, transition period

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INTRODUCTION

The beneficial effects of dietary fiber (**DF**) from a behavioral and welfare perspective have been thoroughly studied in gestating sows (Bergeron et al., 2000; Ramonet et al., 2000; Meunier-Salaün et al., 2001; Holt et al., 2006). However, data on the effects of DF on reproductive performance are scarce (Meunier-Salaün and Bolhus, 2015). Oliviero et al. (2009) suggested that inclusion of DF in sow diets may improve the farrowing process whereas Theil et al. (2014) reported that DF increased the sow colostrum production. The farrowing process (Oliviero et al., 2010) and insufficient colostrum intake (Quesnel et al., 2012) are likely associated with stillbirth and preweaning mortality, respectively. Studies by Guillemet et al. (2007) and Krogh et al. (2015) reported nonsignificant but contrasting effects of DF on stillbirth, which could be due to the small sample size. Running such studies in commercial farms may be a way to avoid lack of power and reveal whether DF affects stillbirth rate. Because feed allowance is commonly low before farrowing and glucose is only net absorbed during the first 4 to 6 h after feeding (Serena et al., 2009), inclusion of DF may be beneficial

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to stabilize the postabsorptive energy status in sows. Therefore, supplementing sows with DF may be a way to potentially reduce the risk of stillbirth and to improve colostrum production (Theil et al., 2014) and thereby decrease total piglet mortality. Up to now, classical experiments have typically reported stillbirth and mortality of live-born piglets during the colostrum period or from litter equalization to weaning, whereby mortality of cross-fostered piglets is not considered. This experiment was specifically designed to study mortality of all born piglets, including cross-fostered piglets. Therefore, the present study aimed to investigate the impact of supplemented DF fed to late gestating sows in the last 2 wk of gestation on the stillbirth rate, preweaning mortality, and total mortality of piglets in a commercial farm.

MATERIALS AND METHODS

The study was conducted in a commercial sow farm (Slagelse, Denmark) with Danish Landrace × Danish Yorkshire (DanAvl, Copenhagen, Denmark) sows. All procedures involving animals were conducted in accordance with the guidelines of the Danish Ministry of Justice with respect to animal experimentation and care of animals under study (The Danish Ministry of Justice, 1995).

Farm Selection, Randomization, and Housing

The farm was selected on the basis of its ability to mix and feed individual diets and its flexibility to apply different feeding programs. The farm has a SpotMix feeding system (Schauer Agrotronic GmbH, Prambachkirchen, Austria) that enables separate feeding of different dietary components for individual gestating and lactating sows during the trial and allowed feeding of 2 different diets for gestating sows using electronic sow feeding stations (Schauer Agrotronic GmbH).

The study included a total of 644 first- to eighth-parity sows (Danish Landrace × Danish Yorkshire; DanAvl), which were studied during the last 2 wk before expected farrowing. The sows were inseminated in weekly batches with Duroc semen (Hatting KS, Horsens, Denmark), and sows with odd and even ear numbers were assigned to the control ($n = 310$) and the treatment ($n = 334$) groups, respectively. Sows were included in the experiment in 32 subsequent weeks with 13 to 26 sows per week.

Sows were kept loose in large dynamic gestation units until they were moved to the farrowing pens 1 wk before expected farrowing. From d 109 of gestation and throughout lactation, sows were individually kept in the farrowing pens (2.5 by 1.6 m) made of 64% concrete insulated floor and 36% cast-iron slatted floor. Each farrowing pens was designed with a separate creep area for piglets including cover, floor heat, and an infrared heating lamp to keep the ambient temperature of the creep area at 32°C around farrowing. The room temperature was kept at 20°C and controlled with diffuse ventilation. All sows farrowed naturally, that is, without inducing parturition.

Diets and Feeding

Three different diets, a gestation diet, a transition diet, and a lactation diet, were formulated to ensure sows were fed according to or above Danish recommendations (Tybirk et al., 2013). In addition, a DF-rich supplement based on wheat, dehulled sunflower seed, sugar beet pulp, soybean hulls, and soybean oil was formulated to contain high fiber and slightly more CP than the gestation and the transition diets (Table 1). The gestation diet, the transition diet, and the lactation diet were all based on wheat, barley, oat, soybean meal, and soybean oil (Table 1). The supplementary DF was designed to replace part of the daily gestation diet from d 102 to 108 of gestation or part of the daily transition diet from d 109 of gestation until farrowing without affecting the daily NE intake of the sows. Sugar beet pulp was included as a DF source because it has shown an interesting numerical effect on stillborn piglets (8.3 vs. 4.9% for control and high fiber, respectively; Krogh et al., 2015), and soybean hulls was included because it is commonly used in sow diets. Dehulled sunflower seed was included to slightly increase the daily protein supply, because factorial calculations indicated that late gestating sows required extra protein for their colostrum production (Theil, 2015). Dietary ingredients and calculated and analyzed chemical compositions of the diets are presented in Table 1.

Before d 101of gestation and throughout the lactation period, all sows were fed according to the normal feeding strategy of the farm. On d 102 of gestation, sows were assigned to either the control group or the treatment group based on their ear number. The treatment group was fed 2 dietary components each day during the experimental period. Therefore, 280 g of the daily gestation diet was replaced with 350 g of the supplementary DF during d 102 to 108 of gestation and 570 g of the daily transition diet was replaced with 700 g of the supplementary DF from d 109 of gestation until farrowing. The amount of supplementary DF that replaced either part of the gestation or transition diet was chosen to achieve the same NE intake on a daily basis; therefore, the treatment group received slightly more feed (in kg; Fig. 1A) per day than the control group due to the lower energy density, on a NE basis,

Table 1. Dietary ingredients, calculated and analyzed chemical composition of the gestation diet (GD), transition diet (TD), lactation diet (LD), and supplemented dietary fiber (SDF)

Item	GD	TD	LD	SDF
Dietary ingredients, g/kg, as-is basis				
Wheat	598	509	501	282
Barley	150	127	125	–
Oats	120	200	120	–
Soybean meal, dehulled	106	120	197	–
Soybean oil	–	10	22	32
Sunflower seed dehulled, high protein	–	–	–	192
Sugar beet pellets, unmolassed	–	–	–	240
Soybean hulls	–	–	–	240
Sugar beet molasses	–	–	–	5
Premixes[1]	26	34	35	9
Calculated composition, as-is basis				
DM, %	86.9	87.0	87.4	88.7
CP, g/kg	122.6	128.9	157.4	142.0
SID[2] protein, g/kg	101.0	106.1	132.4	100
SID lysine, g/kg	4.6	5.0	7.9	3.7
Crude fat, g/kg	2.52	3.65	4.65	5.10
Crude fiber, g/kg	41	47	46	173
Ca, g/kg	6.9	7.9	8.3	5.6
P, g/kg	4.0	5.0	5.3	3.7
Energy, MJ NE/kg feed	9.69	9.64	9.91	8.91
Analyzed composition, as-is basis				
DM, %	87.2	87.5		88.7
CP, g/kg	123	130		153
Crude fat, g/kg	27	37		44
Crude fiber, g/kg	31	43		153
Nonstarch polysaccharides, g/kg DM	129	139		388
Klason lignin, g/kg DM	21	28		41
Dietary fiber, g/kg DM	150	167		429
Ca, g/kg	6.4	7.4		6.0
P, g/kg	4.0	4.7		3.7

[1] Supplied per kilogram of the GD: 4.02 g chloride, 42.59 mg Mn, 85.18 mg Fe, 15 mg Cu, 106.48 mg Zn, 0.21 mg I, 0.4 mg Se, 8,520 IU vitamin A, 1,000 IU 850 IU vitamin D_3, 63.89 mg α-tocopherol, 4.26 mg vitamin K_3, 2.13 mg thiamin, 5.32 mg riboflavin, 3.19 mg pyridoxine, 0.02 mg vitamin B_{12}, 15.97 mg D-pantothenic acid, 21.30 mg niacin, 1.6 mg folic acid, 250 mg choline chloride, 0.44 mg biotin, 1,875 mg Ronozyme (Vitfoss, DK-6300 Gråsten, Denmark), 1.96% N, 0.4% P, and 0.65% K.

[2] SID = standardized ileal digestible.

of the supplementary DF. Subsequently, sows in the control group received 3.27 and 3.30 kg/d and those in the treatment group received 3.34 and 3.44 kg/d from d 102 to 108 of gestation and from d 109 of gestation until farrowing, respectively. The daily supply of feed (kg/d), DF (g/d), CP (g/d), and fat (g/d) during the study period are presented in Fig. 1A, 1B, 1C, and 1D, respectively. Feed supply on d 114 of gestation and on the day of farrowing were intentionally reduced by 14% compared with the preceding days to minimize farrowing problems associated with gut fill. Sows were fed 3 meals per day of equal portions at 8-h intervals.

Farrowing Sows and Piglet Handling

Normal farrowing surveillance and farrowing assistance was provided in both groups during farrowing. Sows were inspected every 45 to 60 min during farrowing either for the presence of newborn wet piglets in the pen (indicator of farrowing progression) or presence of expelled placenta (indicator of cessation of farrowing), as a standard procedure in the farrowing unit, typically during the working hours. Moreover, farrowing sows were supervised once during the middle of the night. If no progression was observed, then obstetric aid was performed. However, oxytocin was not used during the obstetric aid as it can only be used to facilitate milk letdown in Danish swineherds.

The numbers of live-born and stillborn piglets were recorded for individual sows. Live-born piglets were ear marked to allow identification of treatment and week of farrowing for individual piglets until weaning. Any live-born piglets that were found weak and lying behind the sow were placed under the heating lamp. Piglets that were found dead right behind the sow as well as piglets that were found wrapped in their placental membranes were recorded as stillborn piglets, but lung autopsies were not performed to confirm this. Therefore, piglets may have been misclassified as stillborn in the current study according to presence or absence of breathing after delivery, but this strategy was chosen to distinguish between piglets that died before or during the birth process from piglets that were viable enough to potentially suckle colostrum. All litters were standardized to 13 to 15 piglets within 24 h postpartum on the basis of functional teats. After litter standardization, surplus piglets were cross-fostered to the nurse sows, defined as sows that wean an additional litter (nurse litter) after weaning their own litter (Bruun et al., 2016). Within the dietary treatment, piglets were cross-fostered to maximize the number of weaned piglets, as is commonly done at the farm. Piglets cross-fostered to nurse sows always remained at their own dams for at least 12 h postpartum to ensure adequate colostrum intake. On average, the nurse sows nursed the cross-fostered piglets for about 21 d. The average weaning age was close to 4 wk, but piglets that were too small were either nursed for 7 extra days at their own dam or moved to a 1-step nurse sow (Bruun et al., 2016) that received small piglets from several litters within the treatment groups.

Recording of Preweaning Piglet Mortality and Presumed Causes

Mortality of live-born piglets and the presumed main causes of death were recorded according to the criteria described in Table 2. Basically, identification of the causes of death was established post hoc and based

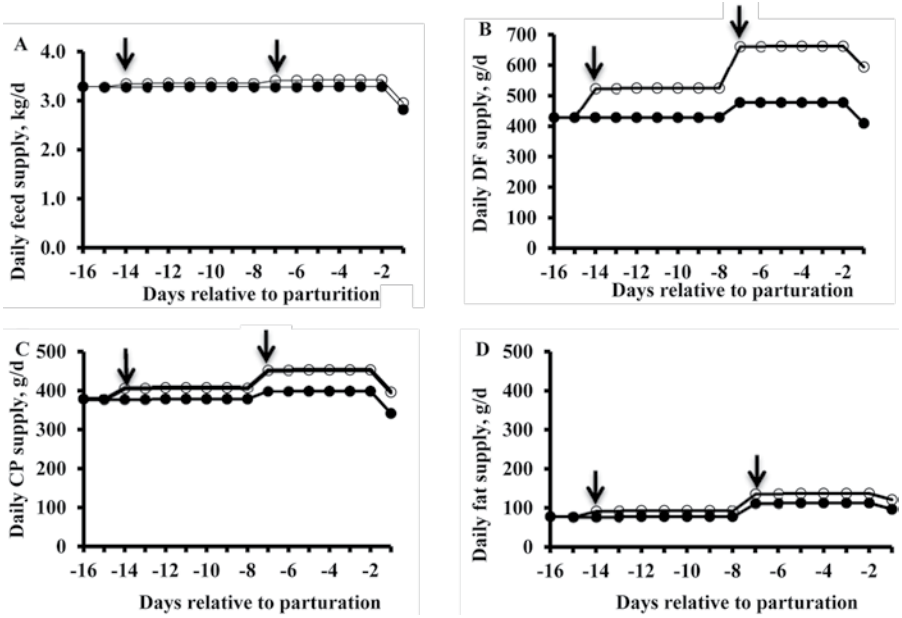

Figure 1. (A) The daily feed supply during the experimental period for the sows that were fed the control diet (solid squares) or the dietary fiber–supplemented treatment diet (open squares). Feed supplies on d 1 before expected farrowing and on the day of farrowing were intentionally reduced by 14% to minimize farrowing problems associated with gut fill. Sows fed the control diet received 3.3 kg/d of feed from d −14 until −1, whereas the treatment group received an isoenergetic amount (on a NE basis) where part of the diet was replaced with a fiber-rich supplement (280 g of diet was replaced with 350 g of supplement from d −14 until −8 and 570 g of diet was replaced with 700 g of supplement from d −7 until −2). The arrow at d −14 indicates change to dietary treatment and the arrow at d −7 indicates transfer of both groups to the transition diet (and increased inclusion level of the dietary supplement). (B–D) Daily supplies of dietary fiber (DF), CP, and fat, respectively, in sows that were fed the control diet (solid circles) or DF-supplemented treatment diet (open circles) during the last 2 wk of gestation. The arrow at d −14 indicates change to dietary treatments and the arrow at d −7 indicates transfer of both groups to the transition diets.

on physical examination of the dead piglets combined with some observations made before the death. The procedure with recording the cause of piglet mortality had been done for several years at the farm before we performed this experiment. Only experienced personnel (trained by the owner) took care of this procedure, and most of the observations were indeed performed by the owner. Accordingly, crushing, low birth weight, poor viability at birth, starvation, diarrhea, joint infection, and "unidentified" were recorded as the presumed causes of mortality of live-born piglets in lactation (see Table 2 for full description). The total number of deaths in each category was recorded for the respective group within each weekly batch, and the values were expressed as a percentage of total live-born piglets.

Feed Sampling and Analysis

Feed samples were collected every second week and pooled every sixth week over the experimental period. In total, 4 pooled samples of the gestation diet and supplementary DF and 5 pooled samples of the transition diet were analyzed in duplicate for DM, CP, crude fat, crude fiber, Ca, and P. All analytical procedures was performed according to European Commission ([EC] 152/2009; European Commission, 2009). Nonstarch polysaccharide and Klason lignin were analyzed as described by Knudsen (1997), and the sum was reported as DF.

Statistical Analysis

All statistical analyses were performed using SAS Enterprise Guide version 7.1 (SAS Inst. Inc., Cary, NC).

The number of stillborn piglets as a proportion of the total born piglets, preweaning piglet mortality as a proportion of the total born piglets, and total piglet mortality (sum of stillborn and preweaning deaths) as a proportion of the total born piglets were analyzed using the GLIMMIX procedure including treatment group as a fixed effect and weekly batch as a random effect, and total born piglets was used as a covariate. Furthermore, total born piglets, number of live-born piglets, and number of weaned piglets per litter were analyzed using the MIXED procedure including treatment group as a fixed effect and weekly batch as a random effect. Causes of death were analyzed using a χ^2 test using the FREQ procedure to test differences between the 2 groups, and results were reported as a proportion relative to the number of total born piglets. Moreover, to investigate the difference of the 2-frequency function of the binomial distributions of stillborn piglets within the treatment groups, 8 χ^2 tests were performed, and the results were reported as a percent of stillborns per litter. The effect of parity

Table 2. Description of the different presumed causes of preweaning piglet mortality in lactation

Cause of death	Description of the cause
Crushing	Piglets that were found dead underneath or beneath the sow or with visible signs of crushing (e.g., squashed or bruised)
Low birth weight	Piglets were found lying down in the pen, typically in the corners or under the heat lamp, away from the other piglets. They were skinny and weak but did not show signs of having been crushed.
Poor viability at birth	Piglets with no or minor physical activity (likely weakened by asphyxia) or piglets born with deformities
Diarrhea	Piglets that were found dead with visible sign of diarrhea under the tail or on the rear part of the piglets
Starvation	Piglets that have been alive for a couple of days and became very skinny, spent more time in proximity to the udder, holding teat in the mouth and massaging after the suckling bout already finished
Joint infection	Piglets that were found dead with noticeable swelling or injury on the joints/hooves
Other causes	When the causes of death were uncertain or unidentified

on the incidence of stillbirths was analyzed using the GLIMMIX procedure including treatment group and parity as a fixed effect and weekly batch as a random effect, and no interaction was seen between treatment group and parity ($P = 0.08$). Due to the focus on mortality of all born piglets, less attention was given to the sows and their actual day of lactation. Therefore, for weekly preweaning piglet mortality, all dead piglets within each weekly batch were grouped in the following ages, based on the mean date of farrowing within each weekly batch: d 0 to 7, d 8 to 14, d 15 to 21, and d 22 to 28, where d 0 is the mean day of farrowing within a weekly batch. Therefore, the stages represent the age of piglets as ±3 d from the mean day of farrowing. This was done because the trial design was based on analyzing survival and mortality within weekly batch and after cross-fostering, but it was only possible to link the dead piglets to the weekly batch, not to individual sows. A statistical difference was declared at $P < 0.05$.

RESULTS AND DISCUSSION

The analyzed chemical composition of the diets was fairly close to the intended composition. The high-fiber supplement contained 43% DF whereas the gestation and the transition diets contained 15 and 17% DF, respectively. Moreover, the supplemented DF contained slightly more CP (14%) than the gestation and the transition diets, which both contained 11%. On a daily basis, the sows in the treatment group received 23 (on d −14 through −8) and 38% (on d −7 through −2) more DF than the control group. Concomitantly, the treatment group received 8% more CP and 19% more fat on d −14 through −8 and 14% more CP and 21% more fat on d −7 through −2 compared with the control group. Consequently, the obtained effects in the present study on stillbirth rate were regarded to be due to the difference in daily DF supply and not due to the different supplies of CP or other nutrients. In line with this, a previous Danish study with 1,400 sows fed either a standard gestation diet or a diet with elevated CP content during the last trimester did not demonstrate any effect on rate of stillbirth and preweaning mortality until d 7 of lactation (Sørensen, 2008).

Dietary Fiber and Impact on Litter Size and Piglet Mortality

The high-fiber supplement had no impact on the number of total born piglets ($P = 0.38$; Table 3). A meta-analysis by Reese et al. (2008) reported an increased litter size in response to high DF fed to sows over multiple successive reproductive cycles. However, in the present study, sows received high DF only during the last 2 wk before expected farrowing, which is likely too late to affect the litter size.

Supplemented DF resulted in a reduction of stillbirths per litter from 8.8% in the control group to 6.6% in the treatment group ($P < 0.001$; Table 3). Such a striking impact of high DF observed in the present study is believed to be a breakthrough in our effort to improve piglet survival through dietary manipulation. Therefore, the result indicates a new avenue toward the reduction of stillbirths by improving the sow feeding strategy during the transition period and was in line with our hypothesis that high DF in late gestation can reduce piglet mortality. Interestingly, the reduction was found in a commercial farm, which already had a stillbirth rate below the national average of 9.8% in Danish commercial farms (Jessen, 2015). As a consequence, we believe that such a feeding strategy will be favorable for many farms. In support of our results, Krogh et al. (2015) found a stillbirth rate of 8.3% for control sows and 4.9% for sows fed sugar beet pulp with experimental diets similar to those used in the present study, although differences in the study by Krogh et al. (2015) were not statistically significant due to a low number of sows. To our knowledge, the present study is the first to document a beneficial impact of high DF on stillbirth rate. The large sample size used in the present study compared with previous studies (Guillemet et al., 2007; Oliviero et al., 2009; Loisel et al., 2013; Krogh et al., 2015) may explain why beneficial impact of transition feeding on stillbirth rate has not been previously reported.

The underlying mechanisms of DF on the stillbirth rate observed in the present study may be related to multiple effects of DF on the nutrient digestibility pattern and/or the passage rate of the digesta. Observations on farrowing durations, fecal scores, and energy status of the sows during farrowing could have added to our understanding, but due to the nature of the large sample size in the present study, it was not possible to include such explanatory variables in the study protocol. Although the sequence of events leading to reduced stillbirth rate cannot be explicitly described from the present study, 2 modes of action of DF on the stillbirth rate may likely be involved. First, sows that were fed high DF in late gestation would less likely develop constipation before parturition due to increased intestinal activities and the high water-holding capacity of the DF (Oliviero et al., 2009; Krogh et al., 2015; Zhao et al., 2015), and water in the colon digesta in turn increases the softness of the feces. According to Krogh et al. (2015), sows supplemented with high DF have a greater incidence of soft feces at farrowing than their nonsupplemented counterparts (68 vs. 29%, respectively; $P = 0.04$), and this is in line with what Oliviero et al. (2009) reported. Soft feces may prevent physical blockage of the birth canal and allow rapid passage of piglets during parturition, and therefore, feeding high DF during the transition period is likely favorable to the farrowing process (Oliviero et al., 2009). The other potential beneficial effect of high DF may be related to a longer postprandial energy uptake from the gastrointestinal tract in sows fed high DF (Serena et al., 2007), which stabilizes interprandial blood glucose levels (de Leeuw et al., 2004). In line with this, Serena et al. (2009) found that approximately 30% of net absorbed energy originated from VFA in sows fed high DF. Therefore, the possible modes of actions of high DF in reducing the stillbirth rate could be through softening of the feces and/or due to increased postprandial energy uptake around farrowing, both of which may contribute to shorter farrowing durations and ultimately reduce stillbirth.

Preweaning and Total Piglet Mortality

Supplemented DF had no impact on total born piglets ($P = 0.38$) or live-born piglets ($P = 0.78$) per litter or preweaning mortality of live-born piglets ($P = 0.21$; Table 3). The preweaning mortality was 10.4 vs. 10.0%, 2.3 vs. 2.1%, 1.1 vs. 1.0%, and 0.7 vs. 0.5% in first, second, third, and fourth week, respectively, of lactation in the control and the treatment group. In the present study, it was hypothesized that supplemented DF and a slightly elevated CP supply in late gestation could increase sow colostrum production and subsequently reduce preweaning piglet mortality, because colostrum is vital for piglet survival immediately after birth (Quesnel et al., 2012). However, the preweaning mortality of live-born piglets was only numerically reduced in the treatment group compared with the control group (13.7 vs. 14.6%, respectively), indicating that neither DF nor CP was able to substantially increase the colostrum production.

Table 3. Effect of supplemented dietary fiber on stillbirth, live-born, and total born piglet mortality and the causes of preweaning piglet mortality expressed as a percent of total born piglets in sows that were fed the control diet (Control) or dietary fiber–supplemented diet (Treatment) during the last 2 wk of gestation

Item	Control	Treatment	SEM[1]	*P*-value
Number of sows	310	334		
Number of nurse sows	52	56		
Number of total born piglets	18.4	18.1	0.29	0.38
Number of live-born piglets	16.8	16.9	0.25	0.78
Number of weaned piglets	14.2	14.4	0.23	0.66
Stillborn piglets, % of total born	8.8^{a}	6.6^{b}	0.47	<0.001
Preweaning mortality, % of total born	14.6	13.7	0.68	0.21
Overall mortality, % total born	22.3^{a}	19.9^{b}	0.71	0.004
Causes of preweaning piglet mortality, % of total born				
Crushing	4.7	5.0		0.41
Low birth weight	3.2	3.6		0.24
Poor viability at birth	2.8^{a}	1.5^{b}		<0.001
Unidentified	2.3	1.9		0.20
Starvation	0.8	1.0		0.36
Joint infection	0.5	0.5		0.91
Diarrhea	0.7^{a}	0.3^{b}		0.004

[a,b]Means within a row with different superscripts differ ($P < 0.05$).

[1]The largest SEM.

Supplemented DF reduced total piglet mortality ($P = 0.004$; Table 3), reflecting the reduced stillbirth rate in sows fed high DF, whereas the contribution of preweaning mortality did not differ between treatments. Piglet mortality is a major determinant of sow productivity (Weber et al., 2009; Kirkden et al., 2013; Moustsen et al., 2013), and according to our study, it is possible to increase total piglet survival by nutritional means. Evidently, the majority of improvement in total piglet survival was achieved through the reduction in peripartum death by supplementing DF in late gestation. Because dietary intervention was terminated at farrowing in the present study, any difference observed between the groups during lactation could be attributed to the carryover effect of the dietary treatment in late gestation.

Causes of Preweaning Piglet Mortality

Crushing, low birth weight, and poor viability at birth were the top 3 contributors of mortality, in descending order, in the present study (Table 3). Dietary treatment had no significant impact on the proportion

Table 4. Frequency distribution of stillborn piglets per litter in sows fed either a control diet (Control) or a dietary fiber–supplemented diet (Treatment) during the last 2 wk of gestation

Stillborn per litter	Frequency,[1] %		*P*-value
	Control	Treatment	
0	31.6 (98)	38.9 (130)	0.05
1	26.4 (82)	31.1 (104)	0.18
2	17.4 (54)	14.7 (49)	0.35
3	9.7 (30)	8.7 (29)	0.67
4	7.1 (22)	3.0 (10)	0.02
5	2.9 (9)	1.2 (4)	0.13
6	2.3 (7)	1.2 (4)	0.30
≥7	2.6 (8)	1.2 (4)	0.20

[1] The number in parenthesis indicated the number of sows within each category of stillborn per litter.

of death due to crushing, low birth weight, or starvation (Table 3). In agreement with earlier studies (Jarvis et al., 2005; Alonso-Spilsbury et al., 2007; KilBride et al., 2012; Kirkden et al., 2013), crushing was a major contributor to preweaning piglet mortality in the present study. However, the proportion of dead piglets due to crushing in the present study is lower than the ranges of 50 to 75% that have been frequently reported (Marchant et al., 2000, 2001; Alonso-Spilsbury et al., 2007). The greater number of causes of mortality recorded in the present study, compared with earlier reports, may explain the lower proportion of death recorded due to crushing. In their studies, Jarvis et al. (2005) concluded that some sows consistently crush more piglets across parities, whereas Andersen et al. (2005) suggested that crushing as a cause of piglet mortality is highly related to mothering ability rather than to dietary treatments.

Interestingly, supplemented DF reduced the proportion of death due to poor viability at birth ($P < 0.001$) and piglet diarrhea ($P = 0.004$; Table 3). Sows that were fed high DF may have shorter farrowing durations as discussed above (see the Dietary Fiber and Impact on Litter Size and Piglet Mortality section), thereby causing less-distressed piglets during farrowing. Therefore, the most possible explanation for the improved viability at birth in the present study is likely due to the premise that supplemented DF resulted in shorter farrowing durations and consequently reduced piglet distress during farrowing. However, we speculate whether increased plasma content of short-chain fatty acids of newborn piglets may also explain why fewer piglets die due to poor viability when sows are fed high DF, because these piglets probably had an improved energy status. In contrast to other studies (Larson and Schwartz, 1987; Coolman et al., 2002; Alonso-Spilsbury et al., 2007), piglet diarrhea was ranked as the least contributor to preweaning piglet mortality in the DF-supplemented group (Table 3). Even though piglet diarrhea was found to be the least contributor to preweaning mortality in the present study, the prevalence of diarrhea was 2.33-fold greater for the non-fiber-supplemented group than for the DF-supplemented group. According to Quesnel et al. (2012), 200 g of colostrum per piglet is the minimum consumption to provide adequate immunity, ensure survival, and reduce risk of infection. Therefore, the less-prevalent piglet diarrhea observed in the piglets nursed by the sows that were fed supplemented DF may be attributed to a greater colostrum intake than the control group, although the amount ingested was not quantified in this study. Alternatively, the prebiotic effect of DF in inhibiting the growth of enteric pathogenic bacteria (Lindberg, 2014) might also indirectly have contributed to the less-prevalent piglet diarrhea in litters nursed by sows fed DF in late gestation.

Frequency Function of Stillbirth and Parity Effect on Stillbirth

Zero stillbirths was the most frequently observed outcome in both groups (Table 4), but its frequency was greater in the DF-supplemented group than in the control group (38.9 vs. 30.5%, respectively; $P = 0.05$). Supplemented DF reduced the rate of stillbirths when the number of stillbirths per litter was 2 or more, although it was only significantly different between the 2 dietary treatments when 4 stillborn piglets per litter were observed ($P = 0.02$). One stillborn piglet per litter may not be regarded a major problem, because this may occur by chance and is not necessarily related to farrowing difficulties; for instance, it could be due to an entangled umbilical cord. However, a stillbirth rate of 2 or more per litter could be regarded as problematic (Baxter et al., 2013; Rutherford et al., 2013) and cause reduced production efficiency. If the recorded data were categorized in 2 classes (i.e., ≤1 and ≥2 stillborn piglets per litter) in the present study, 43.1 and 30.0% of the sampled population gave birth to 2 or more stillborn per litter in the control and in the DF-supplemented group, respectively ($P < 0.01$). These findings suggest that including high DF in the diet for late gestating hyperprolific sows is a promising way forward in the modern swine industry to reduce the stillbirth rate.

The risk of stillbirth increased with parity in the present study (Table 5; $P < 0.001$), which is in agreement with earlier studies (Leenhouwers et al., 2003; Canario et al., 2006; KilBride et al., 2012). The increased risk of being stillborn with parity may be related to larger litter size (KilBride et al., 2012; Kraeling and Webel, 2015) or reduced frequency and intensity of uterine contractions in older sows (Olmos-Hernández et al., 2008), which all may contribute to a prolonged

Table 5. The effect of parity on the stillbirth rate expressed as percent of total born

Parity	No.[1]	Stillbirth rate, %
1	131	5.3^{d}
2	154	5.2^{d}
3	117	6.7^{c}
4	92	8.5^{bc}
5	74	9.3^{bc}
6	42	11.8^{b}
≥7	34	16.1^{a}

$^{a–d}$Means within a row with different superscripts differ ($P < 0.05$).

[1] Number of sows in each parity class.

farrowing duration. Moreover, a larger litter size in older parity sows may lead to intrauterine growth restriction thereby reducing piglet birth weight, which is a risk factor of being stillborn, particularly late in the birth order (Canario et al., 2006). The increased risk of stillbirth late in the birth order might be related to a possibly lowered energy status of the sows that impairs uterine contractions or the cumulative effect of successive uterine contractions that reduce oxygenation of unborn piglets, which, in turn, causes asphyxia (Herpin et al., 1996; Alonso-Spilsbury et al., 2005). Even though stillbirth was progressively increased with parity, inclusion of high DF in the diet during late gestation favorably reduced the rate of stillbirths per litter ($P < 0.001$) independent of the parity, as no interaction between parity and dietary treatment on the number of stillbirths was found ($P = 0.08$).

Conclusions and Implications

It can be concluded from the present study that high DF supplemented to late gestating sows in the last 2 wk before expected farrowing reduced the proportion of stillborn piglets and consequently reduced total piglet mortality. Fewer live-born piglets died due to poor viability at birth and due to piglet diarrhea. Further investigations are needed to reveal the mode of action of DF to reduce the stillbirth rate using various fiber sources.

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