

# Birth weight threshold for identifying piglets at risk for preweaning mortality

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**ABSTRACT:** Several studies have suggested there is a critical relationship between piglet birth weight and preweaning mortality. Thus, the objective of the current work was to identify a birth weight threshold value for preweaning mortality. Birth weight and survival data from two studies involving a combined total of 4,068 piglets from 394 litters on four commercial farms (three European, one U.S.) were compiled for a pooled, multistudy analysis. Overall preweaning mortality across the two studies was 12.2%. Key variables used in the analysis were piglet birth weight (measured within 24 h of birth) and corresponding survival outcome (dead or live) by weaning at 3–4 wk of age. A mixed effects logistic regression model was fit to estimate the relationship between preweaning mortality and birth weight. A random effect of study was included to account for overall differences in mortality between the two studies. A piecewise linear predictor was selected to best represent the drastic decrease in preweaning

mortality found as birth weight increased in the range of 0.5–1.0 kg and the less extreme change in weight above 1.0 kg. The change point of the birth weight and preweaning mortality model was determined by comparing model fit based on maximizing the likelihood over the interval ranging from 0.5 to 2.3 kg birth weight. Results from the analysis showed a curvilinear relationship between birth weight and preweaning mortality where the birth weight change point value or threshold value was 1.11 kg. In the combined data set, 15.2% of pigs had birth weights  $\leq 1.11$  kg. This subpopulation of pigs had a 34.4% preweaning mortality rate and represented 43% of total preweaning mortalities. These findings imply interventions targeted at reducing the incidence of piglets with birth weights  $\leq 1.11$  kg have potential to improve piglet survivability. Additional research is needed to validate 1.11 kg as the birth weight threshold for increased risk of preweaning mortality.

**Key words:** birth weight, pigs, preweaning mortality, survival, swine

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## INTRODUCTION

Selection for litter size has enabled marked advances in sow productivity (Danish Pig Research Centre, 2013, 2015; Knauer and Hostetler, 2013). However, as litter size increases, birth weight

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decreases and the number of small piglets (<1 kg) increases (Quiniou et al., 2002; Boulot et al., 2008; Bergstrom, 2011). Furthermore, the number of embryos may exceed uterine capacity, resulting in intrauterine growth restriction (IUGR) (Foxcroft, 2012), which negatively affects neonatal survival (Wu et al., 2006). Piglets with IUGR are commonly referred to as “runts.” Common measurements used to classify “runt” or IUGR pigs are birth weight, birth weight relative to litter average, body mass index, crown-to-rump length, and plasma insulin like growth factor 1 concentrations (Bauer et al., 1998; Hales et al., 2013).

Pigs are at greatest risk for mortality in the first 4 d of life. The most common causes of death are crushing, low viability, and starvation (KilBride et al., 2014). Low birth weight and IUGR negatively affect locomotor skills, vitality, ability to nurse, blood glucose, fat deposition, and thermoregulation (Kammersgaard et al., 2011; Pedersen et al., 2011; Amdi et al., 2013, 2016; Vanden Hole et al., 2018), which place these pigs at a competitive disadvantage relative to heavier counterparts (Devillers et al., 2007; Baxter et al., 2008).

It is well known that piglet birth weight is an important metric for survival (Fix et al., 2010a; Bergstrom, 2011; Krahn, 2015), but birth weight classifications vary greatly across studies, and a birth weight threshold for increased preweaning mortality has not been previously established. Therefore, the objective of the analysis was to identify a birth weight threshold associated with increased risk for preweaning mortality. This will allow researchers to benchmark the incidence of low birth weight piglets in commercial settings that are a target population for interventions, biological investigations, and genetic improvement programs.

## MATERIALS AND METHODS

### *Animal Care and Use*

Data were utilized from two studies (Bergstrom, 2011; Jourquin et al., 2015), which followed the animal husbandry principles outlined in the Guide

for the Care and Use of Agricultural Animals in Agricultural Research and Teaching (FASS, 2010) and complied with the EU directive 2008/120/EC (EU Directive, 2008) for minimal standards for the protection of pigs, respectively. The protocols for Bergstrom (2011) and Jourquin et al. (2015) were reviewed and approved by the Institutional Animal Care and Use Committees at Kansas State University and the Ethical Review Board of Elanco Animal Health, respectively.

### *Study Design*

Birth weight and preweaning survival data ( $n = 4,068$  piglets) were analyzed from two studies to identify a relationship between birth weight and increased preweaning mortality. These data sets were selected as they represent modern commercial conditions and procedures representative of the United States and Europe. The Bergstrom (2011) data set included 216 litters and 2,205 live born piglets from one farm in the United States, while the Jourquin et al. (2015) data set consisted of 178 litters and 1,863 live born piglets from three farms in Spain. Table 1 provides additional details on the genetics, parities, and weaning ages used on each farm. According to farm standard operating procedures, male piglets on the U.S. farm were surgically castrated within the first 7 d of life, while male piglets in Spain were not castrated.

### *Data Collection*

In both studies, the total number of piglets born alive, stillborn, and mummified were recorded for each litter. Within 24 h of farrowing, after initial colostrum consumption, each live piglet was identified with a unique ear tag and weighed using a scale with a locking digital display. Body weight was recorded to the nearest 0.1 kg. Survival status of each piglet was monitored and tracked from birth until weaning.

**Table 1.** Background information on the data sources used in the pooled, multistudy analysis of birth weight threshold

Study	Farm	Country	Piglet sire line	Piglet dam line	Sow parity	Piglet records	Weaning age, days
Bergstrom, 2011	1	USA	PIC327	Triumph TR4 × PIC 1050; PIC 1050	1–9	2,205	22–28
Jourquin et al., 2015	2	Spain	Pietrain	Large White × Landrace	2–8	772	21–29
Jourquin et al., 2015	3	Spain	Pietrain	ACMC	2–8	632	21–29
Jourquin et al., 2015	4	Spain	Pietrain	Large White × Landrace	2–8	459	21–29

### Birth Weight Categories

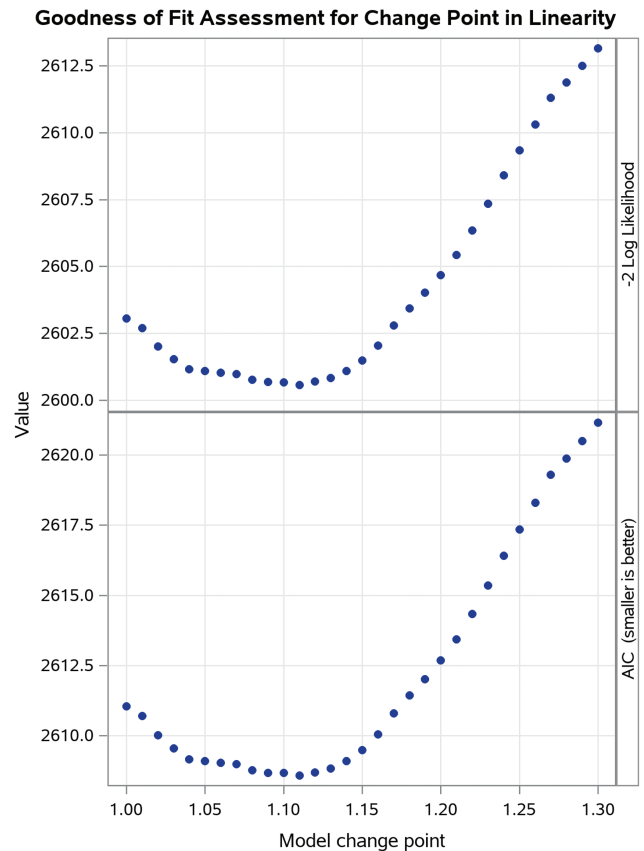
The birth weight categories used in this study ranged from 0.50 to 2.30 kg on 0.10 kg intervals. Piglets with birth weights below 0.50 kg and over 2.30 kg were placed into the 0.50 and 2.30 kg groups, respectively.

### Statistical Analysis

Descriptive statistics were calculated for litter size, birth weight, and preweaning mortality on each farm using the PROC MEANS procedure of SAS (SAS Institute Inc., Cary, NC). Piglet birth weights were summarized into the 18 different birth weight categories. Preweaning mortality was summarized for each category and results were plotted. Individual piglet birth weight and survival status were analyzed in a mixed effects logistic regression model using PROC GLIMMIX of SAS to estimate the probability of preweaning mortality based on birth weight. Study was included as a random effect to account for overall differences in mortality between the two studies. A piecewise linear predictor was selected to best represent the drastic decrease in preweaning mortality as birth weight increased in the range of 0.50–1.00 kg, and the less extreme change in preweaning mortality observed for changes in weight above 1.00 kg. The change point for the effects of birth weight on piglet survival was determined by comparing models with birth weight change points ranging from 0.5 to 2.3 kg. The birth weight with the lowest  $-2$  log likelihood was then selected as the change point for the linearity of the log odds for piglet mortality (Figure 1).

## RESULTS AND DISCUSSION

The average litter size across the two data sets was 13.18, but the EU study averaged 2.12 more pigs per litter than the U.S. study (Table 2; Figure 2). The average birth weight across studies was  $1.51 \pm 0.38$  kg, and there were no major differences in birth weights or birth weight percentiles between the two studies (Table 3; Figure 3). The average preweaning mortality across the two studies was 12.2%, but preweaning mortality was 5.6% units greater in the European study than in the U.S. study (Table 3). These data for litter size, piglet birth weight, and preweaning mortality are in line with results from previous studies conducted in Europe (Quiniou et al., 2002; Varona et al., 2007; Matheson et al., 2018) and the United States (Fix et al., 2010b; Knauer and Hostetler, 2013; Krahn, 2015).



**Figure 1.** Goodness of fit assessment for change point in linearity of the log odds for preweaning mortality. The best model fit based on the lowest  $-2$  log likelihood was observed at 1.11 kg.

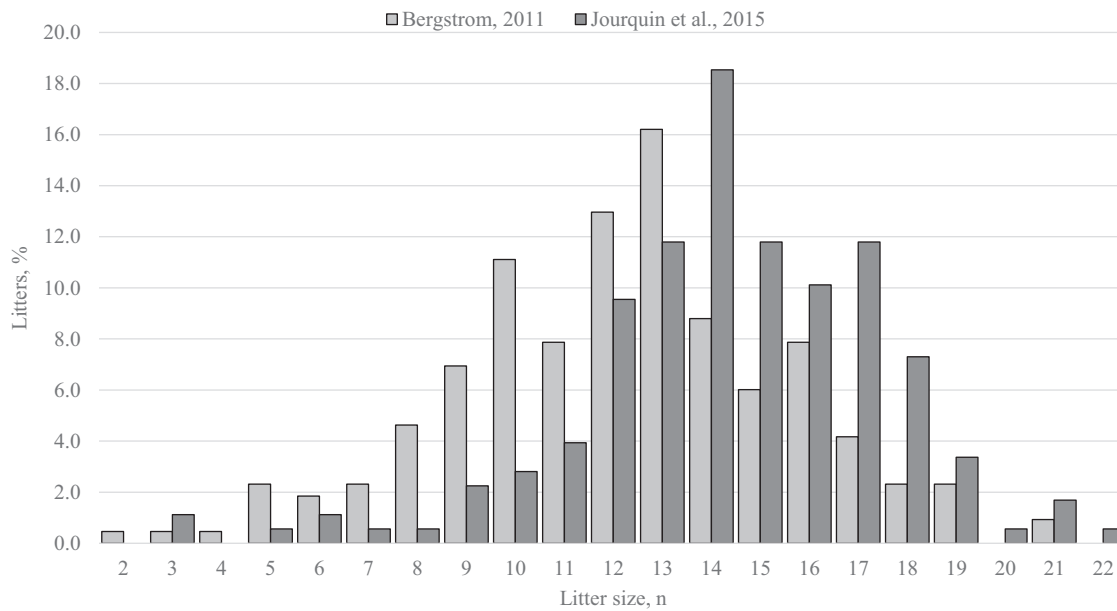
The effects of piglet birth weight on preweaning mortality were evaluated within the European (Jourquin et al., 2015), U.S. (Bergstrom, 2011), and combined data sets. Preweaning mortality plotted against piglet birth weight suggested a curvilinear relationship between birth weight and preweaning mortality in both studies, where preweaning mortality rates were higher for low birth weight pigs, but preweaning mortality rates declined and plateaued as birth weights increased above 1.00 kg in the U.S. data set and above 1.2 kg in the European data set (Figure 4).

To more precisely define a birth weight threshold for preweaning mortality, logistic regression models were developed for the European, U.S., and combined data sets to estimate the probability of preweaning mortality based on birth weight. The change point or threshold value for birth weight on preweaning mortality was estimated to be 1.09 kg in the U.S. data set, 1.13 kg in the EU data set, and 1.11 kg for the combined data set (Table 4). It is interesting to note that adding sow (biological dam) to the model as a random effect also resulted in a birth weight threshold value of 1.11 kg for preweaning mortality within the combined data set (data

**Table 2.** Litter size from the data sources used in the pooled, multistudy analysis of birth weight threshold

Study	No. litters	Litter size <sup>a</sup>					
		Average	Minimum	25th percentile	Median	75th percentile	Maximum
Bergstrom, 2011	216	12.22	2.0	10.0	12.0	14.0	21.0
Jourquin et al., 2015	178	14.34	3.0	13.0	14.0	17.0	22.0
Combined	394	13.18	2.0	11.0	13.0	16.0	22.0

<sup>a</sup>Litter size includes all piglets born live, dead, and mummified.



**Figure 2.** Distribution of litter size from the data sources used in the birth weight threshold analysis. Litter size includes all piglets born live, dead, and mummified.

not shown). This suggests that the birth weight of 1.11 kg is of biological significance for piglet survival regardless of litter size or weight.

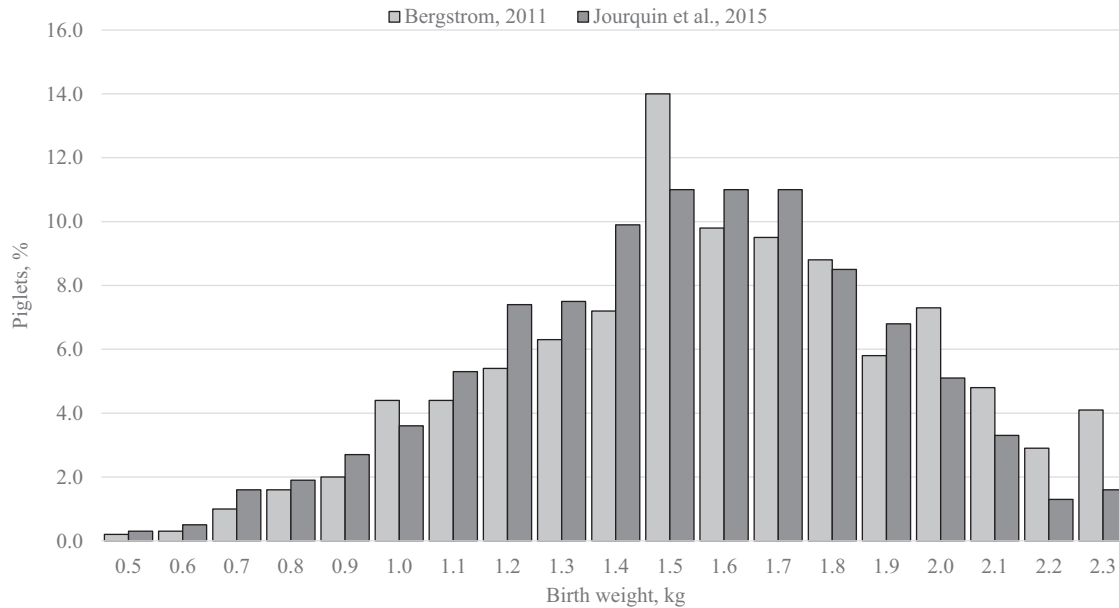
In order to understand the biological significance of birth weight on preweaning mortality, it becomes important to understand how piglet birth weight affects locomotor skills, vitality, ability to nurse, blood glucose, fat deposition, and thermoregulation. Recent research has shown that low birth weight or runt piglets have reduced locomotor skills and vitality scores compared with their normal littermates (Vanden Hole et al., 2018). Piglets with low birth weight are also less vigorous in their attempts to suckle and obtain less colostrum, which places them at a competitive disadvantage relative to their heavier counterparts (Devillers et al., 2007; Baxter et al., 2008). Furthermore, birth weight is considered a critical determinant of neonate recuperation from hypothermia (Kammersgaard et al., 2011), and piglets with lower body temperatures after birth have increased risk of mortality due to crushing, starvation, and disease (Pedersen et al., 2011). Given that IUGR piglets have hypothermia,

hypoglycemia, and substantially lower colostrum intakes during the first 24 h of life compared with normal pigs (Amdi et al., 2013, 2016), Amdi et al. (2017) recently demonstrated that runt piglets may require special interventions such as colostrum boluses during the first 24 h of life for survival.

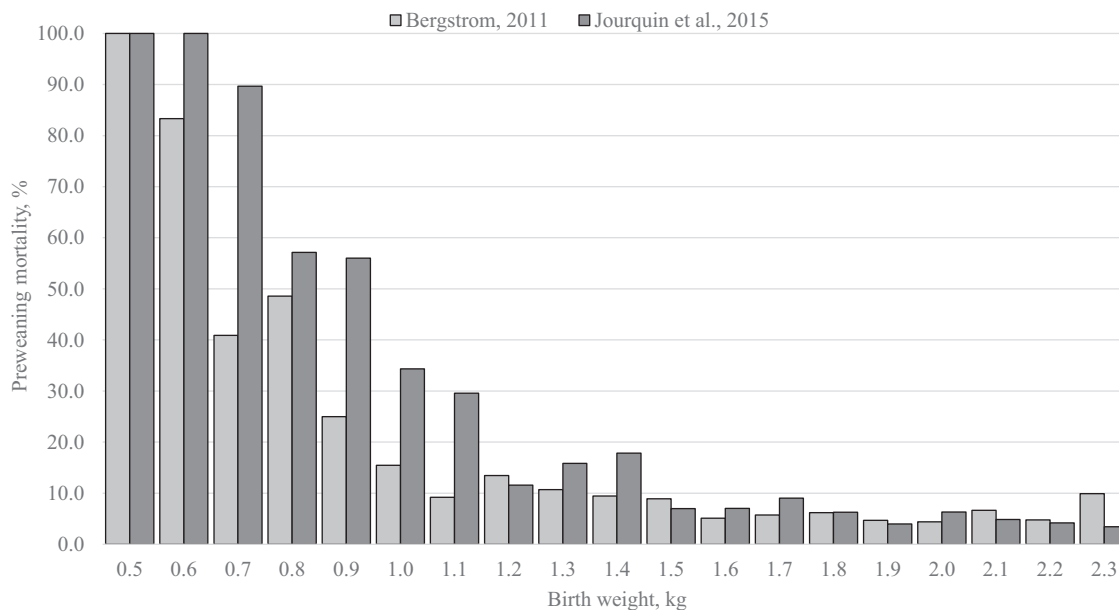
The European, U.S., and combined data sets were summarized to determine the percentage of pigs above and below the birth weight threshold values and their corresponding preweaning mortality rates (Table 4). Within the combined European and U.S. dataset ( $n = 4,068$  piglets), 15.2% of the pigs had birth weights less than 1.11 kg, while 84.8% of the pigs had birth weights greater than or equal to 1.11 kg. Piglets with birth weights below the threshold value of 1.11 kg had fourfold greater preweaning mortality rates than piglets with birth weights  $\geq 1.11$  kg (34.4% vs. 8.2%, respectively; Table 4). Furthermore, calculating the odds ratio for preweaning mortality for both birth weight groups demonstrated that pigs with birth weights less than 1.11 kg were at 5.9 times greater risk for death than pigs with birth weights  $\geq 1.11$  kg.

**Table 3.** Preweaning mortality and piglet birth weight from the data sources used in the birth weight threshold analysis

Study	No. piglets	Preweaning mortality, %	Piglet birth weight, kg					
			Average	Minimum	25th percentile	Median	75th percentile	Maximum
Bergstrom, 2011	2,205	9.6%	1.54	0.45	1.27	1.54	1.77	2.72
Jourquin et al., 2015	1,863	15.2%	1.47	0.43	1.23	1.49	1.72	2.58
Combined	4,068	12.2%	1.51	0.43	1.27	1.52	1.77	2.72



**Figure 3.** Distribution of piglet birth weights from data sources used in the birth weight threshold analysis. Piglets with birth weights <0.5 and >2.3 kg are included in the 0.5 and 2.3 kg birth weight groups, respectively.



**Figure 4.** Effects of piglet birth weight on preweaning mortality from the data sources used in the birth weight threshold analysis. Piglets with birth weights <0.5 and >2.3 kg are included in the 0.5 and 2.3 kg birth weight groups, respectively.

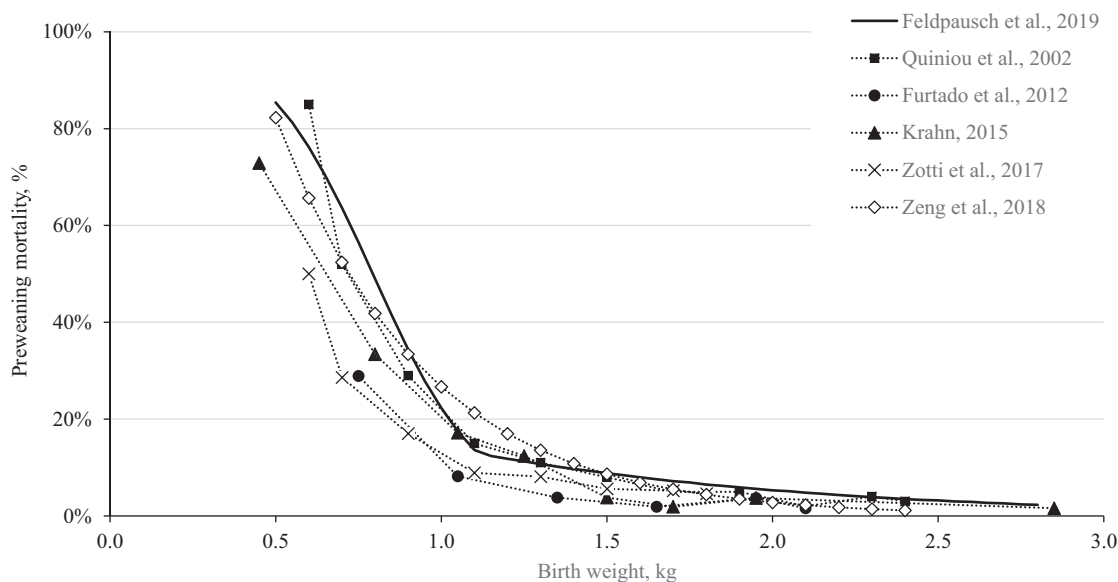
To our knowledge, this is the first study to model and estimate a birth weight threshold value for preweaning mortality as most studies only

compare preweaning mortality rates amongst different birth weight categories (e.g., Heavy, Medium, and Light). Interestingly, several large commercial

**Table 4.** Piglet birth weight threshold values for preweaning mortality

Study	Birth weight threshold value		Below threshold value		At or above threshold value	
	Change Point, kg	95% confidence interval	Pigs, %	Mortality, %	Pigs, %	Mortality, %
Bergstrom, 2011	1.09	0.64–1.73 <sup>a</sup>	13.9%	22.9%	86.1%	7.4%
Jourquin et al., 2015	1.13	0.71–1.21 <sup>a</sup>	16.8%	45.7%	83.2%	9.1%
Combined	1.11	0.90–1.56 <sup>a</sup>	15.2%	34.4%	84.8%	8.2%

<sup>a</sup>Values derived from bootstrap simulations for the regression model.



**Figure 5.** Effects of piglet birth weight on premortality across various studies. Feldpausch et al. (2019) values are based on the predicted preweaning mortality values of the current work. Values for Zeng et al. (2018) were derived from a prediction equation published by those authors.

studies (Quiniou et al., 2002; Furtado et al., 2012; Krahn, 2015; Zotti et al., 2017; Zeng et al., 2018) have shown similar curvilinear relationships between birth weight and preweaning mortality, whereby preweaning mortality rates were greater for piglets with birth weight categories less than or equal to 1.0–1.2 kg (Figure 5) compared with heavier categories, and thus, the findings of the current work are in line with previous studies. Additional research is warranted across different geographies, farms, and genetic lines to validate 1.11 kg as a birth weight threshold for increased risk of preweaning mortality.

Improving pig survival at all stages of production has recently been identified as a swine industry priority (FFAR, 2018). The U.S. swine industry benchmark average values over the last 6 years (2012–2017) for preweaning, nursery, and finishing mortalities were 17.6%, 4.6%, and 5.3%, respectively. This corresponds to overall birth to market swine mortality rates of approximately 27.5% with 64.0% of the mortality occurring prior to weaning (NPB, 2018). It then becomes important to understand the major causes of mortality for each of the three different stages of swine production.

Obviously, managing pig health and disease becomes a top priority for driving reductions in mortality. However, another factor of interest for managing pig survival is piglet birth weight as the current work demonstrates: 1) a curvilinear relationship between piglet birth weight and preweaning mortality where piglets born with birth weights less than or equal to 1.11 kg had a 34.4% preweaning mortality rate and 2) 15.2% of the piglets had birth weights less than or equal to 1.11 kg and represented 43% of the total preweaning mortalities. The effects of low birth weight on preweaning mortality and early performance have already been discussed. Furthermore, recent studies have shown that piglet birth weight also affects wean-to-market survival (Fix et al., 2010a; Kohler and Bierman, 2014). Therefore, managing and controlling piglet birth weight has large potential for improving pig survival from birth to market. In order to realize these opportunities, future research should focus on: 1) validating 1.11 kg as the birth weight threshold for increased risk of preweaning mortality, 2) quantifying the percentage of commercial pigs with birth weights up to 1.11 kg, and 3) identifying management strategies to improve the survival and

lifetime performance of piglets with birth weights less than or equal to 1.11 kg.

*Conflict of interest statement.* None declared.

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