Implications of early-life indicators for survival rate, subsequent growth performance, and carcass characteristics of commercial pigs[1]

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ABSTRACT: As a result of genetic selection for increased litter size, modern, highly prolific sows often produce large litters with an increased percentage of light birth weight (**BiW**) piglets compared with less prolific females. However, there is limited information elucidating what proportion of light BiW piglets that express compensatory growth and how these pigs might be identified at a young age. The objective of this study was to analyze the effect of birth weight and early phase growth on preweaning mortality, subsequent growth performance, and carcass characteristics of pigs. Individual records collected on 7,654 commercial crossbred pigs were used for analyses. A segmented regression model was used to analyze the effect of birth weight on preweaning survival and a series of mixed models were used to analyze the effect of birth weight (n = 7,654) group on weights recorded at: weaning (n = 6,777), nursery exit (n = 4,805), and finishing exit (n = 1,417); hot carcass weight (**HCW**), and lean percentage (n = 4,572). The effect of growth rate group was defined during suckling (< 225 or ≥ 225 g/d) or the nursery phase (< 424 or ≥ 424 g/d). Preweaning mortality, growth rate, BW, and carcass traits were adjusted to a standard age, and ADG and lean percentage were calculated. Results of segmented regression analysis showed that the slope of preweaning mortality on birth weights below 0.99 kg differed (P < 0.05) from the slope of preweaning mortality regressed on birth weights above 0.99 kg. The mixed model analyses showed a positive linear effect (P < 0.05) of BiW and quadratic effect (P < 0.05) of sow parity on age-adjusted finishing weight (**FiW**), HCW, and lean percentage. The positive influences of increasing BiW were greater (P < 0.05) in age-adjusted FiW and HCW for pigs with slow suckling growth rate compared with those with fast suckling growth rate. Pigs with fast nursery growth rate had greater (P < 0.05) age-adjusted FiW and HCW compared with the slow growing nursery contemporaries. In conclusion, piglets born weighing less than 1 kg were at a higher risk of preweaning mortality than piglets born weighing 1 kg or greater. Light BiW pigs, but not heavy BiW pigs, may lose compensatory growth capability if growth rate during the suckling phase is below the average level.

Key words: birth weight, early phase growth, carcass characteristics, growth performance, pigs

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INTRODUCTION

Genetic advancement over the last decade has resulted in increased litter size at birth and weaning. However, this increase is associated with

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a linear reduction in the mean birth weight (**BiW**) of piglets and an increased percentage of small piglets within litters (Quiniou et al., 2002; Beaulieu et al., 2010). Piglets born with light BiW are at greater risk of preweaning mortality, express reduced growth rates throughout their life (Quiniou et al., 2002; Calderón Díaz et al., 2017), and have poorer meat quality (Gondret et al., 2006) than higher BiW contemporaries. However, after studying 2 datasets that contained 40,000 and 90,000 records, Douglas et al. (2013) suggested that piglets with light BiW were capable of compensatory postnatal growth and argued that light BiW had less influence on lifetime performance than did body weight of pigs at weaning or at entry to the growing-finishing phase. Other researchers (Quiniou et al., 2002; Paredes et al., 2012) observed that most of pigs with light BiW remained lighter than normal BiW contemporaries at slaughter age, but a small minority of pigs met or exceeded the average BW of normal BiW piglets. Unfortunately, there is limited information elucidating the proportion of light BiW piglets that express compensatory growth and how to identify these pigs at a young age.

Light BiW piglets fed starter diets with increased nutrient density achieved similar growth performance by day 70 of life compared with normal BiW piglets (Douglas et al., 2014b), but high specification diets fed during the grower phase (63 to 91 d of age) appeared too late to elicit compensatory growth of light BiW pigs to harvest (Douglas et al., 2014a). These studies demonstrated that BiW and early phase growth of piglets are critical indicators of performance to slaughter age. Therefore, we hypothesized that light BiW piglets that have rapid growth during the early phases of life (suckling and nursery periods) may also show compensatory growth during the growing-finishing phase so that harvest weight is not different than contemporary pigs with normal BiW. The objective of this study was to analyze the effect of piglet BiW and early growth rate on preweaning mortality, subsequent growth performance, and carcass characteristics.

MATERIALS AND METHODS

The data used for this study were collected as part of routine data recording in a commercial breeding program. The Schothorst Feed Research farm strictly operates in accordance with Dutch law regarding the protection of animals (Gezondheids- en welzijnswet voor dieren).

Data were obtained from the commercial breeding company, Topigs Norsvin, collected at the Schothorst Feed Research B.V. (Lelystad, The Netherlands) under commercial conditions. Records obtained from 536 commercial crossbred litters [Synthetic boar × (Large White × Landrace)], from January to December 2015, were used.

Pigs (n = 7,654) were weighed individually within 24 h of birth (BiW) and again around 26 days of age at weaning (**WeW**). Pigs were subsequently transferred to a nursery barn, and BW was recorded individually (n = 4,805) when pigs reached about 25 kg BW. Growth performance in the growing-finishing period (25 to 120 kg BW) was monitored for a subset of pigs (n = 1,417). When pigs reached a live weight of approximately 120 kg, pigs were shipped to a commercial abattoir where hot carcass weight (**HCW**), loin depth (**LD**), and backfat thickness (**BF**, measured using a "capteur gas maigre" (CGM; Sydel, France) probe) were recorded. Pigs were fed a commercial creep feed until weaning. After weaning, pigs were gradually transitioned to weaner diets until the start of the growing phase (± 25 kg BW). From start of the growing phase to slaughter, a 3-phase feeding scheme was used. Within phase of production, all pigs received the same vitamin and mineral-fortified diet based on wheat, barley, soybean meal, and rapeseed meal formulated to meet or exceed nutrient recommendations described by CVB (2007).

Numerous variables that described sow and pig performance were provided in the original dataset (Table 1). In addition to the existing variables, a number of new variables for each individual pig were calculated using the following formulas:

$$\text{Daily BW gain (g/d)} = (\text{BW2, kg} - \text{BW1, kg}) / (\text{age at BW2, d} - \text{age at BW1, d}) \times 1{,}000$$

$$\text{Finishing BW } (\textbf{FiW}\text{, kg}) \text{ adjusted for age (167 d)} = \text{average daily gain (ADG, g/d) grow} - \text{finish} \times (167\text{ d} - \text{actual age, d}) \times \text{Ka} + \text{FiW, kg}$$

$$\text{Carcass lean, \%} = (66.86 - 0.6549 \times \text{BF, mm} + 0.0207 \times \text{LD, mm}) \times 100$$

$$\text{HCW, kg adjusted for age (174 d)} = (\text{HCW, kg} - \text{WeW} \times 0.7\text{, kg}) / ((\text{age at slaughter} - \text{age at weaning}) \times (174\text{ d} - \text{age at slaughter})) \times \text{Ka} + \text{HCW, kg}$$

Table 1. Descriptive statistics

Item	*n*	Mean	CV (%)	Min	Max
Sow traits					
Parity	536	4.6	54.1	1	14
Live born/litter	536	14.3	22.5	3	21
Pigs weaned/litter	536	12.6	23.1	2	19
Body weight, kg					
Birth (live)	7,654	1.32	25.9	0.1	4.2
Weaning	6,777	7.19	21.3	2.0	12.2
Nursery exit	4,805	24.7	17.4	9.6	42.0
Finishing exit	1,417	120.0	6.0	58.5	146.0
Adjusted finishing (day 167)[1]	1,417	120.6	9.6	74.5	171.2
Pig age, d					
Weaning	6,777	26.2	7.1	18.0	46.0
Nursery exit	4,805	67.1	10.8	52.0	105
Finishing exit	1,417	166.9	5.7	99.0	196
Slaughter	4,574	174.4	8.4	139	306
Average daily gain, g					
Suckling (birth to weaning)	6,775	223	23.5	17	387
Nursery (Weaning to day 66)	4,805	428	18.9	118	769
Grow-Finish	1,417	932	10.4	499	1,409
Overall (weaning to finish)	1,417	802	9.1	500	1,116
Carcass characteristics					
Hot carcass wt., kg	4,574	92.6	6.2	65.6	119.2
Adjusted HCW (day 174), kg[2]	4,573	93.4	11.1	42.2	133.1
Backfat depth, mm	4,570	13.3	19.4	5.7	23.8
Loin depth, mm	4,570	63.2	10.8	37.3	87.2
Lean percentage[3], %	4,572	59.5	2.83	52.7	64.3
Lean growth rate, g/d	4,571	345	9.6	167	506

[1]Adjusted finishing (day 167) weight = Average daily gain (ADG, kg/d) grow-finish × (167 d – actual age) × 1.16 + finishing BW, kg.

[2]Adjusted HCW (day 174) = (Hot carcass weight, HCW, kg – weaning weight × 0.7, kg)/ (age at slaughter – age at weaning) × (174 d– age at slaughter) × 1.16 + HCW, kg.

[3]Lean percentage, % = 66.86 − 0.6549 × backfat depth (mm)+ 0.0207 × loin depth (mm).

$$\text{Lean growth rate } (\textbf{LGR};\ g/d) = 1,000 \times (\text{HCW, kg} \times \text{Carcass lean, } \% - \text{WeW, kg} \times k_w) / (\text{age at slaughter} - \text{age at weaning})$$

Growth rate during finishing phase (BW > 100 kg) was 1.16 times higher than overall ADG from weaning to finishing (NRC, 2012); hence, Ka was set to 1.16 in the equation to calculate adjusted FiW and HCW. The lean content of weaned piglets (k_w) was estimated to be 88% (Mitchell et al., 2012).

Mean growth rates for individual piglets were calculated to be 225 g/d during the suckling period and 424 g/d during the nursery period. Within the suckling phase, pigs were divided into slow (ADG ≤ 225 g/d) or fast growing (ADG > 225 g/d) categories. Similarly, in the nursery phase, pigs were divided into slow (ADG ≤ 424 g/d) or fast growing (ADG > 424 g/d) categories. Designations of "slow" and "fast" in suckling and nursery phases were determined solely by the pig's ADG during that period.

Records of the number of pigs that died and the date of death were maintained from birth to harvest. Two approaches were used to determine the effects of BiW on preweaning mortality. In the first approach, piglets were grouped into 4 BiW categories (< 1.0 kg; 1.0 to 1.3 kg; 1.3 to 1.6 kg; and > 1.6 kg) then preweaning mortality for each category was calculated for analysis. In addition, pigs were assigned to extremely light or heavy BiW groups when BiW was less than 0.5 or greater than 2.1 kg, while the other pigs were categorized by 0.1 kg increments for BiW from 0.5 to 2.1 kg. The average HCW at day 174 was 93.4 kg. Any pig with HCW (adjusted to day 174) weighing 87.7 kg (mean value – SD: 93.4 – 5.7 kg) or greater was considered to have produced a full value pig. Within each category, the average BiW and preweaning mortality (removal counts / total number of the group) were calculated. Similar calculations were also conducted for likelihood of full value pigs (Number of pigs with adjusted HCW > 87.7 kg/total number of the group).

Statistical Analyses

To examine the effect of BiW on preweaning mortality of pigs, a continuously segmented regression model was fitted to the data using the PROC NLIN procedure of SAS 9.4 (SAS Inst. Inc., Cary, NC). The model was adapted from Robbins et al. (2006) and consisted of 2 sloping lines intersecting at a breakpoint value. The statistical unit was BiW categories that were 0.1 kg wide and ranged from 0.5 to 2.1 kg. The segmented regression model described preweaning mortality in relation to BiW (kg) by the following equations:

$$Y = a + b \times (X - R) \text{ if } X < R \text{ and}$$
$$Y = a + c \times (R - X) \text{ if } X > R,$$

In which Y is the dependent variable (preweaning mortality), and X is the independent variable (BiW). Parameter a is the intercept, and parameter b is the slope of the line up to break point R, which occurs at the intersection of the 2 different linear responses, and c is the slope of the linear response when X > R.

Growth performance and carcass characteristics were analyzed using the Mixed procedure of SAS 9.4 (SAS Inst. Inc.). The statistical unit was individual pig. Kenward–Roger adjustments for degrees of freedom were used for all models to account for unbalanced data across fixed effects (Littell et al., 2006). The fixed effects included sex, growth rate (suckling or nursery phase), and random effects included sire and litters nested within sire. The covariates included BiW, BiW × growth rate (suckling or nursery), parity, and parity × parity. Differences were considered significant when $P \leq 0.05$, and a trend when $0.05 < P < 0.10$.

RESULTS

Descriptive Statistics

The average parity of sow was 4.6 with a range of 1 to 14 (Table 1). Pigs were weaned at day 26.2 of age with average WeW of 7.19 kg, exited the nursery barn at approximately 67.1 days of age with average nursery weight (**NuW**) of 24.7 kg, and achieved market weight (120 kg) at day 167. The body weight and growth rate during early life (BiW, WeW, and NuW) were highly variable (CV > 17%) while the CV of FiW, adjusted FiW, and ADG during the growing-finishing phase were 10% or less. Pigs were harvested with average HCW of 92.6 kg and 59.5% carcass lean.

Effects of Birth Weight on Preweaning Mortality

In this dataset, 872 out of 7,654 piglets were removed before weaning, for an average preweaning mortality of 12.9%. Pigs with the lightest BiW (<1.0 kg) accounted for 54.1% ($n = 472$) of the total preweaning losses ($n = 872$), whereas the heavy piglets accounted for 24.2, 14.2, and 7.5% of the total preweaning death losses for BiW categories 1.0 to 1.3 kg, 1.3 to 1.6 kg, and > 1.6 kg, respectively (Fig. 1A). The percentage of preweaning mortality increased linearly ($P < 0.05$) as piglet BiW decreased (Fig. 1B). Results of segmented regression analysis show that pigs with a BiW below 0.99 kg were at higher risk of mortality (slope: −137 vs. −8.04, $P < 0.05$) than pigs with BiW above 0.99 kg.

Birth Weight and Growth Rate During Suckling

During suckling phase, fast growing piglets had 0.24 kg greater ($P < 0.05$) BiW than slow growing piglets (Table 2). Significant interaction effects ($P < 0.05$) of BiW with suckling growth rate for WeW, NuW, FiW, and adjusted FiW, as well as ADG during suckling, grow-finish, and overall (weaning to finish) were detected. The adjusted FiW of slow growing suckling pigs increased ($P < 0.05$) more rapidly (12.47 vs. 6.54 kg/kg, $P < 0.05$) with increasing BiW compared with those growing fast during the suckling phase (Fig. 2A). Similarly, FiW and ADG of pigs during the grow-finish phase with slow growth rate during the suckling phase increased more steeply (FiW, 4.20 vs. 1.36 kg/kg $P < 0.05$; ADG, 79.29 vs. 27.80 g/d kg^{-1} $P < 0.05$) with increasing BiW compared with those growing fast during the suckling phase. However, fast growing suckling pigs had greater ($P < 0.05$) BiW linear coefficients for WeW (1.86 vs. 1.54 kg/kg), NuW (2.09 vs. 0.53 kg/kg), and ADG of the suckling period (33.23 vs. 19.68 gd^{-1}/kg) compared with pigs with slow growth rate during the suckling phase.

Significant interaction effects ($P < 0.05$) between BiW and growth rate during suckling were observed for age at nursery exit and slaughter; and tendencies towards significant interaction effects were detected for age at weaning and finish exit ($P < 0.10$). The influences of increasing BiW were greater ($P < 0.05$) on age at nursery exit and age at slaughter for slow growing suckling pigs than those with fast suckling growth rate. Specifically, an increase in BiW of 1 kg decreased ($P < 0.01$) age at nursery exit and age to slaughter by 8.51 and 17.87 d, respectively, in slow

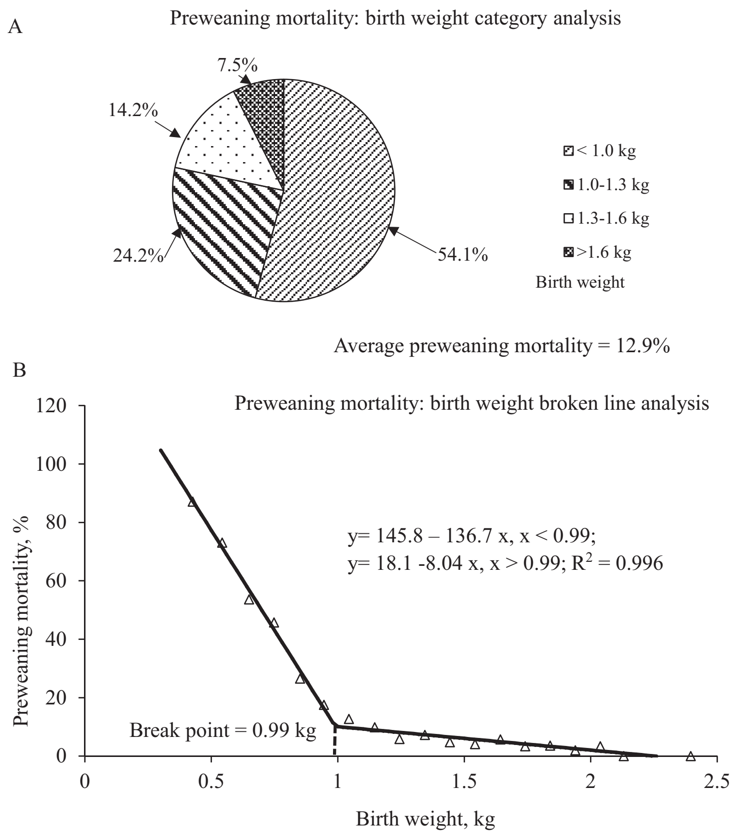

Figure 1. Effects of birth weight (BiW) on preweaning mortality of piglets. Panel A: category analysis (piglets were assigned into 4 BiW categories: < 1.0 kg; 1.0 to 1.3 kg; 1.3 to 1.6 kg; and > 1.6 kg); Panel B: broken line regression analysis (piglets were categorized by 0.1 kg increments for BiW from 0.5 to 2.1 kg and BiW less than 0.5 or greater than 2.1 kg).

growing suckling pigs but 4.86 and 10.62 d for pigs with fast suckling growth rate.

Significant interaction effects ($P < 0.01$) between BiW and growth rate during suckling were observed for adjusted HCW and lean growth rate (**LGR**). With 1 kg increase in BiW, adjusted HCW and LGR increased ($P < 0.01$) by 12.87 kg and 35.52 g/d for pigs with slow suckling growth rate, and 9.80 kg and 24.15 g/d for fast growing suckling pigs. Increases in adjusted HCW and LGR per 1 kg of BiW were greater ($P < 0.01$) in slow growing pigs compared with fast growing pigs during suckling. With 1 kg increase in BiW, HCW, LD, and lean percentage were increased linearly ($P < 0.01$) while BF decreased linearly ($P < 0.05$).

Birth Weight and Growth Rate During Nursery

Birth weight was 0.16 kg greater ($P < 0.01$) for fast growing nursery pigs compared with pigs expressing slow nursery growth rate (Table 3). Pigs with fast growth rate during nursery phase had a greater ($P < 0.05$) adjusted FiW compared with slow growing nursery pigs at the same BiW, and both pig categories showed linearly improved ($P < 0.01$) adjusted FiW with increasing BiW (Fig. 2B). Similarly, fast growing nursery pigs had a greater ($P < 0.05$) NuW and FiW compared with slow growing nursery pigs, as well as ADG of nursery and overall. With increasing BiW, the WeW and ADG of the suckling and grow-finish phases, and overall were linearly increased ($P < 0.01$). A significant interaction effect ($P < 0.05$) was detected between BiW and nursery growth rate for ADG of the nursery phase, which increased ($P < 0.01$) 34.79 g/d in fast growing nursery pigs and 20.01 g/d in slow growing nursery pigs with a 1 kg increase in BiW. The ADG of suckling and grow-finish periods were not related to growth rate during the nursery period.

With a 1 kg increase in BiW, age at nursery exit, finish exit, and slaughter were decreased linearly ($P < 0.05$) with a range of −5.94 d to −16.70 d for both of the slow and fast growing nursery pigs. The age at slaughter with the same BiW was delayed ($P < 0.05$) by slow growth rate during nursery compared with the fast growing nursery pigs.

Increasing BiW linearly improved ($P < 0.01$) HCW, adjusted HCW, LD, lean percentage, and LGR for both of slow and fast growing nursery pigs. A significant BiW by nursery growth rate interaction effect ($P < 0.05$) was detected for analysis of BF, and a tendency toward a significant

Table 2. Effects of birth weight (BiW) and suckling growth rate on pig performance and carcass characteristics[1]

	Suckling growth rate			BiW coefficient[2]			*P*-value[3]		
Item	Slow	Fast	SE	Slow	Fast	SE	GR	B	GR×B
Body weight, kg									
Birth	1.22	1.46	0.01				<0.01		
Weaning	6.2	8.0	0.05	1.54	1.86	0.07	<0.01	<0.01	<0.01
Nursery exit	25.1	25.2	0.27	0.53	2.09	0.36	<0.01	<0.01	<0.01
Finishing exit	119	120	0.60	4.20	1.36	1.36	<0.01	0.140	0.036
Adjusted finishing (day 167)[4]	119	123	0.87	12.47	6.54	2.06	<0.01	<0.01	<0.01
Pig age, d									
Weaning	26.1	26.0	0.15	−0.15	−0.06	0.05	0.012	0.143	0.053
Nursery exit	69.6	65.3	0.37	−8.51	−4.86	0.56	<0.01	<0.01	<0.01
Finishing exit	167	165	0.77	−9.13	−5.85	1.72	<0.01	<0.01	0.057
Slaughter	178	170	0.58	−17.87	−10.62	1.28	<0.01	<0.01	<0.01
Average daily gain, g/d									
Suckling (birth to weaning)	187	260	1.10	19.68	33.23	2.50	<0.01	<0.01	<0.01
Nursery (Weaning to day 66)	437	436	4.68	54.80	57.30	6.84	0.660	<0.01	0.714
Grow-Finish	927	945	7.47	79.29	27.8	18.21	<0.01	0.023	<0.01
Overall (weaning to finish)	801	814	5.58	70.25	28.81	13.40	<0.01	<0.01	<0.01
Carcass characteristics									
Hot carcass weight, kg	92.3	92.2	0.28	1.36	2.07	0.56	0.204	<0.01	0.208
Adjusted HCW (day 174)[5], kg	91.0	95.8	0.44	12.87	9.80	0.89	<0.01	<0.01	<0.01
Backfat, mm	13.7	13.6	0.13	−0.49	−0.39	0.25	0.403	0.040	0.670
Loin depth, mm	62.4	62.8	0.29	1.25	1.38	0.67	0.809	<0.01	0.856
Lean percentage[6], %	54.6	54.6	0.16	0.35	0.29	0.16	0.420	0.019	0.724
Lean growth rate, g/d	327	332	1.45	35.52	24.15	2.88	<0.01	<0.01	<0.01

[1]Least squares mean of suckling growth rate categories (slow and fast) were presented with BiW = 1.30 kg and parity =4.6. Pigs with ADG during the suckling period less than 225 g/d were assigned to the slow category and equal or above 225 g/d were assigned to the fast category.

[2]Partial regression coefficient for BiW.

[3]GR = Growth rate effect, B = Birth weight effect, GR×B = interaction between growth rate and birth weight.

[4]Adjusted finishing (day 167) weight = Average daily gain (ADG, g/d) grow-finish × (167 d – actual age) × 1.16 + finishing BW, kg.

[5]Adjusted HCW (day 174) = (Hot carcass weight, HCW, kg – weaning weight × 0.7, kg)/ (age at slaughter – age at weaning) × (174 d– age at slaughter) × 1.16 + HCW, kg.

[6]Lean percentage, % = 66.86 − 0.6549 × backfat depth (mm)+ 0.0207 × loin depth (mm).

effect ($P = 0.073$) for adjusted HCW. With a 1 kg increase in BiW, BF declined more ($P < 0.01$) sharply (−0.89 mm) in slow growing nursery pigs compared with (−0.29 mm) fast growing nursery pigs. The fast growing nursery pigs tended to have a greater (13.27 vs. 11.77 kg/kg, $P < 0.01$) BiW coefficient for adjusted HCW than those with slow nursery growth rate. The LGR with BiW at 1.3 kg was increased by (336 vs. 320 g/d, $P < 0.01$) fast growth rate during the nursery phase compared with slow growing nursery pigs.

Full Value Pigs

A positive association between birth weight and likelihood of survival to the desired market carcass weight (87.7 kg, mean – 1 × standard deviation) at 174 d of age (when BiW was below threshold (fast growing suckling pigs = 1.48 kg; slow growing suckling pigs = 1.89 kg) was detected ($P < 0.01$), which was affected by ADG during the suckling period (Fig. 3A) and growth rate during the nursery phase (Fig. 3B). The relationship between BiW and likelihood of producing a desired carcass for slow and fast growing suckling pigs were linear up to 1.89 and 1.48 kg, respectively, after which any increase in BiW did not result in an increased likelihood of achieving the desired carcass weight. For slow and fast growing nursery pigs, BiW increases up to 1.85 kg and 1.56 kg resulted in increased likelihood of producing a desired carcass.

Parity of Sow

When pigs were categorized by growth rate in the suckling phase, BiW tended ($P = 0.063$) to be associated linearly with parity of sow (Table 4). The adjusted FiW was quadratically improved

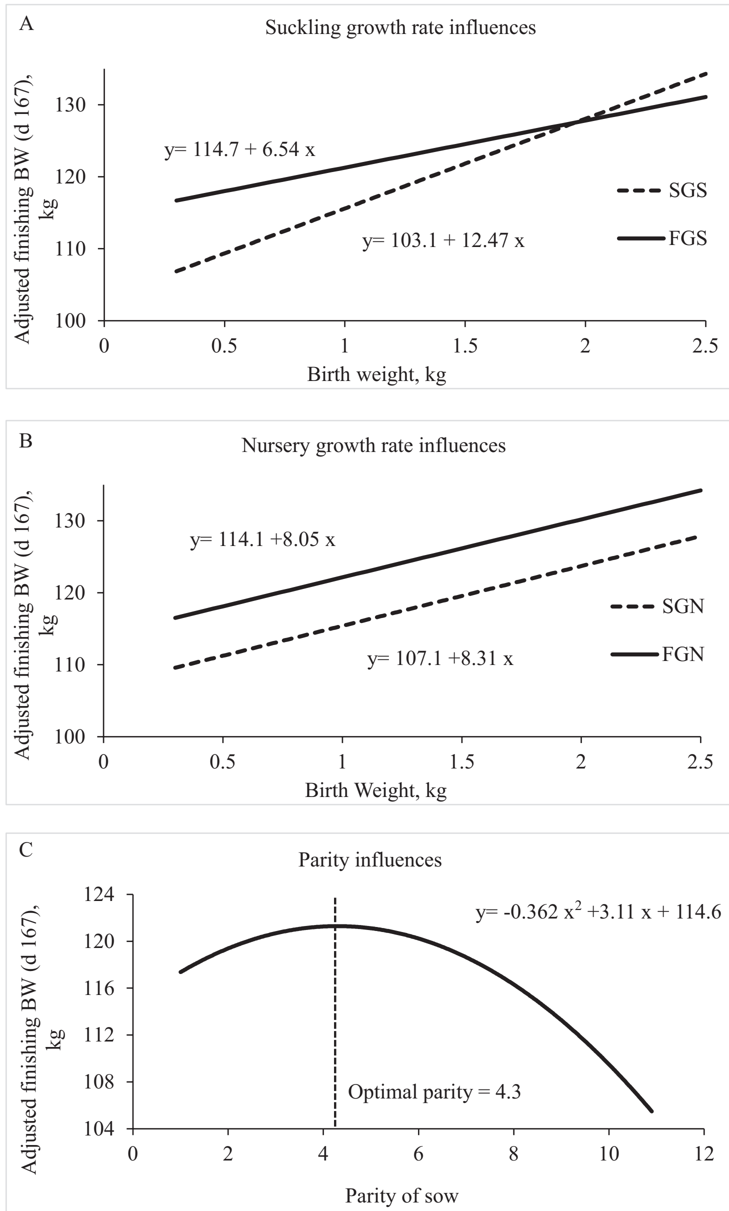

Figure 2. Adjusted finishing BW (FiW, day 167) was affected by birth weight, suckling growth rate (A), nursery growth rate (B), and parity of sow (C). SGS = piglets with slow suckling growth rate (< 225 g/d); FGS = piglets with fast suckling growth rate (≥ 225 g/d); SGN = piglets with slow nursery growth rate (< 424 g/d); FGN = piglets with fast nursery growth rate (≥ 424 g/d).

(P < 0.01) with increasing parity of the sow (Fig. 2C). Similarly, there was quadratic improvement (P < 0.01) for WeW and NuW with increasing parity of the sow. The optimal parities were 4.8, 6.8, and 4.3 for WeW, NuW, and adjusted FiW, respectively. Parity of sow decreased quadratically (P < 0.01) pig age at finish exit and slaughter when the parity was below 4.8 and 4.3, respectively. Average daily gain of pigs during the suckling, nursery, and grow-finish phase, and overall were quadratically improved (P < 0.01) by increased parity with optimal parity range of 4.1 to 5.3. The adjusted HCW and BF were increased quadratically (P < 0.01) with increased parity when parity was below 3.8 and 4.7 for adjusted HCW and BF, respectively. With increased parity, the loin depth and lean percentage were decreased quadratically when parity was below 6.7 and 4.8, respectively.

DISCUSSION

This study aimed to identify early-life indicators (BiW, growth rate during suckling and nursery) that affect subsequent lifetime performance and carcass characteristics of pigs. The variance of BiW, WeW, and FiW from the dataset was consistent with previous literature, whereas the average parity in the current dataset (4.6) was greater than that

Table 3. Effects of birth weight (BiW) and nursery growth rate on pig performance and carcass characteristics[1]

	Nursery growth rate			BiW coefficient[2]			*P*-value[3]		
Item	Slow	Fast	SE	Slow	Fast	SE	GR	B	GR×B
Body weight, kg									
Birth	1.27	1.43	0.01				<0.01		
Weaning	7.2	7.2	0.07	2.84	2.76	0.11	0.490	<0.01	0.447
Nursery exit	22.7	27.4	0.20	0.26	0.01	0.28	<0.01	0.975	0.359
Finishing exit	119	121	0.57	3.40	1.45	1.29	0.013	0.131	0.131
Adjusted finishing (day 167)[4]	118	125	0.81	8.31	8.05	1.91	0.012	<0.01	0.894
Pig age, d									
Weaning	26.1	26.1	0.15	0.00	−0.18	0.05	<0.01	<0.01	<0.01
Nursery exit	67.2	67.7	0.37	−9.46	−8.85	0.55	0.656	<0.01	0.268
Finishing exit	169	164	0.72	−5.94	−7.31	1.59	0.190	<0.01	0.392
Slaughter	177	171	0.57	−16.40	−16.70	1.22	<0.01	<0.01	0.802
Average daily gain, g/d									
Suckling (birth to weaning)	228	227	2.52	71.82	68.00	4.04	0.484	<0.01	0.345
Nursery (Weaning to d 66)	375	487	2.35	20.01	34.79	4.38	<0.01	<0.01	<0.01
Grow-Finish	920	950	7.12	42.26	46.23	17.35	0.319	<0.01	0.819
Overall (weaning to finish)	782	827	5.05	37.47	36.03	12.30	<0.01	<0.01	0.907
Carcass characteristics									
Hot carcass weight, kg	91.9	92.6	0.28	1.38	1.61	0.53	0.649	<0.01	0.654
Adjusted HCW (day 174)[5], kg	90.8	95.5	0.42	11.77	13.27	0.84	0.018	<0.01	0.073
Backfat, mm	13.5	13.7	0.13	−0.89	−0.29	0.23	0.082	0.093	0.010
Loin depth, mm	62.5	62.8	0.29	1.34	1.55	0.63	0.974	<0.01	0.740
Lean percentage[6], %	54.5	54.7	0.16	0.61	0.22	0.15	0.086	0.046	0.011
Lean growth rate, g/d	320	336	1.36	35.52	24.15	2.88	<0.01	<0.01	0.295

[1]Least squares mean of nursery growth rate categories (slow and fast) were presented with BiW = 1.30 kg and parity =4.6. Pigs with ADG during the nursery period less than 424 g/d were assigned to slow category and equal or above 424 g/d were assigned to fast category.

[2]Partial regression coefficient for BiW.

[3]GR = Growth rate effect, B = Birth weight effect, GR×B = interaction between growth rate and birth weight.

[4]Adjusted finishing (day 167) weight = Average daily gain (ADG, g/d) grow-finish × (167 d – actual age) × 1.16 + finishing BW, kg.

[5]Adjusted HCW (day 174) = (Hot carcass weight, HCW, kg – weaning weight × 0.7, kg)/ (age at slaughter – age at weaning) × (174 d– age at slaughter) × 1.16 + HCW, kg.

[6]Lean percentage, % = 66.86 -0.6549 × backfat depth (mm)+ 0.0207 × loin depth (mm).

of previous studies which ranged from 2.7 to 3.3 (Douglas et al., 2013; Calderón Díaz et al., 2017). Most such studies usually exclude pigs considered to have particularly light BiW (typically < 0.8 kg) as they are considered to be runts and would be expected to influence the value of the conclusions drawn (Nissen and Oksbjerg, 2009). By contrast in our study, piglets with BiW as low as 0.1 kg were considered and there were 153 carcass records for piglets with BiW below 0.8 kg.

Preweaning mortality of piglets is one of the major reproductive issues that affect herd productivity in the swine industry. In agreement with previous studies, lighter BiW is associated with an increased risk of preweaning mortality (Quiniou et al., 2002; Fix et al., 2010; Muns et al., 2013). As reviewed by Muns et al. (2016), light piglets at birth have less body energy reserves, poor passive immunity, less competitiveness for a teat, and reduced ability to maintain body temperature compared with heavier pigs. Consequently, light piglets (< 0.7 kg) can have a very low survival rate (33%), whereas over 90% of heavy piglets at birth (> 1.8 kg) survive (Chris et al., 2012). In the current study, light piglets (< 1 kg) had a mortality rate of 43.9% and contributed to 51.2% of the total preweaning losses. Piglets with BiW below 0.99 kg had a mortality rate that was 8.5 times higher than piglets with BiW greater than 0.99 kg. This BiW threshold is similar to the results reported by Calderón Díaz et al. (2017) of 0.95 kg and Feldpausch et al. (2016) of 1.11 kg of BiW. There may be biological mechanisms underlying this phenomenon that the BiW threshold of preweaning mortality risk is around 1 kg. For example, intrauterine growth restriction that leads to pigs weighing less than 1.1 kg at birth increases the risk for metabolic disorders

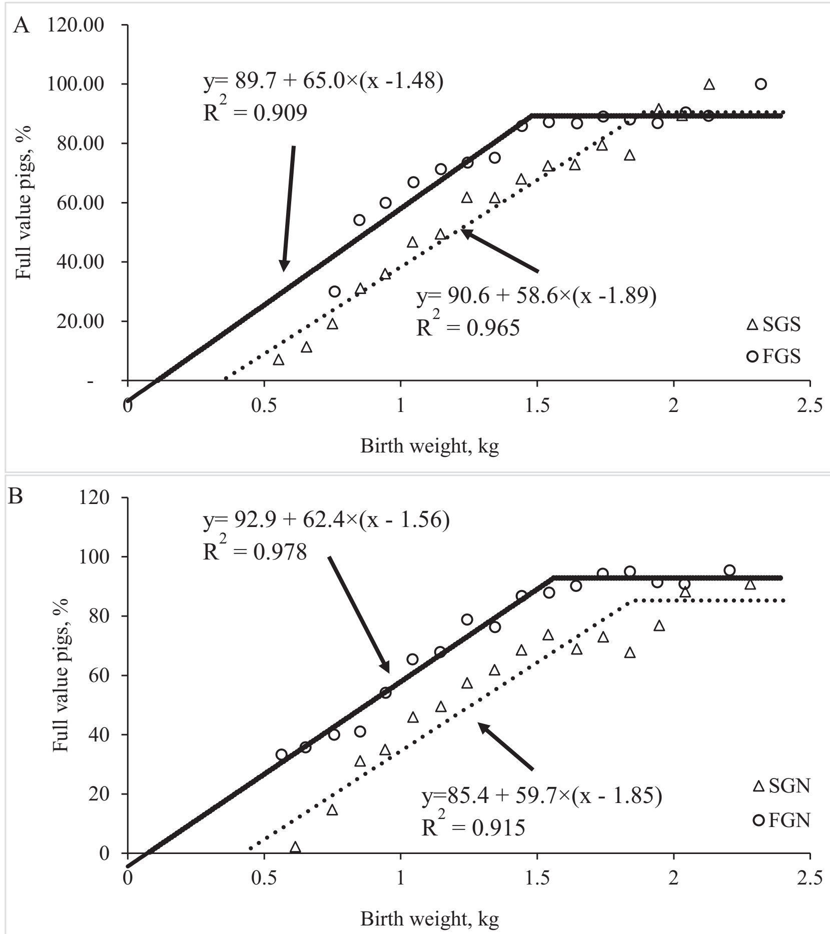

Figure 3. The effects of birth weight on probability of full value pigs (adjusted hot carcass weight at day 174 > 87.7 kg) with different suckling growth rate (A) or nursery growth rate (B). SGS = piglets with slow suckling growth rate (< 225 g/d); FGS = piglets with fast suckling growth rate (≥ 225 g/d); SGN = piglets with slow nursery growth rate (< 424 g/d); FGN = piglets with fast nursery growth rate (≥ 424 g/d).

(including hypoglycemia), and permanent negative impacts on organ structure, neonatal adjustment, postnatal growth, feed efficiency, lifetime health, skeletal-muscle composition, and the onset of adult diseases (Ji et al., 2017; Wang et al., 2017).

Several researchers (Paredes et al., 2012; Douglas et al., 2013; Collins et al., 2017) have reported that piglet BiW and WeW are the most critical factors for lifetime performance of pigs. In agreement with these studies, our results showed that increasing BiW by 1 kg was associated with improvement of WeW by 1.5 to 1.9 kg, adjusted FiW by 6.6 to 12.5 kg, or a decrease in days to slaughter by 10.6 to 17.9 d. Weaning weight may be a better indicator of subsequent growth performance than BiW in pigs (Douglas et al., 2013). Mahan et al. (1998) reported that pigs with heavier weaning weight (7.5 kg at day 23) reached 105 kg of BW approximately 8 d sooner than those with lighter weaning weight (5.5 kg at day 23). The concern with these studies is that BiW is confounded with weaning weight. Controlling for this confounding factor, Cabrera et al. (2010) evaluated long-term performance of pigs with similar BiW (1.43 kg). They found that pigs weighing between 5.0 and 5.9 kg at 20 d of age were able to reach 125 kg of BW 8 d sooner than pigs weighing between 4.1 and 5.0 kg at 20 d of age. However, there was limited information pertaining to the interactions between BiW and WeW. A novel finding of the current study was that the influence of weaning weight (or preweaning growth rate) on lifetime performance of pigs depended on BiW of piglets. For heavy BiW pigs (assuming BiW = 2 kg), fast preweaning growth rate increased weaning weight by 2 kg, but did not impact the adjusted FiW at day 167, compared with slow growing suckling pigs. However, for light BiW pigs (assuming BiW = 0.8 kg), the slow growing suckling pigs weighed 1.7 kg less at weaning and 6.9 kg less adjusted FiW at day 167 than the counterparts with fast suckling growth rate. These results imply that heavy pigs with poor preweaning growth rate may still catch up and potentially show compensatory growth during postweaning growth. However, light

Table 4. Effects of sow parity on pig performance and carcass characteristics[1]

	Quadratic coefficient			Linear coefficient			
Item	Estimate	SE	*P*-value	Estimate	SE	*P*-value	Optimal parity[2]
Body weight, kg							
Birth	−0.002	0.001	0.272	0.03	0.01	0.063	NA
Weaning	−0.009	0.004	0.012	0.09	0.04	0.014	4.8
Nursery exit	−0.046	0.021	0.026	0.62	0.20	<0.01	6.8
Finishing exit	−0.068	0.057	0.231	0.30	0.54	0.583	NA
Adjusted finishing (day 167)[3]	−0.362	0.080	<0.01	3.11	0.76	<0.01	4.3
Pig age, days							
Weaning	0.000	0.012	0.975	−0.04	0.12	0.716	NA
Nursery exit	0.039	0.032	0.224	−0.14	0.31	0.659	NA
Finishing exit	0.321	0.077	<0.01	−3.05	0.72	<0.01	4.8
Slaughter	0.197	0.056	<0.01	−1.68	0.53	<0.01	4.3
Average daily gain, g/d							
Suckling (birth to weaning)	−0.376	0.104	<0.01	4.02	1.01	<0.01	5.3
Nursery (Weaning to day 66)	−1.411	0.376	<0.01	14.63	3.61	<0.01	5.2
Grow-Finish	−2.374	0.690	<0.01	19.35	6.52	<0.01	4.1
Overall (weaning to finish)	−2.207	0.518	<0.01	18.19	4.89	<0.01	4.1
Carcass characteristics							
Hot carcass weight, kg	0.005	0.023	0.831	−0.18	0.22	0.403	NA
Adjusted HCW (day 174)[4], kg	−0.136	0.040	<0.01	1.02	0.38	<0.01	3.8
Backfat, mm	−0.048	0.011	<0.01	0.45	0.11	<0.01	4.7
Loin depth, mm	0.046	0.025	0.074	−0.61	0.24	0.012	6.7
Lean percentage[5], %	0.032	0.007	<0.01	−0.31	0.07	<0.01	4.8
Lean growth rate, g/d	−0.192	0.131	0.143	0.73	1.25	0.560	NA

[1]Parity and parity × parity served as covariates in the statistical model, the coefficient of parity and parity × parity are reported in the table.

[2]Calculated from the quadratic (a) and linear (b) coefficients: b/(-2a). (NA: there was no optimal parity when *P* (quadratic) > 0.10.

[3]Adjusted finishing (day 167) weight = Average daily gain (ADG, g/d) grow-finish × (167 d – actual age) × 1.16 + finishing BW, kg.

[4]Adjusted HCW (day 174) = (Hot carcass weight, HCW, kg – weaning weight × 0.7, kg)/(age at slaughter – age at weaning) × (174 d – age at slaughter) × 1.16 + HCW, kg.

[5]Lean percentage, % = 66.86 − 0.6549 × backfat depth (mm)+ 0.0207 × loin depth (mm).

pigs may lose the compensatory growth capability if the ADG during suckling phase was below the average level (225 g/d for the current study). Other studies suggest that light BiW piglets are, to some extent, able to catch up in growth with heavy piglets and have the potential to compensate during postnatal growth (Quiniou et al., 2002; Douglas et al., 2013; Pardo et al., 2013).

However, piglets with fast growth rate during the nursery phase had consistently greater overall ADG and adjusted FiW compared to slow growing nursery pigs (at a similar BiW). This means that if heavy BiW piglets (assuming BiW = 2 kg) perform very poorly during the nursery phase (assuming ADG during nursery < 424 g/d), they may lose compensatory growth capability and have, on average, 7 kg lower adjusted FiW compared to fast growing nursery pigs with the same BiW (assuming BiW = 2 kg). A similar situation also applied to light BiW piglets with poor nursery performance. These results imply that nursery management and nutrition show similar influence on both light and heavy BiW piglets and that poor nursery performance reduced market weight, regardless of BiW.

In the current study, BiW was associated negatively with BF and linearly increased the LD of carcass. As expected, lean percentage was improved by 0.22 to 0.61% (depending on nursery ADG) with a 1 kg increase in BiW in the current study. In agreement with our results, Heyer et al. (2004) reported that carcass meat content and percentage of valuable cuts increased and BF thickness decreased with increasing piglet BiW. Similarly, Gondret et al. (2005) reported that light BiW pigs had greater BF thickness and fat content and less muscle content compared with heavy BiW pigs at the same slaughter weight. Rehfeldt and Kuhn (2006) found a tendency toward leaner carcass in pigs with heavy BiW (1.80 kg) compared with lighter counterparts (BiW = 0.94 kg) at a similar slaughter age. In contrast, it was also reported that fat thickness was not affected by BiW for pigs fed ad libitum to a constant age (Rehfeldt et al., 2008). Other studies reported no relationship between BiW and lean percentage when the range of BiW was only 0.85 kg or less (Berard et al., 2008; Beaulieu et al., 2010). Rekiel et al. (2015) reviewed effects of piglet BiW on carcass muscle, fat content, and pork quality and did not draw a solid conclusion due to inconclusive results of different researchers. It appears that the influences of BiW on carcass composition were not very robust, which can be detected by a linear model with large sample size or a categorical model with substantial BiW differences.

Hot carcass weight is one of the primary factors for carcass value evaluation. A relatively light HCW may reduce net income since slaughter processing cost per head is fixed. Pork producers may extend feeding days of slow-growing pigs to meet minimum weight requirements of packers, which decreases facility utilization and increases fixed expense per pig produced. Therefore, it is vital for pork producers to produce more pigs that reach the standard HCW at a standard age. In the current study, average HCW minus standard deviation at day 174 (87.7 kg) was set as a criterion to identify a full value pig. Likelihood of a pig to achieve full value was improved linearly with increased BiW and reached a plateau when BiW was above 1.48 and 1.56 kg for fast growing suckling and nursery pigs, respectively. Although the heavy piglets (fast growing suckling pigs with BiW > 1.48 kg or fast growing nursery pigs with BiW > 1.56 kg) had fast growth rate during the suckling or nursery phases, there were still about 10% of pigs that failed to achieve the desired carcass weight (87.7 kg). Further studies are encouraged to investigate what factors contribute to the low carcass weight (< 87.7 kg) for those pigs with medium or heavy BiW (> 1.48 kg) and good early phase growth performance (ADG of suckling > 225 g/d or nursery > 424 g/d). Birth weight appears to have similar influences on the likelihood of producing a desired carcass for pigs with different early phase growth rate. Every 100 g increase in BiW was associated with a 5.9 to 6.5 % increase in the likelihood of producing full value pigs. In addition, when BiW was less than 1.48 kg, pigs with fast suckling growth rate showed 16 to 21% greater likelihood of producing full value pigs compared with slow growing suckling pigs, and fast growing nursery pigs had 21 to 24% greater likelihood of producing full value pigs than slow growing nursery pigs.

First-parity sows have been well documented to have piglets with light BiW and produce less milk during lactation compared with multiparous sows (Milligan et al., 2002; Larriestra et al., 2006). Growth rate of pigs suckling from first-parity sows is likely to be decreased, and hence, leads to poorer nursery and finishing growth compared with progeny of multiparous sows (Smits and Collins, 2009; Carney et al., 2013; Miller et al., 2013). However, there is little information in the scientific literature pertaining to progeny of geriatric sows (parity > 6). In the current study, quadratic responses to parity of sows (range from 1 to 14) were observed in NuW, adjusted FiW, adjusted HCW, and lean percentage. The optimal parity ranged from 3 to 6 for these measures.

In conclusion, our results reinforce the importance of BiW on preweaning mortality and lifetime performance. Results show that light birth weight piglets were more likely to die prior to weaning than high birth weight pigs and that increased birth weight was associated with faster growth during the suckling, nursery, and grow-finish phases as well as increased weaning weight, decreased age at nursery exit, finish exit, and slaughter, and improved HCW, adjusted HCW, LD, lean %, and LGR. Heavy piglets (BiW > 2 kg) with slow suckling growth rate were able to achieve similar lifetime performance compared with their counterparts. However, light birth weight pigs may lose compensatory growth capability if ADG during the suckling phase is below average. Therefore, light birth weight piglets (i.e., <1.0 kg of BW) require special attention during the suckling phase to reduce the likelihood of preweaning mortality and to improve later life performance. Results from this study also show that parity of the dam impacts piglet performance, and that progeny from mid-parity sows (3 to 6) had optimal lifetime growth performance.

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