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Sow and piglet traits associated with piglet survival at birth and to weaning

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Abstract

Understanding the relationship between sow and piglet characteristics that are associated with stillborn rate and preweaning mortality is beneficial as litter size continues to increase. Two experiments were previously conducted to evaluate prefarrowing nutrition regimens on sow and litter characteristics. These two datasets (experiments 1 and 2) were then used to identify sow and piglet characteristics associated with stillborn rate and piglet survival to weaning. A total of 1,201 sows that gave birth to 19,168 pigs comprised the dataset. The following characteristics were used in multivariate logistic regression analysis for traits associated with stillborn rate or survival to weaning: parity, litter weight, mean piglet birth weight, sow backfat, and BW at day 113 of gestation, gestation length, farrowing duration, litter size, piglet birth order, farrowing assistance, pig to teat ratio, colostrum intake, and colostrum yield. Sows within each experiment (herd) were categorized into quartiles for each of the independent variables to quantify the relationship to stillborn rate or survival to weaning. Increased stillborn rate was associated ($P < 0.01$) with heavier litter weights, lighter piglet birth weights, and larger litters in both experiments. In experiment 1, increased stillborn rate was associated ($P < 0.01$) with longer farrowing duration. Increased stillborn rate was associated with sows with less backfat depth at day 113, older parity, or increased farrowing assistance in experiment 2. In both experiments, pigs born later in the birth order had an increased ($P < 0.01$) risk of being stillborn. In both experiments, heavier piglet birth weight, greater colostrum intake, and lower total born were associated ($P < 0.01$) with increased survival to weaning. In experiment 2, pigs born in the first 75% of the litter, or in a litter with lower pig to teat ratio were associated ($P < 0.01$) with increased survival to weaning. Although the stillborn rate was similar between experiments (6.5% vs. 6.6%), differences in the traits associated with stillborn rate between studies indicate that some associated traits may be herd dependent. However, improving piglet birth weight, placing an emphasis on assisting pigs born later in the birth order and increasing colostrum intake will increase piglet survival from birth to weaning.

Key words: birth order, farrowing duration, lactation, piglet survival, stillborn, sow

Introduction

Currently in U.S. swine herds, stillborn and mummified fetuses represent 9.8% of total born pigs, while preweaning mortality is 17.8% on average (Stalder, 2018). Therefore, over 25% of total born pigs do not survive to weaning. This represents both an economic cost and a welfare concern for the swine industry.

Abbreviation

BIC	Bayesian information criterion

Stillborn pigs are typically a result of hypoxia due to successive contractions constricting the umbilical cord (Alonso-Spilsbury et al., 2005), which increases stillbirth rate for those piglets born later in the farrowing process. Typically, longer farrowing duration is associated with an increased stillborn prevalence (Theil, 2015). Several studies have reported longer farrowing duration is associated with litter size, sow constipation score, and time since last meal prior to farrowing (van Dijk et al., 2005; Feyera et al., 2018; Langendijk and Plush, 2019). Even if a piglet is live born, it is estimated that 15% to 20% are hypoxic at birth which could impact piglet survival in the first 24 h and to weaning. Hypoxic piglets have reduced suckling response leading to reduced colostrum intake and poor temperature homeostasis (Langendijk and Plush, 2019).

Although several reviews and studies have focused on areas associated with stillborn rate and preweaning mortality, little data are available that associated piglet survival at birth and at weaning to sow and piglet traits that could be easily measured or influenced by management or nutrition (van Dijk et al., 2005; Rootwelt et al., 2012; Udomchanya et al., 2019). Furthermore, these studies are typically conducted in research settings with small sample sizes (Panzardi et al., 2013; Nuntapaitoon et al., 2018).

Therefore, the objective of the present study was to evaluate individual sow and piglet records from two commercial sow research studies to: (1) identify sow characteristics associated with increased stillborn rate, (2) identify piglet characteristics associated with being a stillborn pig, and (3) identify sow and piglet characteristics that are associated with piglet survival to weaning.

Materials and Methods

The results presented in the current paper are based on data from two independent studies that evaluated the effects of peripartum feeding strategies on piglet survival, colostrum production, and litter performance (Gourley et al., 2020a; 2020b). The two studies were conducted on commercial sow farms in southern Minnesota. Sows were individually housed in environmentally controlled and mechanically ventilated barns and were fed corn–soybean meal-based diets during gestation and lactation.

Study population

Experiment 1

Data were collected from May to August 2018. Sows were fed 2 kg of gestation diet until day 107, at which time dietary feeding strategies were imposed until farrowing as previously described (Gourley et al., 2020a), then fed lactation diet ad libitum until weaning (20.7 d ± 1.6). The study used 473 sows (PIC Large White × Topigs Norsvin Landrace; parity 1.7 ± 1.6) that gave birth to 7,154 pigs (6,458 live-born and 481 stillborn). Mummified fetuses (n = 215) were excluded from the analysis and total born calculations. Litters (n = 11) with total born of six or fewer were not used in the analysis. Piglets remained with their birth sow until 24 h postfarrowing, then were cross fostered within dietary treatments to equalize litter size.

Experiment 2

Data were collected from May to August 2019. Sows were fed 2 kg of gestation diet until entry to farrowing house (day 113 ± 1.7), at which time dietary feeding strategies were imposed until farrowing as previously described (Gourley et al., 2020b), then fed lactation diet ad libitum until weaning (21.7 d ± 3.3). The study used 728 sows (Fast Large White × PIC Landrace; parity 3.9 ± 1.7) that gave birth to 12,014 pigs (10,758 live-born and 817 stillborn), where mummified fetuses (n = 439) were excluded from the analysis and total born calculations. Litters (n = 8) with total born of five or fewer were not used in the analysis. No piglets were cross-fostered and, thus, all pigs remained with birth sow until weaning.

Sow management and recordings around farrowing

For both experiments, sows were housed in individual stalls from days 0 to 113 of gestation, then moved to an individual farrowing stall. Sows were weighed and backfat was measured (P2 position; Renco Lean-Meter; S.E.C. Repro Inc., Quebec, Canada) upon entry into the farrowing house at approximately day 113 of gestation.

Sows were supervised daily around farrowing for signs of parturition. Once parturition began, each farrowing was monitored to record birth time, birth weight, birth order, and classify piglets as born alive, stillborn, or mummified fetus. Farrowing assistance was given to sows if the birth interval exceeded 30 to 45 min from the previous piglet birth with no evidence of farrowing progress. Piglets were classified as born alive if they physically moved or took a breath immediately after birth. Stillborn piglets were classified as fully formed piglets with the absence of a detectable heartbeat at birth. Mummified fetuses were recorded but excluded from the total born calculation. Live born piglets were individually identified with an ear tag. All live born pigs were individually reweighed at 24 h after the birth of the first pig in the litter. Colostrum intake per pig and sow colostrum yield was calculated using the equation in the study Theil et al. (2014). Piglet mortalities between birth and weaning were recorded on an individual pig basis, with the day of death, dead weight, and individual pig identification recorded.

Calculations

Total born is a summation of born alive and stillborn pigs. Farrowing assistance was recorded as assisted or unassisted for each sow. Farrowing duration was considered the time from birth of first pig until the last pig was expelled from the sow. Birth order ranking (0 to 100) was calculated as [(birth order − 1)/(total born − 1) × 100], to standardize for differences in litter size. The first pig born in each litter was assigned rank 0 and the last pig born was assigned the rank 100. Pig to teat ratio was calculated by dividing born alive pigs by the number of functional teats per sow, where a number greater than 1 means there were more pigs nursing than teats available.

Statistical analysis

Each herd was analyzed separately due to differences in the population studied. Data were first analyzed for characteristics related to stillborn rate. Stillborn rate was considered the dependent variable and analyzed as a binomial variable with the numerator being number of stillborn pigs and denominator being number of total born pigs per sow. Two separate models were utilized to analyze stillborn rate either including or removing litter weight as a covariate, as it is confounded with litter size. Piglet survivability to weaning was analyzed as a binomial, where number of pigs weaned was the numerator and number of total born pigs per sow was the denominator. All data were analyzed using R statistical program (Version 3.5.2).

Experiment 1

For characteristics related to stillborn rate two separate models (including or removing litter weight as a covariate) were used which included either eight or nine independent variables (parity, litter weight, average pig birth weight, day 113 backfat, day 113 BW, gestation length, dietary treatment, farrowing duration, and farrowing assistance) were included in a multivariate logistic regression model to evaluate which variables were related to stillborn rate. Stepwise elimination based on improving Bayesian information criterion (**BIC**), where the model with the lowest BIC is preferred, was used to determine the final model which included the variables: litter weight or day 113 sow BW, piglet birth weight, and farrowing duration. Quartiles of each variable were derived to create categorical responses. To analyze for differences in stillborn rate between quartiles of each respective variable, a generalized linear model for a binomial response was fit, with a Tukey adjustment for multiple comparisons used for mean separation between quartiles.

Experiment 2

For characteristics related to stillborn rate, two separate models (including or removing litter weight as a covariate) were used which included 10 or 11 variables (parity, litter weight, average pig birth weight, day 113 backfat, day 113 BW, gestation length, time since last meal pre-farrow, feed amount day 113 to farrow, farrowing duration, farrowing assistance, and oxytocin use) were included in a multivariate logistic regression model to evaluate which variables were related to stillborn rate. Stepwise elimination based on improving BIC was used to determine the final model which included the five variables of: litter weight or day 113 sow BW, piglet birth weight, sow backfat, farrowing assistance, and parity. Quartiles of each variable were derived to create categorical responses. To analyze for differences in stillborn rate between quartiles of each respective variable, a generalized linear model for a binomial response was fit, with a Tukey adjustment for multiple comparisons used for mean separation between quartiles.

Piglet data

Because total born was used as the denominator in the logistic model, it was unable to be tested as a variable in the analysis for sow factors. Individual piglet data were used to analyze for effect of total born and birth order on stillborn rate in both experiments. For survivability to weaning, individual piglet data were used to analyze for the effect of total born, birth order, colostrum intake, and pig to teat ratio. A binary response was used to test the relationship of stillborn or survival to weaning and the variables birth order, total born, and colostrum intake with piglet as the experimental unit. Similar to the analysis of sow data, quartiles were used to categorize the piglet population for each response variable.

Results

The sows in experiment 1 were younger (1.7 vs. 3.9 parity), heavier conditioned at day 113 (19.0 vs. 13.8 mm backfat), farrowed fewer total born (14.8 vs. 15.9), and had heavier piglet birth weights (1,410 vs. 1,230 g) than the herd in experiment 2 (Table 1). Regardless of the differences in population, the average born alive percentage (93.5 vs. 93.4%) and stillborn rate (6.5 vs. 6.6%) were similar between the two herds. In addition, more females were studied in experiment 2 compared with experiment 1 (n = 728 vs. 473). When utilizing individual pig records for survival to weaning analysis, 4.8% of pig records (experiment 1) and 1.6% of pig records (experiment 2) were excluded from analysis due to missing weaning records.

Stillborn rate

Experiment 1

The first multivariate logistic regression model indicated that litter weights, average piglet birth weight, and farrowing duration were associated (P < 0.001) with stillborn rate in the sow population (Table 2). The second model, which did not include litter weight as a variable, indicated that sow BW on day 113 of gestation, average piglet birth weight, and farrowing duration were associated (P < 0.001) with stillborn rate in the sow population. Using quartiles to explain changes in stillborn rate among the different litter weight categories, litters weighing <18.1 kg had a lower (P < 0.05) stillborn rate compared with litters weighing >21.3 kg, with the heaviest quartile (>24 kg) having the highest (P < 0.05) stillborn rate compared with the lowest two quartiles (Table 3). Sows categorized in the lowest quartile for average pig birth weight (<1,300 g) had

Table 1. Population statistics for experiments 1 and 2

	Experiment 1[1]		Experiment 2[2]	
Characteristic	Mean (±SD)	Min–Max	Mean (±SD)	Min–Max
Sow				
Parity, *n*	1.7 (1.6)	0 TO 6	3.9 (1.7)	0 to 8
Gestation length, d	115.8 (0.8)	113 TO 119	115.5 (1.3)	113 to 119
Backfat at farrow, mm	19.0 (3.9)	8.0 TO 31.0	13.8 (3.8)	7.0 to 30.0
Farrowing duration, min	251 (126)	33 TO 739	228 (100)	52 to 749
Total born, *n*	14.8 (3.1)	7 TO 22	15.9 (3.6)	6 to 26
Born alive, %	93.5 (8.1)	50 TO 100	93.4 (7.7)	57.9 to 100
Stillborn, %	6.5 (8.1)	0 TO 50	6.6 (7.7)	0 to 42.1
Piglet				
Piglet birth weight, g	1,410 (213)	310 TO 2,630	1,230 (220)	230 to 2,290
Litter birth weight, kg	21.2 (4.2)	8.6 TO 34.3	19.9 (4.1)	8.3 to 31.0

[1]A total of 473 sows (PIC Large White × Topigs Norsvin Landrace; parity 1.7 ± 1.6) that gave birth to 6,939 pigs (6,458 live-born and 481 stillborn) were used in analysis.

[2]A total of 728 sows (Fast Large White × PIC Landrace; parity 3.9 ± 1.7) that gave birth to 11,575 pigs (10,758 live-born and 817 stillborn) were used in analysis.

Table 2. Multivariate logistic regression analysis equations for sow characteristics associated with stillborn rate

Experiment 1[1]		
Response	Equation	BIC[3]
Stillborn rate[4], %	= -3.07 + (0.073 × litter weight (kg)) – (0.001 × piglet weight (g)) + (0.0016 × farrowing duration (min))	1128
Stillborn rate[5], %	= -3.51 + (0.002 × sow BW day 113 (kg)) – (0.0006 × piglet weight (g)) + (0.0017 × farrowing duration (min))	1145
Experiment 2[2]		
Response	Equation	BIC[3]
Stillborn rate[4], %	= –3.648 + (0.068 × litter weight (kg)) – (0.001 × piglet weight (g)) – (0.049 × sow backfat day 113 (mm)) + (0.404 × farrowing assistance (0 or 1[6]) + (0.137 × parity)	1769
Stillborn rate[5], %	= –3.332 + (0.008 × sow BW day 113 (kg)) – (0.652 × piglet weight (g)) – (0.081 × sow backfat day 113 (mm)) + (0.282 × farrowing assistance (0 or 1[6]) + (0.093 × parity)	1793

[1]A total of 473 sows (PIC Large White × Topigs Norsvin Landrace; parity 1.7 ± 1.6) that gave birth to 6,939 pigs (6,458 live-born and 481 stillborn) were used in analysis.
[2]A total of 728 sows (Fast Large White × PIC Landrace; parity 3.9 ± 1.7) that gave birth to 11,575 pigs (10,758 live-born and 817 stillborn) were used in analysis 0 for no farrowing assistance, 1 for at least one pig assisted.
[3]Bayesian information criterion.
[4]Analysis utilizing litter weight as a variable in the model.
[5]Analysis removing litter weight as a variable in the model.
[6]Farrowing assistance reported as no pigs assisted (0), or at least one pig assisted (1) per sow.

Table 3. Quartiles for sow and piglet characteristics associated with stillborn rate, experiment 1

Litter weight[1], kg	<18.1	18.1 to 21.2	21.3 to 23.9	>24	SEM	P-value
Stillborn, %	4.9[c]	6.0[bc]	7.1[ab]	8.6[a]	0.55	<0.001
Mean pig birth weight[1], g	<1,300	1,300 to 1,420	1,430 to 1,570	>1,580	SEM	P-value
Stillborn, %	8.8[a]	6.7[ab]	5.7[b]	5.9[b]	0.53	0.011
Farrowing duration[1], min	<162	162 to 224	225 to 307	>308	SEM	P-value
Stillborn, %	4.5[c]	5.9[bc]	6.8[b]	9.3[a]	0.60	<0.001
Sow BW day 113[1], kg	<236	236 to 266	267 to 292	>292	SEM	P-value
Stillborn, %	5.7[b]	5.9[b]	7.2[ab]	8.4[a]	0.64	0.036
Total born[2]	<13	13 to 14	15 to 16	>16	SEM	P-value
Stillborn, %	4.7[c]	5.7[bc]	7.1[b]	10.5[a]	0.51	<0.001
Birth order ranking[2]	<25	25 to 50	50 to 75	>75	SEM	P-value
Stillborn, %	1.6[d]	3.2[c]	6.4[b]	18.7[a]	0.50	<0.001

[1]A total of 473 sows were categorized into quartiles within each response variable, with each quartile representing ~25% of sows in the study population.
[2]A total of 6,939 piglets (6,458 live-born and 481 stillborn) were categorized into quartiles within each response variable, with each quartile representing ~25% of sows or piglets in the study population.
[a–d]Means within a row not sharing a common superscript differ, $P < 0.05$.

the highest observed stillborn rate (8.8%) and it was greater ($P < 0.05$) than sows categorized in the two heaviest piglet birth weight quartiles (>1,430 g). Sows categorized in the lowest quartile for farrowing duration (<162 min) had the lowest stillborn rate (4.5%), with stillborn rate increasing ($P < 0.05$) with each increase in quartile up to 9.3% stillborn pigs for sows categorized with farrowing durations longer than 308 min. Sows categorized with day 113 BW <266 kg were associated with a lower ($P < 0.05$) stillborn rate compared with sows with day 113 BW >292 kg, with those with day 113 BW between 267 and 292 kg intermediate.

Individual piglet data were used to evaluate effect of birth order and total born on stillborn rate. As position in the birth order increased from first quartile to last quartile, percentage of stillborn pigs increased ($P < 0.05$) from 1.6% for pigs born in the first quarter of the litter to 18.7% for pigs born in the last quarter of the litter. As litter size category increased from first quartile (<13 pigs) to third quartile (16 to 17 pigs) stillborn rate increased from 4.7% to 6.9%. Litters categorized in the highest total born quartile (>17 pigs) had the highest ($P < 0.05$) stillborn rate (10.4%) compared with the other three quartiles.

Experiment 2

Similar to experiment 1, two multivariate logistic regression models were used to evaluate stillborn rate. The first model indicated that litter weight, average piglet birth weight, sow backfat at day 113, farrowing assistance, and parity were associated with stillborn rate. The second model indicated that sow BW on day 113 of gestation, average piglet birth weight, sow backfat at day 113, farrowing assistance, and parity were associated with stillborn rate. Sows categorized with litters weighing >22.4 kg observed a greater ($P < 0.05$) stillborn rate compared with litters weighing <16.9 kg, with sows in the middle two quartiles intermediate (Table 4). When sows were categorized according to average piglet birth weight, sows in the lowest quartile (< 1,100 g) had an increased ($P < 0.05$) stillborn rate compared with sows

Table 4. Quartiles for sow and piglet characteristics associated with stillborn rate, experiment 2

Litter birth weight[1], kg	<16.9	16.9 to 19.7	19.8 to 22.4	>22.4	SEM	P-value
Stillborn, %	5.9[b]	6.9[ab]	6.4[ab]	8.1[a]	0.51	0.050
Mean pig birth weight[1], g	<1,100	1,100 to 1,240	1,250 to 1,390	>1,400	SEM	P-value
Stillborn, %	8.2[a]	7.5[ab]	6.4[bc]	5.4[c]	0.50	0.005
Sow back fat day 113[1], mm	<11	11 to 13	14 to 16	>16	SEM	P-value
Stillborn, %	8.7[a]	7.2[ab]	6.8[b]	5.6[b]	0.57	0.004
Sow BW day 113[2], kg	<244	244 to 261	262 to 279	>279	SEM	P-value
Stillborn, %	5.4[b]	6.9[ab]	7.4[a]	7.8[a]	0.50	0.027
Parity[1]	<3	3	4	>4	SEM	P-value
Stillborn, %	4.3[c]	5.5[bc]	6.8[b]	8.6[a]	0.55	<0.001
Sow farrowing assistance[1,2]	No	Yes			SEM	P-value
Stillborn, %	5.0	7.6			0.41	<0.001
Total born[3], *n*	<14	14 to 16	17 to 18	>18	SEM	P-value
Stillborn, %	4.7[c]	6.1[bc]	6.9[b]	10.1[a]	0.50	<0.001
Birth order ranking[3], %	<25	25 to 50	50 to 75	>75	SEM	P-value
Stillborn, %	1.8[d]	3.7[c]	8.0[b]	15.6[a]	0.46	<0.001

[1]A total of 728 sows were categorized into quartiles within each response variable, with each quartile representing ~25% of sows in the study population.
[2]Sow farrowing assistance was recorded for each sow. Yes represents at least one pig was pulled from the sow, no represents that no piglets were assisted out. Means represent the stillborn rate within each category.
[3]A total of 11,575 piglets (10,758 live-born and 817 stillborn) were categorized into quartiles within each response variable, with each quartile representing ~25% of piglets in the study population.
[a–d]Means within a row not sharing a common superscript differ, $P < 0.05$.

categorized with an average piglet birth weight >1,250 kg, with sows in the heaviest quartile (>1,400 g) having the lowest stillborn rate (5.4%). Sows categorized in the lowest quartile for backfat at day 113 of gestation (<11 mm) had an increased ($P < 0.05$) stillborn rate compared to sows categorized in the heaviest two quartiles (>14 mm backfat), with those categorized with 11 to 13 mm backfat intermediate. Sows categorized in the lowest quartile for day 113 BW (<244 kg) had reduced ($P < 0.05$) stillborn rate compared with sows in the highest two quartiles (> 262 kg), with sows weighing between 244 and 261 kg at day 113 intermediate. Sows categorized as parity 3 or younger had a lower ($P > 0.05$) stillborn rate compared to sows categorized as parity 4 or greater, with sows categorized as parity 5 or older having the highest stillborn rate (8.6%). Sows categorized as receiving farrowing assistance observed a higher ($P < 0.05$) stillborn rate compared with sows with no assistance (5.0 vs. 7.6%).

Individual piglet data were used to evaluate birth order and total born as predictors of stillborn rate. The lowest quartile for total born (<14 pigs) observed the lowest ($P < 0.05$) stillborn rate (4.7%) compared with the highest two quartiles (>17 pigs). Pigs categorized in the middle quartile (14 to 16 total born pigs) had a lower ($P < 0.05$) stillborn rate compared with pigs in litters with >18 total born. Pigs categorized as born in the first quarter of the litter observed the lowest ($P < 0.05$) stillborn rate, with stillborn rate increasing as position in the birth order increased from first to last quartile (1.8% vs. 15.6%).

Survival to weaning

Experiment 1

Piglet birth weight, total born, and colostrum intake were associated ($P < 0.001$) with piglet survival to weaning (Table 5). The lowest birth weight quartile (<1,190 g) had the lowest ($P < 0.05$) percentage of pigs surviving to weaning (59.5%) compared with the other three quartiles. In addition, the heaviest birth weight quartile (>1,670 g) had greater ($P < 0.05$) percentage of pigs weaned than pigs categorized in the lower three quartiles. Pigs categorized in the lowest two quartiles for total born (<13 and 13 to 14 pigs) had an increased ($P < 0.05$) percentage of pigs weaned compared with the highest two quartiles (15 to 16 and >16 pigs). Pigs categorized in the lowest quartile for colostrum intake (< 337 g) had decreased ($P > 0.05$) percentage of pigs weaned compared with pigs that had consumed more than 337 g of colostrum.

Experiment 2

Multivariate analysis indicated average piglet birth weight, birth order ranking, total born, pig to teat ratio and colostrum intake were associated ($P < 0.01$) with piglet survival to weaning (Table 6). Each increase in average pig birth weight quartile from lowest to highest improved ($P < 0.05$) the percentage of born alive pigs that were weaned from 62.2% in the lowest quartile (<1,100 g) to 79.2% in the highest quartile (>1,400 g). Pigs categorized as born in the last quarter of the birth order had decreased ($P > 0.05$) survival to weaning compared with pigs born in the first three quarters of the birth order. Each increase in total born quartile from lowest to highest reduced ($P < 0.05$) the percentage of born alive pigs that were weaned from 80.5 in the lowest quartile (<14 pig) to 60% (>18 pigs). Pigs categorized in the lowest quartile for pig to teat ratio (>0.81) had an increased percentage of pigs survive to weaning compared with pigs in the remaining three quartiles. Pigs in the middle two quartiles for pig to teat ratio (0.81 to 1.0 and 1.0 to 1.13) had increased ($P > 0.05$) percentage of pigs survive to weaning compared with pigs in the last quartile (>1.13). Pigs categorized in the lowest quartile of colostrum intake (<302 g) had decreased ($P < 0.05$) percentage survive to weaning compared pigs categorized in the higher three quartiles. Lower colostrum intake was associated with an increased pig to teat ratio (Figure 1; $P < 0.001$).

Discussion

The overall stillborn rate in the current two experiments was similar to values reported by other studies with similar number of total born pigs (Rootwelt et al., 2012; Langendijk et al., 2018). The differences in parity distribution between the two herds in the present study may help to explain some of the differences

Table 5. Quartiles for sow and piglet characteristics associated with survival to weaning, experiment 1[1,2]

Birth weight, g	<1,190	1,190 to 1,430	1,440 to 1,660	>1,670	SEM	P-value
Weaned, %	59.5[a]	82.1[b]	84.4[b]	88.6[c]	1.20	<0.001
Total born, *n*	<13	13 to 15	16 to 17	>17	SEM	P- value
Weaned, %	87.1[a]	83.7[a]	78.3[b]	69.5[c]	1.02	<0.001
Colostrum intake, g	<337	337 to 442	442 to 550	>550	SEM	P-value
Weaned, %	73.7[c]	91.8[b]	94.9[a]	95.9[a]	1.15	<0.001

[1]Percentage weaned is calculated as weaned count divided by total born.
[2]A total of 6,939 piglets (6,458 live-born and 481 stillborn) were categorized into quartiles within each response variable, with each quartile representing ~25% of sows or piglets in the study population.
[a–c]Means within a row not sharing a common superscript differ $P < 0.05$.

Table 6. Quartiles for piglet characteristics associated with survival to weaning, experiment 2[1,2]

Pig birth weight, g	<1,100	1,100 to 1,240	1,250 to 1,390	>1,400	SEM	P-value
Weaned %	62.2[d]	68.6[c]	72.5[b]	79.2[a]	0.89	0.005
Birth order ranking, %	<25	25 to 50	50 to 75	>75	SEM	P-value
Weaned, %	71.4[a]	72.2[a]	70.4[a]	66.1[b]	0.93	<0.001
Total born, *n*	<14	14 to 16	17 to 18	>18	SEM	P-value
Weaned, %	80.5[a]	74.6[b]	68.2[c]	60.0[d]	0.90	<0.001
Pig:Teat[3]	<0.81	0.81 to 1.00	1.00 to 1.13	>1.13	SEM	P-value
Weaned, %	76.8[a]	72.6[b]	69.6[b]	63.3[c]	0.90	0.001
Colostrum intake, g	<302	302 to 408	408 to 509	>509	SEM	P-value
Weaned, %	52.1[d]	83.3[c]	91.6[b]	93.7[a]	0.93	<0.001

[1]Percentage weaned is calculated as weaned count divided by born alive.
[2]A total of 11,575 piglets (10,758 live-born and 817 stillborn) were categorized into quartiles within each response variable, with each quartile representing ~25% of piglets in the study population.
[3]Pig to teat ratio is the number of born alive pigs divided by functional teats per sow.
[a–d]Means within a row not sharing a common superscript differ $P < 0.05$.

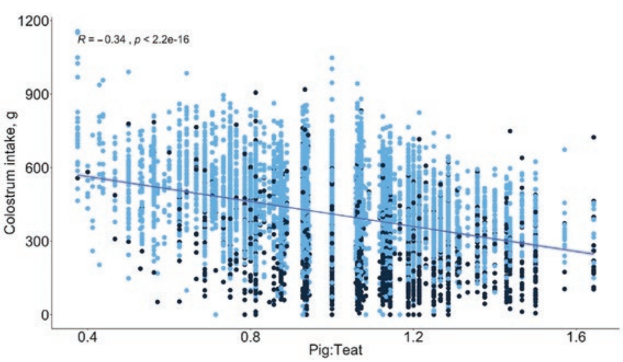

Figure 1. Correlation between pig to teat ratio and colostrum intake, in relation to survival at weaning in experiment 2. A total of 10,758 live-born pigs are represented. Colostrum intake was calculated as described by Theil et al. (2014). Pig to teat ratio is the number of born alive piglets divided by number of functional teats per sow. Light dots represent pigs that were alive at weaning. Dark dots represent pigs that were a mortality before weaning.

observed in other traits associated with stillborn rate. The present study observed that parity was only associated with increased stillborn rate in experiment 2, which had an older average parity compared with experiment 1. It has been well documented that older sows (parity 3 and greater) have an increased stillborn rate, which may be related to poor muscle tone (Vanderhaeghe et al., 2010; Bhattarai et al., 2018). In contrast, first parity sows have also shown evidence for increased stillborn rate, which may be due to a narrower pelvic circumference compared with second parity and older sows (Cowart, 2007); however, this was not observed in the populations of the present study.

Within both herds, sows with lighter average piglet birth weights had a higher stillborn rate, which is potentially a factor of increased total born; however, literature regarding average piglet birth weight and its association with stillborn rate is conflicting. Rootwelt et al. (2012) and Langendijk and Plush (2019) observed no difference in mean piglet birth weight between live born or stillborn pigs. In contrast, several studies have identified light weight pigs to be associated with a higher chance of being stillborn (Herpin et al., 1996; Langendijk et al., 2018; Langendijk and Plush, 2019; Udomchanya et al., 2019). One explanation for the increased stillbirth percentage in light weight pigs is that small pigs are often associated with increased asphyxia as evidenced by increased blood lactate and lower blood pH at birth (Alonso-Spilsbury et al., 2005).

The present study identified heavier litter weights were associated with stillborn rate. To our knowledge, no previous study has evaluated entire litter weight at birth and its association with stillborn rate. The increased stillborn rate associated with heavier litter weights in the current study may be a factor of increased litter size, whereby mean birth weight decreases as litter size increases (Wolf et al., 2008), but total litter birth weight increases. As evidenced above, lighter mean piglet birth weight is associated with increased stillborn rate. Additionally, it has been well established that increased total born is associated with increased stillborn rate (van Dijk et al., 2005; Oliviero et al., 2010; Kirkden et al., 2013; Udomchanya et al., 2019) and our analysis on the piglet level would also support these findings. Thus, the higher observed stillborn rate in the present study as litter weight increased is likely a combination of increased number of total born pigs with lighter mean birth weights. Further, a second model was used for analysis that did not include litter weight due to confounding of litter weight and litter size variables. This model demonstrated that the only change in variables associated with stillborn rate was the addition of sow BW on day 113 of gestation. Litter size could not be used in the model due to being the denominator in the logistic model; therefore, it could not be identified as a variable associated with stillborn rate. Because litter size is associated greatly with stillborn rate, by removing litter weight from the model, sow BW was the next variable that shares a relationship with litter size. The explanation for increased stillborn rate as sow BW on day 113 increases could be a factor of increased weight of fetus, placental membranes, and fluids with additional total born (Smit et al., 2015).

An increase in farrowing duration was associated with a higher stillborn rate in experiment 1, which is similar to previous data (Oliviero et al., 2010; Vanderhaeghe et al., 2010; Udomchanya et al., 2019). In contrast, farrowing duration in experiment 2 was not associated with stillborn rate. This may be due to the difference in the mean farrowing duration between populations (251 vs. 222 min, experiment1 and experiment 2, respectively), where the shorter mean farrowing duration in experiment 2 did not create a scenario supporting increased stillborn rate. In support of this, Vanderhaeghe et al. (2010) indicated that the probability of stillborn pigs was increased in sows farrowing for longer than 240 min, in a herd with similar litter size as experiment 2. Therefore, the impact of farrowing duration on stillborn rate may only be relevant when the sow herd mean farrowing duration exceeds 4 h. Further, increasing litter size has been associated with increased farrowing duration (Oliviero et al., 2019). Thus, the selection for increased litter size may further increase the average sow farrowing duration which could have negative impact on stillborn rate.

Previously, over-conditioned sows (>17 mm backfat) have been associated with a longer farrowing duration (Zaleski and Hacker, 1993; Oliviero et al., 2010), and increased BW gain in late gestation associated with increased stillborn rate (Goncalves et al., 2016). It is hypothesized that over-conditioned females have excess adipose tissue surrounding the birth canal or contributes to a delayed decline in progesterone (Oliviero et al., 2010). In experiment 1, there was no evidence for sow backfat to influence stillborn rate (mean = 19 ± 3.9) at day 113 of gestation. In contrast, data from experiment 2 demonstrated thin sows (<14 mm backfat) were associated with an increased stillborn rate compared with sows with backfat >14 mm at farrowing. Similarly, two previous studies have observed that sows with backfat <12.5 mm at day 109 of gestation (Thongkhuy et al., 2020) or <16 mm at farrowing (Vanderhaeghe et al., 2010) had increased risk of stillborn pigs compared with sows with more backfat. One explanation for the increase in stillborn rate with decreasing backfat in experiment 2 may be attributed to the older average parity herd having a naturally higher stillborn rate, which may have confounded the effect of a sow being both thin and old increasing stillborn rate. Nonetheless, Thongkhuy et al. (2020) observed older parity sows categorized as thin (<12.5 mm backfat) had increased stillborn rate compared to younger parity sows of the same body condition. Furthermore, as parturition progresses, Le Cozler et al. (1999) observed blood glucose concentrations raise which may indicate sows are mobilizing glycogen stores to aid in the completion of parturition when circulating blood glucose has been depleted. Without ample lipid reserves, it may become difficult to meet the energy demands at the end of parturition which could increase the stillborn rate. Although no blood measurements were collected in the present study, the understanding of blood parameters may help to explain the physiology behind the response observed. Care must be taken to not over interpret the current data as the average body condition between the two populations was significantly different. These results suggest that association between sow backfat and stillborn rate may be curvilinear and reiterate the importance of managing sow body condition to avoid too thin or excess body fat in sows entering the farrowing house to minimize risk of stillborn pigs.

Feyera et al. (2018) observed that as time from when a meal was last offered prior to farrowing increased, so did farrowing duration. In experiment 2, this variable was included in the multivariate analysis but was not found to be associated with stillborn rate or survival to weaning. This may be due to sows in the present study having a shorter average farrowing duration (3.7 vs. 5.8 h) compared with Feyera et al. (2018), and thus not experiencing extreme fatigue during parturition. As litter size continues to increase in U.S. herds, meal timing prior to farrowing may need to be re-evaluated for its association with stillborn rate.

Piglets born later in the birth order have an increased risk of being stillborn (Herpin et al., 1996; Alonso-Spilsbury et al., 2005; Rootwelt et al., 2012). The mechanism for increased stillbirths associated with longer sow farrowing duration and pigs born later in the birth order is largely believed to be due to fetal asphyxia. Farrowing duration can be explained on the sow level, while birth order explains effects observed on the piglet level. Herpin et al. (1996) concluded that pigs born later in the birth order have increased blood lactate and partial pressure of carbon dioxide, and decreased blood pH, which have been documented as signs of asphyxia (Randall, 1972). These physiological changes occurring intrapartum can be attributed to interruption of the oxygen flow through the umbilical cord due to repeated contractions, or even rupturing of the umbilical cord prior to expulsion (Alonso-Spilsbury et al., 2005). Therefore, an increase in farrowing duration naturally increases the risk of all piglets but is exponentially increased with pigs born later in the birth order that experience repeated uterine contractions.

The intrauterine stress often associated with pigs born later in the birth order can reduce the survival of pigs in the extrauterine environment (Zaleski and Hacker, 1993). Pigs are known to be more susceptible to brain damage caused by rupture of the umbilical cord within 5 min of delivery (Alonso-Spilsbury et al., 2005). As evidenced in experiment 2 of the present study, a reduced percentage of pigs were weaned as pigs were born later in the birth order, with this change statistically higher in the last quarter of the litter. This suggests that extra attention needs to be placed on sows near the end of parturition and the live-born piglets in the last 25% of the litter, as this has implications on survival of pigs at birth and through weaning.

Farrowing assistance through obstetrical intervention of piglets is a common practice to aid in sows experiencing dystocia (Kirkden et al., 2013). While stillborn rates are known to be higher in sows that have received farrowing assistance compared with sows farrowing naturally (Vanderhaeghe et al., 2010), if that same sow had not received farrowing assistance her actual number of stillborn pigs likely would increase. In the present study, farrowing assistance was given if the birth interval exceeded 30 to 45 min. While this may have artificially reduced the natural farrowing duration, a greater number of the pigs born that received farrowing assistance were stillborn compared with born alive. This indicates that dystocia was already occurring in the sow; however, it is unknown whether the stillborn pig is the cause of dystocia or the sow's fatigue and lack of uterine contractions caused the stillborn pig (Langendijk and Plush, 2019).

Pig to functional teat ratio was associated with survivability to weaning, where having the same as or fewer number of pigs than functional teats on the sow resulted in improved number of pigs weaned. This is likely due to a decrease in colostrum available per pig, as litter size has not been shown to impact colostrum yield (Devillers et al., 2011; Decaluwé et al., 2014). It is well established that increased colostrum intake is associated with decreased preweaning mortality (Devillers et al., 2011; Kirkden et al., 2013). Previous data would suggest that a pig needs to consume a minimum of 200 g of colostrum to survive to weaning (Devillers et al., 2011; Quesnel et al., 2012), whereas our data would suggest that consuming <307 g colostrum resulted in almost 50% mortality to weaning. The differences in required colostrum for survival could be explained in part by differences in the equation used to calculate colostrum intake. Previous studies used an equation developed by Devillers et al. (2004), which underestimates colostrum intake by 30% compared with a recently developed equation (Theil et al., 2014) used in the current studies.

Conclusion

The interrelated physical and environmental traits of both sow and piglets (intrauterine and extrauterine) represent a large challenge to identify characteristics that can be influenced in order to improve piglet survivability. Often times, effects of these traits are unable to be completely separated from each other due to biology, therefore making it difficult to identify one key area to focus on. Rather, there are several areas contributed from the sow (litter size, sow body composition, farrowing duration, and parity) and from the piglet (birth weight, birth order, and colostrum intake) that may have an influence on each other for improved piglet survival. By understanding the magnitude, each trait can have toward piglet survival, management strategies in the peripartum to achieve ideal sow body condition, identifying older parity sows needing farrowing assistance, and placing emphasis on pigs born later in the birth order or light weight will lead to increased survival of piglets to weaning. In addition, research strategies to maintain a short farrowing duration (<4 h) as litter sizes continue to increase will be essential to reduce stillborn rate related to hypoxia.

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Conflict of interest statement

The authors declare no real or perceived conflicts of interest.

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