ABSTRACT

FIX, JUSTIN SCOTT. Relationship of Piglet Birth Weight with Growth, Efficiency, Composition, and Mortality (Under the direction of Dr. M. Todd See).

The objectives of this project were two-fold; first, to estimate to impact of birth weight in a commercial production system on economically important traits; second, to estimate the heritability of individual birth weight and its genetic relationship with economically important traits. To accomplish the first goal two trials were conducted. Both trials involved collecting individual piglet birth weights within 24 hours of birth on a commercial sow farm. All pigs were farrowed from Large White x Landrace sows bred to Duroc boars. In trial one, 5,727 pigs were initially weighed. Individual mortality was tracked and BW weights were collected at weaning and placement in the finisher. Approximately half of the remaining live pigs at finishing placement were followed through finishing and individual BW were collected 16 weeks into finishing. During BW collections, pigs were given a quality score based on BW and health (3 = acceptable weight and no visible injuries/health issues; 2 = somewhat light weight and/or minor injuries/health issues; 1 = severely light weight and/or minor injuries/health). Nonlinear associations for birth weight with BW (weaning, finishing placement, and 16 weeks into finishing), mortality (pre-weaning and nursery), quality score (weaning, finishing placement, and 16 weeks into finishing) were estimated. In each instance as birth weight decreased an unfavorable effect occurred in all traits; impact was especially great for the lightest birth weight pigs. Similarly as birth weight decreased the likelihood of a pig being full value near the end of finishing (combination of the previous traits) decreased.

In the second study 440 pigs were transferred to the Swine Evaluation Station (Clayton, NC) to focus on the impact of birth weight on feed efficiency. Pigs were penned by birth weight, and BW and feed intake were tracked through the conclusion of finishing. Light birth weight pigs were more efficient; however, the advantage in efficiency was apparently due to benefits associated with being lighter weight throughout the trial.

The third and final portion of this work was estimating (co)variances for birth weight and other production parameters. Data were from nucleus Large White and Landrace records provided by a large swine production company. Estimated direct heritability for individual birth weight was low, < 0.10; however, it was moderately and favorably correlated with future BW (weaning weight and off-test weight). Based on these results direction selection for birth weight may have limitations but genetic change would be expected through genetic selection for growth.

Birth weight is strongly associated with traits of economic importance from pre-weaning to finishing. Unfortunately, birth weight is lowly heritable; however, favorable genetic correlations do exist with economically important traits. Regardless of the method, genetic selection or management, steps need to be taken reduce the impact light birth weight pigs have on a production system.

Relationship of Piglet Birth Weight with Growth, Efficiency, Composition, and Mortality

by
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BIOGRAPHY

Justin S. Fix was born on November 17, 1982 in Muscatine, Iowa. Involvement in 4-H and FFA led to participation in livestock judging. This participation in livestock judging resulted in Justin attending Lake Land College in Mattoon, Illinois upon graduation from Muscatine High School in 2001 to compete as a member of the livestock judging team. After completing his Associates of Science degree in 2003, Justin enrolled in Iowa State University. During his time at Iowa State University, Justin once again participated on the livestock judging team. Through this participation Justin began working for Dr. Tom Baas and Dr. Ken Stalder. This worked helped to create an interest in swine breeding and genetics which in turn led to Justin beginning a Master's of Science Degree at North Carolina State University. Justin completed work on his M.S. degree with Dr. Todd See in 2007. His M.S. worked involved a comparison of 1980 vs. 2005 genetics and feeding programs and their impact on economically important production traits from weaning through pork quality. After completion of his Masters Degree, Justin participated in a summer internship with Pig Improvement Company in the Genetic Services Group under the guidance of Dr. David Casey. Following his internship Justin returned to North Carolina State University to work on his PhD, once again under the direction of Dr. Todd See.

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Chapter 1: Literature Review

Introduction

Continued improvement in production, is vital to the economic stability of swine production companies, especially during harsh economic climates. One of the most important production parameters, which encompasses all phases of production, is number of full value pigs marketed per sow per year. This is compromised of reproductive traits such as, conception rate, number born alive, number weaned, wean-to-estrus, etc., along with nursery and finishing performance, mortality, pig quality, sufficient growth to reach minimum harvest weight requirements, etc. Improvement in all of these traits in some form or another is the focal point of many genetic selection programs and management practices. However, many factors, both environmental and genetic, impact various production parameters mentioned. One factor, which is becoming more prominent, is individual piglet birth weight.

Therefore, four areas are covered in this literature review: first, causes of low birth weight pigs; second, implications of low birth weight pigs on production; third, the biological basis for the impact of low birth weights on future production parameters; fourth, genetic parameters associated with birth weight and economically important production parameters of commercial market swine.

Causes of Low Birth Weight Piglets

A review by Foxcroft et al. (2006) summarized a variety of studies detailing the causes of low birth weight pigs. In the review two main factors associated with a greater likelihood or incidence of low birth weight pigs were uterine capacity and maternal uterine nutrition. One study in particular, Johnson et al. (1999), selected for increased ovulation rate and embryonic survival for 11 generations followed by increased litter size for 3 generations; after 14 generations the select line had increased by nearly 1.5 live pigs and 3 fully formed pigs. However, the total litter weight at birth had not changed, indicating pigs in the larger litters, were on average smaller. Based on these results, increasing litter size is possible; however, uterine capacity may limit the total litter weight and consequently larger litters lead to decreased birth weights in genetic lines common to U.S. commercial swine production.

The effect of increased litter size on piglet birth weight may potentially be increasing in importance to the U.S. swine industry. More specifically, continued and/or increased emphasis in recent years on sow prolificacy, both from a genetic and management standpoint, has resulted in an increase in number born alive of more than a pig (10.2 vs. 11.35) from 1998 to 2008 (PIGCHAMP 1998, 2008). In addition to the effect of uterine capacity on birth weight discussed in Johnson et al. (1999), other studies have reported similar associations. A small study (n = 60 pigs), which focused on the impact of piglet birth weight on carcass traits, reported pigs from larger litters were heavier at birth vs. pigs born to smaller litters (Bérard et al., 2008). Two much larger studies (n > 10,000 pigs) reported similar findings; increased litter size was associated with reduced birth weight (Roehe, 1999; Quiniou et al., 2002). Holl and Long (2006) concluded that increased litter size was associated with decreased average birth weight and an increased incidence of pigs weighing less than 2 pounds at birth.

Based on the combination of increased litter size in the U.S. swine production over the last decade and the association between litter size and birth weight, it can be concluded that there are a greater number of light birth weight pigs within production systems. The impact of these light birth weight pigs on production are of great economic importance to swine producers.

Impact of Low Birth Weight on Economically Important Production Traits

Mortality

The impact of birth weight on mortality, particularly prenatal and pre-weaning mortality, has been studied in detail. Few studies have detailed the impact of birth weight on mortality beyond weaning, especially after the nursery phase. Also, a number of studies have looked into the association between within-litter variation in birth weight and prenatal and pre-weaning survival. Results and thus conclusions vary as to which is of greater importance to mortality, individual birth weight or within-litter variation in birth weight. Therefore, the review will focus on both aspects of piglet birth weight and their relationships with mortality.

Within-litter variation. Two studies, Milligan et al. (2002ab), reported increased pre-weaning mortality associated with greater within-litter variation. Similar associations were reported in Milligan et al. (2001) and Wolf et al. (2008), a tendency ($P < 0.10$) and small (0.05) phenotypic correlation, respectively. Roehe and Kalm (2000) also estimated significant effects of increased within-litter variation on increased pre-weaning mortality; however, when individual birth weight was included in the model it was a better predictor of pre-weaning mortality. In contrast to the previous studies mentioned, within-litter variation in birth weight was not associated with prenatal mortality (Zaleski and Hacker, 1993; Leenhouwers et al., 1999; Le Cozler et al., 2002 Wolf et al., 2008) or pre-weaning mortality

(Pettigrew et al., 1986; Gardner et al., 1989; Knol et al., 2002) in a number of studies across populations. None of these studies estimated the effect of within-litter variation of birth weight on mortality beyond weaning.

There is not a consensus on the effect of within-litter variation on prenatal or pre-weaning survival. However, the majority of studies reported no effect, a couple reported minor effects or it was secondary to actual birth weight, and only two actually published an association of any magnitude. Therefore, it is likely the effect is population dependent and secondary to other factors more important to the prediction of prenatal and pre-weaning mortality.

Birth weight: pre-weaning. The effect of individual birth weight on prenatal and pre-weaning mortality, in particular, is more consistent across studies than within-litter variation. Several studies were published, describing an association between reduced piglet birth weight and increased likelihood of being a stillborn (De Roth and Downie, 1976; Quiniou et al., 2002; Canario et al., 2006). Zaleski and Hacker (1993) reported individual birth weight did not affect the likelihood of a pig being a still born vs. born alive but did observe pigs born to litters of lower average birth weight were more likely to be stillborns. A major component of prenatal mortality is asphyxia during parturition (Sprecher et al., 1974; Alonso-Spilsbury et al., 2007). Herpin et al. (1996) found pigs subject to greater levels of asphyxia were less viable at birth than pigs subject to less asphyxia. De Roth and Downie (1976) reported low birth weight pigs had lower viability scores. Therefore, lower birth weight pigs may be more susceptible to asphyxia during parturition and as a result are more prone to being a stillborn (Leenhouwers et al., 1999; Quiniou et al., 2002).

Increased birth weight was associated with a reduced likelihood of pre-weaning mortality (Bereskin et al., 1973; Pettigrew et al., 1986; Gardner et al., 1989; Roehe and Kalm, 2000; Quiniou et al., 2002). There could be a variety of biological causes for this reported association, both from a prenatal development and a postnatal environmental standpoint. Two of the postnatal factors which have been studied and presented in the literature are vitality and energy consumption. De Roth and Downie (1976) reported lower birth weight pigs were given lower, or poorer, viability scores immediately following birth, and were more likely to suffer pre-weaning mortality. Lower birth weight pigs have been shown to consume less colostrum and be more likely to suffer pre-weaning mortality (Devillers et al., 2005; Devillers et al., 2007). Other than crushing of piglets by the sow, early life mortality is most likely attributable to insufficient colostrum consumption (Le Dividich et al., 2005). While most pre-weaning mortality occurs early in lactation (Roehe and Kalm, 2000), there is also the potential for pigs to fall behind due to reduced milk consumption. Lighter birth weight pigs have been shown to be at a competitive disadvantage and subject to less milk consumption (Hartsock and Graves, 1976). Milk intake is vital to the survival of the piglet. Despite the availability of creep feed, pigs are mostly dependent on the sow to meet their nutrient and energy requirements prior to weaning (Sørensen et al., 1998). Regardless of the biological basis, birth weight plays a vital role in predicting a piglet's susceptibility to prenatal and pre-weaning mortality. Further discussion of the postnatal environmental associations for light birth weight pigs with respect to growth will be presented in a subsequent section.

Birth weight: post-weaning. Once again, the number of studies reporting estimates for the effect of birth weight on mortality after weaning is limited. However, two studies Larriestra et al. (2006) and de Grau et al. (2005) did estimate significant effects of weaning weight on mortality during the nursery phase. Pigs lighter at weaning were less likely to survive through the nursery phase. As summarized, a number of studies reported strong associations between birth weight and weaning weight. Therefore, this association could describe an impact of birth weight on mortality during the nursery phase. Smith et al. (2007) directly studied the impact of birth weight on nursery mortality. The authors reported that pigs in the lightest birth weight category were the least likely to survive during the nursery phase but the effect of birth weight on mortality was not consistent across all birth weight categories.

Based on the association between birth weight and mortality prior to weaning few light birth weight pigs survive till the nursery period or beyond. Therefore, data censoring issues may arise when analyzing post weaning data because the majority of light birth weight pigs do not survive past weaning or especially beyond the nursery phase.

Body weight and growth

A number of studies have estimated the phenotypic association between birth weight and future BW or growth. Studies have used a variety of populations and comprised of a number of different sample sizes and experimental designs. However, there is a consensus across all studies; increased birth weight is associated with increased BW at a constant age or fewer days to reach a constant BW. Because findings were in accordance across studies, the review herein will be condensed.

The majority of studies used small numbers of animals (n < 1000 pigs) and divided birth weight into categories for analysis or penning purposes. Typically birth weight classifications consisted of heavy vs. light or heavy vs. medium vs. light. Effects of birth weight were not identical in magnitude across studies; however, pigs in the heavier birth weight categories had greater BW measured later in life (Powell and Aberle, 1980; Wolter et al., 2002; Nissen et al., 2004; Poore and Fowden, 2004; Gondret et al., 2005 and 2006; Rehfeldt and Kuhn, 2006; Bérard et al., 2008; Rehfeldt et al., 2008). Two studies, Quiniou et al. (2002) and Smith et al. (2007), divided pigs into a greater number of categories by 200 g increments and one-half standard deviations, respectively. In both studies, pigs in the heavier birth weight categories were heavier later in life. Quiniou et al. (2002) also analyzed the effect of birth weight as a continuous effect and noted a quadratic association which was similar to the relationship reported in Schinckel et al. (2007 and 2010). In Quiniou et al. (2002) and Schinckel et al. (2007 and 2010) as birth weight increased, BW measured later in life, increased at a decreasing rate. More specifically, an incremental increase in birth weight below the mean was associated with a greater increase in future BW compared to an increase in birth weight above the mean. Based on results of studies analyzing birth weight as a continuous effect and not categorical, the association between birth weight and future BW is not linear. This potential nonlinear association must be considered when estimating the relationship between birth weight and important production parameters.

The basis for the association between birth weight and future BW is likely a combination of both pre and postnatal effects. One prenatal effect is the number of muscle fibers which is determined prenatally; however, the increase in the size of the muscle fibers impacts growth (Dwyer et al., 1993; Rehfeldt et al., 2000; Herfort Pedersen et al., 2001). Lower birth weight is associated with a reduced number of muscle fibers in pigs (Nissen et al., 2004; Gondret et al., 2005, 2006; Rehfeldt and Kuhn, 2006). Consequently, differences in muscle fibers between pigs of varying birth weights accounts for a portion of the variation in future BW.

Based on the associations described above, light birth weights pigs begin life with reduced potential for future growth. In addition, there are also contributing postnatal factors which potentially leave light birth weight pigs with a further disadvantage with respect to future growth. More specifically, colostrum from the sow provides the newborn piglet with vital energy and maternal antibodies vital to piglet development (Le Dividich et al., 2005). Several studies reported at least a minor relationship between increased birth weight and the selection of anterior teats (McBride, 1963; Fraser, 1975; Hartsock et al., 1977) which have been shown to produce a greater amount of colostrum (Fraser and Lin, 1984). Pigs reportedly gained more BW when nursing anterior teats (Kim et al., 2000). Other studies have measured colostrum intake and reported reduced intake in lower birth weight pigs (Devillers et. al., 2005, 2007). This difference in both colostrum intake and nursing more productive underline sections may further exacerbate the difference in future BW due to piglet birth weight. In summary, pigs begin life lighter, have less potential for future BW, and are further negatively impacted by postnatal environmental factors. All of which lead to light birth weight pigs being considerably lighter at harvest or requiring a greater number of days to reach an appropriate harvest BW.

Feed Intake

Differences in feed intake due to birth weight have been explored in fewer studies than BW. An even more limited number of studies have collected feed intake on a very large number of pigs with recorded birth weights. The studies which did estimate the association between birth weight and average daily feed intake, utilized an experimental design that included a fixed BW as the determinant for the conclusion of test periods. Two studies reported that increased birth weight was associated with increased average daily feed intake during a finishing period (Wolter et al., 2002; Bérard et al., 2008); however, both of these studies reported no differences in average daily feed intake during nursery period. Also, Gondret et al. (2006) and Schinckel et al. (2010) reported no association between piglet birth weight and average daily feed intake. These are limited results in which only BW was used as an off-test constraint. Low birth weight pigs grow slower and take more days to reach a suitable market weight. Consequently, these pigs would require more feed strictly for maintenance that their faster growing contemporaries (NRC, 1998).

Gain to feed

Once again the literature is limited with respect to estimates of the association between birth weight and efficiency. Heavier birth weight pigs were reported to have greater gain to feed during the finishing period (Wolter et al., 2002; Gondret et al., 2006; Bérard et al., 2008). All three of these studies either began or concluded test periods based on the animals reaching a predetermined BW. In each situation of pigs being removed from test once a specified BW was reached, lighter birth weight pigs required 7 to 12 d more to reach final BW. Reduced gain to feed for lighter birth weight pigs may be attributed to more feed consumed on maintenance during the extra days required. Schinckel et al. (2010) used nearly 2000 pigs housed in pens with individual feed intake recorded with FIRE® feeders, reported feed to gain increased as birth weight decreased. Birth weight was analyzed as a continuous variable, this was the only study to analyze the data this way; however, similar to other studies, pigs were removed from test based on a predetermined BW, not age. Other research has shown no impact of birth weight on efficiency; either for various test periods or the whole trial. Wolter et al. (2002) did report increased gain to feed from weaning to 14 kg BW for heavier birth weight pigs but no difference from 25 to 54 kg BW, which is in agreement for Bérard et al., (2008) during the postweaning and growing periods. Similarly, Powell and Aberle (1980) reported no difference in feed to gain during any phase of the trial.

One possible explanation for the increased gain to feed in heavier birth weight pigs during the finishing phase is the reduced number of days during the test period. In each instance of poorer gain to feed during the finishing phase lighter birth weight pigs were on test for more days. Based on the fact each day pigs have a energy requirement just to be a live (NRC, 1998), light birth weight pigs have more days with energy consumed for maintenance.

Composition

True total body composition is difficult and expensive to determine; however, measures of backfat and muscling are used as predictors. More specifically, real-time ultrasound or actual carcass values of backfat depth and longissimus muscle area or depth are typically collected to predict percent lean. The following summary will focus on associations between birth weight and backfat depth, muscling, and percent lean.

Backfat depth. Published associations between birth weight and backfat were highly variable. A study in which pigs were fed ad libitum and harvested at a constant age, reported no difference in BF among pigs differing in birth weight (Rehfeldt et al., 2008). No difference in fat thickness due to birth weight was also reported for pigs harvested at a constant weight with restricted feeding (Gondret et al., 2005). Powell and Aberle (1980) reported no difference in fat thickness due to birth weight for pigs fed ad libitum to a constant age, but adjusted backfat to a common HCW. A study utilizing ad libitum feeding and measuring backfat at constant BW reported increased backfat in low birth weight pigs (Gondret et al., 2006). Poore and Fowden (2004) measured backfat at 12 months of age and reported increased backfat in low birth weight pigs; of note this particular study collected backfat measures much later in life than other studies, 12 months of age. Schinckel et al. (2010) used a nonlinear model and reported increased backfat depth in lighter birth weight pigs; once again these pigs were fed ad libitum using FIRE® feeders to a constant BW. The association between birth weight and backfat is affected by the type of feeding and endpoint (age or weight) used to determine when backfat is measured. Pigs measured, either by real-time ultrasound or at harvest, at a constant age did not differ in backfat due to birth weight.

However, when a constant weight was used as the constraint, low birth weight pigs, which are older at similar BW, have greater backfat depth.

Muscling. Muscling in pigs is typically reported as either longissimus muscle area or depth. Studies estimating the effect of birth weight on muscling utilized either method but similar results were reported within similar experimental designs. Nissen et al. (2004) and Rehfeldt et al. (2008), again both harvesting at a constant age, reported heavier birth weight pigs had increased muscle mass and longissimus muscle area, respectively. Bérard et al. (2008) and Powell and Aberle (1980) reported no difference in muscling between birth weight classes, when measuring at a constant BW or adjusting for HCW, respectively. Results reported by Schinckel et al. (2010) did contradict those reported in other studies; in that, longissimus muscle depth was reported to be greater in heavier birth weight pigs. This is in agreement with studies that did not adjust for or measure at a constant BW; however, Schinckel et al. (2010) did measure at a constant BW. Reasons for differences among studies with similar designs are unknown. Heavier birth weight pigs with increased muscling when not adjusting for BW is likely explained by the association between piglet birth weight and future BW already discussed. It is commonly known that heavier BW pigs have increased muscling. Similarly, heavier birth weight pigs have increased BW later in life. When this is not adjusted for, the association between birth weight and BW results in increased muscling in pigs with heavier birth weights.

Percent lean. As previously discussed, backfat and muscling are absolute measures used to predict composition or more specifically percent lean. Therefore, it is important to discuss the impact of birth weight on measures of percent lean. Again, results were not consistent across studies. However, most studies reported no difference in percent muscle or percent lean due to differences in birth weight (Powell and Aberle, 1980; Nissen et al, 2004; Gondret et al., 2005; Bérard et al., 2008; Rehfeldt et al., 2008). Rehfeldt et al. (2008) did report a tendency for a birth weight x sex interaction (P = 0.07) for lean meat percent where barrows did not differ across birth weight but gilts in the heaviest birth weight category had a greater percentage lean meat than gilts in either the middle or low birth weight categories. In line with those findings, Gondret et al. (2006) also noted reduced lean meat content for low vs. heavy birth weight pigs. The two studies reporting differences, only observed differences in gilts not barrows. Schinckel et al. (2010) estimated a significant nonlinear effect of birth weight on estimated percent lean. The authors reported associations between birth weight and estimated percent lean differed between sexes. Based on graphical depictions, it appears the effect of birth weight on estimated percent lean was greater in gilts compared to barrows.

Pig Quality

Pig quality, defined as the classification of a full value vs. non-full value pig at some time point in production, greatly impacts the profitability of swine producers. More specifically, all pigs that survive until weaning, finisher placement, harvest, or anytime the ownership may change are not equal in value. This disparity in value may be due to differences in BW, health, etc. To the author's knowledge no studies have studied the effect of birth weight on "pig quality" as it is defined herein. However, one study researched components of "pig quality" and their association with production factors. Morrow et al. (2006) evaluated the economic and welfare implications of euthanasia decisions for compromised pigs during the nursery phase. The authors reported that pigs which had low BW or other health issues during the nursery phase had a lower economic value compared to their healthy cohorts. The authors did not specifically term the combination of these factors as “pig quality” but they do comprise the basis for the definition. Again, the effect of birth weight was on the health and BW of pigs therein; however, based on the previously summarized associations for birth weight with both future BW and mortality, an association between birth weight and pig quality later in life would be expected.

In the literature, there are a number of phenotypic associations between birth weight and economically important traits. For some traits such at fat thickness, muscling, feed intake, and efficiency, the direction of the relationships is not consistent. However, across a number of studies, light birth weight is strongly associated with reduced future BW and increased prenatal and pre-weaning survival. Also, in some reports the relationship is not linear; effects are greatest for pigs below the mean.

Genetics of Piglet Birth Weight

A number of studies evaluated the genetics of birth weight, with regards to direct and maternal heritabilities. In several of these studies, the focus was on the genetic relationship between birth weight and pre-weaning survival. Only a limited number have examined the genetic relationship between birth weight and weaning weight. However, for the review herein the focus is not on the genetic relationships between birth weight and survival. Therefore, this will not be covered. To the author’s knowledge no published studies have estimated genetic correlations between birth weight and performance traits beyond weaning.

The following section will provide a summary of studies which have estimated direct and maternal heritability for birth weight and its genetic relationship with weaning weight. Furthermore, genetic correlations amongst other traits which may help to explain or predict the genetic relationship between birth weight and future performance traits will be detailed.

Heritability

Direct. A number of studies, across breeds and management practices, have estimated direct heritability for piglet birth weight. In general all of the studies estimating genetic parameters for birth weight were in agreement, except for two studies which reported somewhat higher estimates. The majority of published reports estimated direct additive effects accounted for 10% or less of total phenotypic variation; Roehe, (1999), Kaufman et al. (2000), Knol et al. (2002), and Rosendo et al. (2007) reported 0.09, 0.02, 0.10, and 0.04, respectively. Cassady et al. (2002) (0.06 and 0.02) and Arango et al. (2006) (0.03-0.06) utilized multiple datasets and multiple models, respectively; however, these estimates were in agreement with other published reports.

Kerr and Cameron (1995) published a direct heritability of 0.16 which is numerically greater than the other studies but still in or near the range of lowly heritable. Despite different populations which consisted of different breeds in various countries and different facilities, the estimated proportion of phenotypic variation accounted for by direct effects was consistent across studies; however, another study used a population of pigs raised outdoors and reported much higher estimates (0.36) for heritability (Roehe et al., 2009). There was one rather important disparity between this study and the others; the management style of outdoor vs. indoor confinement based, as previously discussed. Even with this difference it is difficult to determine why the individual's genetic effect would account for a greater percent of the phenotypic variation in an outdoor vs. and indoor or confinement setting. However, the authors speculate that because the population used were selected and mated to specifically disentangle direct and maternal effects which could have increased the additive variance. In addition, the populations used therein included some crossbreds which could artificially increase the additive genetic variation.

To summarize, across studies using populations of pigs raised in conventional confinement facilities, the direct heritability of birth weight is low. Therefore, potential for direct genetic selection to improve birth weight or more importantly reduce the incidence of light birth weight pigs is possible but expected gain would be minimal.

Maternal. Similar, to published estimates of direct heritability, estimates of maternal heritability, with the exception of a couple studies, were consistent throughout much of the literature. Roehe (1999), Kaufman et al. (2000), and Knol et al. (2002) all reported maternal variation accounted for 20% or greater of the total phenotypic variation. Two studies reported slightly lower estimates (0.14-0.19 and 0.17) Arango et al. (2006) and Rosendo et al. (2007), respectively. Cassady et al. (2002) estimated maternal heritability for 2 different experiments and reported 0.29 and 0.09. While there appears to be some variability across and within studies in the proportion of total phenotypic variation accounted for by maternal effects, in all instances the maternal variation was numerically greater than the variation attributable to direct effects; in some studies, as much as 4 times greater. In contrast to the discrepancies reported in Roehe et al. (2009) for direct heritability estimates with other published reports, their estimate of maternal heritability, 0.28, was in agreement with the literature. However, the relationship between direct and maternal heritability was different, as Roehe et al. (2009) was the only study with maternal heritabilities numerically less than direct heritability estimates.

Genetic Correlations

Two studies (Kerr and Cameron, 1995; Kaufmann et al., 2000) reported similar moderate to strong, positive, and favorable genetic correlation between birth weight and individual weaning weight; 0.46 and 0.59, respectively. These estimates support the phenotypic associations previously described from the literature. Even though estimates of genetic correlations between birth weight and BW beyond weaning are unavailable, if the genetic relationship is similar to the phenotypic associations reported in other studies, then comparable genetic correlations between birth weight and BW after weaning would be expected.

Genetic correlations between birth weight and measurements of ADFI, muscling, and backfat, to the author’s knowledge have not been published. Still with the phenotypic associations described in the literature genetic correlations in either direction would not be a surprise. One genetic relationship that has been reported in a number of studies which were summarized in Stewart and Schinckel (1991) is BW and ADFI feed intake. In the summary, the genetic correlation was nearly 0.9. Based on this association and the potential genetic correlation between birth weight and BW later in life, a positive genetic correlation between birth weight and ADFI would be expected.

Maternal-direct. Genetic correlations between direct effects and maternal effects for the same trait have been estimated in a number of studies across a variety of traits. In most instances the genetic correlations, regardless of the trait, are negative and unfavorable. A similar genetic relationship between direct and maternal effects for birth weight has been estimated in a number of studies. More specifically, Roehe (1999), Arango et al. (2006), and Rosendo et al. (2007), all reported low to moderate negative genetic correlations. Roehe et al. (2009) estimate was also negative but slightly higher – 0.36. Cassady et al. (2002) conducted two experiments and reported contrasting covariance; however, both were small but one study, the genetic correlation was negative and the other positive. Finally, positive genetic correlations, albeit low 0.10, were reported in one study (Kaufmann et al., 2000). An item of interest reported by Robinson (1996), was the potential for the direct-maternal genetic correlations to be biased in the presence of environmental correlations between direct and maternal effects or genotype by environment interactions. The authors indicated these potential biases for field datasets such as those used herein.

There was some contradiction in the literature with respect to the direction of the genetic correlation; however, in the majority of published reported the relationship between direct and maternal effects for birth weight was antagonistic in nature. Consequently, there may be some concern for unfavorable genetic change due to selection to increase individual birth weight. Though, this unintended issue is likely population specific, and the relationship is not able to be generalized across populations.

Conclusion

Regardless of population or management, birth weight greatly impacts future pig BW; however, based on the results of studies analyzing birth weight as a continuous trait, the association is not linear. As birth weight decreases below the mean, each incremental reduction in birth weight is associated with a greater decrease in future BW. The impact of birth weight on composition depends on the analysis and in some cases the population used. In general, measures of backfat and muscling are measured at a constant BW or adjusted to a constant BW, lighter birth weight pigs are fatter but there is no difference in muscling. Conversely, if measures are collected at a constant age and unadjusted, lighter birth weight pigs do not differ in fat but are lighter muscled. Similar to the association with BW, lighter birth weight pigs are more likely to suffer mortality and the relationship is not linear; incremental decreases in the lightest portion of the birth weight distribution result in greater increases in the likelihood of mortality. This impact of birth weight is greatest during the pre-weaning phase; however, most susceptible pigs die during this period, therefore, few light birth weight pigs are alive during the nursery and finishing phases.

Based on the literature, there is a genetic component to individual birth weight, unfortunately, it is small. The maternal contribution consistently accounts for a greater proportion of the total phenotypic variation and is most often negative in its genetic relationship to the direct effect. While the estimates are limited, birth weight is moderately to strongly, positively, and favorably genetically correlated with BW at weaning.

Based on previous studies it is apparent birth weight is associated phenotypically with economically important traits. Furthermore, the direct additive genetic component for birth accounts for a small portion of the total variance. However, research focusing on the impact of birth weight in modern genetics in a commercial production setting, is limited. In addition, genetic relationships between birth weight and economically important traits beyond weaning are also limited. Finally, an economic analysis of the birth weight's impact on a commercial production system in the final piece needed to determine the complete effect of birth weight for today's U.S. swine producers.

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Chapter 2: Effect of piglet birth weight on body weight, growth, backfat, and longissimus muscle area of commercial market swine.

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ABSTRACT

The objective of this study was to estimate the effect of piglet birth weight on future BW, growth, backfat, and longissimus muscle area of pigs in a commercial U.S. production system. Pigs (n = 5,727) at a commercial farm were individually weighed and identified within 24 h of birth. Weights were collected prior to weaning (n = 4,108), after finisher placement (n = 3,439), and 7 (n = 1,622) and 16 (n = 1,586) weeks into finishing; hot carcass weight was also collected (n = 1,693). Average daily gain during lactation, nursery, finishing, and overall (birth to 16 weeks into finishing) was calculated. During BW collection 16 weeks into finishing, real-time ultrasound backfat thickness and longissimus muscle area were measured. Sex x birth weight (linear and quadratic) interactions were observed for BW at weaning and finisher placement and daily gain during pre-weaning and nursery. Linear birth weight x cross foster interactions were observed for weaning weight and pre-weaning gain. Linear and quadratic effects of birth weight on BW at weaning, finisher placement, 7 and 16 weeks into finishing, and hot carcass weight and average daily gain during pre-weaning, nursery, finishing, and total were observed. For all measures of BW and average daily gain, as birth weight increased subsequent BW and average daily gain increased at a decreasing rate; however, for the sex x birth weight (linear and quadratic) interactions, heavier birth weight barrows were lighter and grew slower than gilts of comparable birth weight. Worth noting, the birth weight x sex interactions described very few pigs in the extreme portion of the birth weight distribution. For birth weight x cross foster interactions, non-cross fostered pigs were increasingly heavier and faster growing as birth weight increased compared to cross fostered pigs. Heavier birth weight pigs tended to have increased backfat depth (*P* =

0.07). Linear and quadratic effects of birth weight on longissimus muscle area were observed; as birth weight increased muscling increased at a decreasing rate. Regardless of interactions or period of production, increased birth weight resulted in heavier future BW, faster daily gain along with larger longissimus muscle area prior to harvest. In all instances the magnitude of the negative effect of birth weight increased as birth weight decreased.

Key words: birth weight, pigs, growth performance, composition.

Introduction

The U.S. swine industry's emphasis on sow prolificacy has resulted in an increase in number born alive of more than a pig (10.2 vs. 11.35) from 1998 to 2008 (PIGCHAMP 1998, 2008). However, increased litter size results in lower individual piglet birth weights (Roehe, 1999; Quiniou et al., 2002). Piglets with lighter birth weights continue to have lighter body weights throughout production (Powell and Aberle, 1980; Quiniou et al. 2002; Schinckel et al., 2007).

Research has shown varying effects of birth weight on fat thickness and muscling. Some groups have reported no differences in backfat (Gondret et al., 2005) or longissimus muscle area and backfat depth (Powell and Aberle, 1980). However, Rehfeldt et al. (2008) reported light birth weight pigs were associated with smaller longissimus muscle.

These studies, except for one, evaluated differences in growth and composition between classes of birth weight. Also, several of these studies used small data sets or were not conducted in commercial U.S. swine production systems. Therefore, the objective of this study was to quantify the effect of birth weight analyzed as a continuous trait, using linear and quadratic effects, on future BW, daily gain, and composition in a modern commercial U.S. swine production system.

Materials and Methods

All animal procedures were consistent with the Guide for the Care and Use of Agriculture Animals in Agriculture Research and Teaching (FASS, 1999).

Animal management and body weight collection

All live born piglets (n = 5,727) used for this study were born from July 6, 2008 to August 3, 2008 from Large White x Landrace (n = 463) females bred to Duroc sires. Pigs were weighed (BIRTHWT) and individually identified within 24 h of birth; immediately following identification 16.7% of pigs were cross fostered to reduce variation among litters for number nursed. Farrowing was not induced for sows used in this trial. Pigs with BIRTHWT < 0.7 kg (n = 132) were not used in the analysis. Within 5 d of age all pigs were processed and male pigs castrated. At approximately 10 d of age pigs were given access to creep feed.

Pigs (n = 4,108) were individually weighed 2 d prior to weaning (WWT) (18.7 ± 2.1 d of age). Pigs used in this trial were weaned once weekly in 4 groups (groups 1, 2, 3, 4) and remained in those groups through nursery and finishing. After weaning, animals were transferred to a commercial nursery facility for a 7 wk nursery phase. Following the nursery phase, animals were transferred to a commercial finishing facility. Within 5 d of finisher placement (FINP) (74.8 ± 1.9 d of age) pigs from all groups were individually weighed (n =

3,439). During finishing phase pigs from groups 2 and 3 were individually weighed 2 times; 7 wks into finishing (FIN7) (120.8 ± 1.8 d of age) (n = 1,622) and 16 wks into finishing (FIN16) (172.8 ± 1.8 d of age) (n = 1,586). During FIN16 pigs were measured for backfat depth (BF) and longissimus muscle area (LMA) at the 10^{th} and 11^{th} rib interface, using real-time ultrasound (Aloka 500; Corometrics Medical Systems, Wallingford, CT). Pigs from all 4 groups were sent to a commercial harvest facility where HCW was collected (n = 1,693) (199.2 ± 12.1 d of age). Due to events, beyond our control HCW was not collected on some pigs. However, a similar distribution of BIRTHWT was represented in animals for which HCW was collected, compared with other BW collections (Table 2.1). Differences in number of animals from birth to harvest are accounted for by several factors. First, mortality during the pre-weaning and nursery phases was elevated (n = 1,300) at this commercial facility during the time of the trial. Also, not all pigs with WWT were kept in the trial, as some of the youngest pigs in weaned group were held back at the sow farm to be weaned the following week.

Management was typical of commercial U.S. swine production protocol throughout all phases of production. Feed and water were provided ad-libitum throughout the nursery and finishing phases. Pigs were fed a standard pelleted commercial nursery and finishing diets formulated to meet NRC 1998 requirements (NRC, 1998).

Statistical analysis

Data were analyzed using the Mixed procedure of SAS (SAS Inst. Inc., Cary, NC). Kenward-Roger adjustment for degrees of freedom was used for all models. Models included fixed effects of sex, weaned group, and cross foster status. Pigs nursing different sows than birth sow at time of WWT collection were classified as cross fostered (16.7 ± 0.01%). Descriptive statistics of cross fostered and non-cross fostered pigs are presented in Table 2.1. To determine if BIRTHWT was similarly represented for both cross fostered and non-cross fostered pigs, tests of normality (Kurtosis, Skewness) were conducted using the Means procedure of SAS (SAS Inst. Inc., Cary, NC); cross fostered: -0.005 and 0.42; non-cross fostered: 0.050 and 0.33.

The effect of BIRTHWT on future economically important traits was the main emphasis of the study herein; however, it has been shown within-litter variation in BIRTHWT affects postnatal survival in pigs. Therefore, partial correlations between within-litter standard deviation of BIRTHWT and future BW, ADG, BF, and LMA were analyzed using the Manova option of the GLM Procedure of SAS (SAS Inst. Inc., Cary, NC) to determine the relationship amongst these traits. Correlations were adjusted by including fixed effects of sex and sow parity and covariates of mean BIRTHWT, number born alive (linear and quadratic), and BIRTHWT (linear and quadratic).

Because commercial swine production typically has a defined time allotment for various phases of production, individual BW was adjusted to a common age. All measures were adjusted for age prior to the analysis of BIRTHWT. Adjustments factors were estimated using the solution option of the Mixed Procedure of SAS (SAS Inst. Inc., Cary, NC). To determine the appropriate adjustment factors covariates of age at time of collections and interactions of age x sex and age x cross foster status were included in the model. Due to significant interactions, WWT (21d) was adjusted within cross foster status; FINP (75 d), FIN7 (121 d), FIN16 (173 d), LMA (173 d), and BF (173 d) were adjusted within sex; no interaction for HCW (195 d).To determine the effect of BIRTHWT on daily gain, ADG was calculated for 4 time periods: pre-weaning (PWADG) (BIRTHWT to WWT), nursery (NADG) (WWT to FINP), finisher FADG (FINP to FIN16), and total gain (TADG) (BIRTHWT to FIN16). For all traits, linear and quadratic effects of BIRTHWT were included in the model as covariates.

All appropriate interactions between fixed effects and covariates were used. Birth litter was included in all models as a random effect; for WWT and PWADG models, a random effect of nurse litter was also included. The Covtest option of mixed and fit statistic, AIC, were used to determine use of birth or nurse litter as a random effect in the model. Effects were removed from the model at $P > 0.05$.

Results

Birth Litter information is presented in Table 2.2. Unadjusted descriptive statistics for BW measures ADG, LMA, and BF are presented in Table 2.3.

Body weight and growth

Linear ($P < 0.01$) and quadratic ($P < 0.01$) effects of BIRTHWT on WWT and PWADG were observed (Table 2.4). However, there were linear BIRTHWT x cross foster status interactions ($P < 0.01$) for both WWT and PWADG. Regardless of cross foster status, as BIRTHWT increased WWT and PWADG increased at a decreasing rate. Therefore, the difference in WWT and PWADG due to incremental changes in BIRTHWT was greater for lighter BIRTHWT than heavier BIRTHWT pigs. Based on the interactions, as BIRTHWT increased the difference in WWT and PWADG between non-cross fostered pigs and cross fostered pigs became greater. There were also significant interactions ($P < 0.01$) of linear BIRTHWT x sex and quadratic BIRTHWT x sex for WWT and PWADG. Similar interactions were observed for FINP ($P < 0.05$; $P < 0.05$) and NADG ($P = 0.07$; $P = 0.05$) (Table 2.4). In all instances the heaviest BIRTHWT barrows were lighter or slower growing than gilts of similar BIRTHWT (Fig. 2.1 and 2.2). Both linear and quadratic effects of BIRTHWT on FINP ($P < 0.01$; $P < 0.01$), FIN7 ($P < 0.01$; $P < 0.01$), FIN16 ($P < 0.01$; $P < 0.01$), and HCW ($P < 0.01$; $P = 0.04$) were observed. Also, linear ($P < 0.01$) and quadratic ($P < 0.01$) effects of BIRTHWT on PWADG, NADG, FADG, and TADG were observed (Table 2.4). In all instances as BIRTHWT increased BW and ADG increased at a decreasing rate.

Real-time ultrasound backfat depth and longissimus muscle area

There was a tendency ($P = 0.07$) for a linear effect of increased BF due to increased BIRTHWT. Linear ($P < 0.01$) and quadratic ($P = 0.04$) effects of BIRTHWT on LMA were also observed. Specifically, as BIRTHWT increased LMA increased at a decreasing rate.

Estimates for WWT, FINP, FIN7, FIN 16, HCW, PWADG, NUR, FADG, TADG, LMA, and BF along intercepts and significant fixed effects, covariates, and interactions are presented in Tables 2.5 and 2.6.

Within-litter variation

No significant partial correlations between BIRTHWT and any future measures of BW, ADG, BF, or LMA were found to be significant (Table 2.7).

Discussion

Body weight and growth

The present study offers a new perspective on the effect of BIRTHWT on future economically important traits, in that it provides an analysis of BIRTHWT as a continuous effect, linear and quadratic, in a commercial setting with a relatively large number of observations. In general conclusions from this study confirm the findings of several previously published reports.

The interactions of sex x BIRTHWT (linear and quadratic) for WWT, PWADG, FINP, and NADG, to the authors' knowledge, have not been reported in any other studies and must be viewed cautiously. Figures 1 and 2 depict the regression lines separated into their respective interactions. In both situations differences between barrows and gilts occurred for pigs with the heaviest BIRTHWT, as such the portion of the BIRTHWT distribution where this difference occurred, few pigs are represented. Specifically, if pigs with BIRTHWT greater than 3 SD above the mean, 64 pigs, were removed all BIRTHWT x sex interactions were no longer significant ($P > 0.20$). Consequently, the rest of the discussion will focus on the underlying main effects. Two studies using small numbers of pigs and dividing BIRTHWT into categories reported increased BW at weaning for pigs in the heavier BIRTHWT categories (Gondret et al., 2005; Bérard et al., 2008). In both studies pigs were weaned at an older age than typically practiced in commercial U.S. swine production; 27 d and 35 d, respectively. Again dividing BIRTHWT into categories but using a slightly larger number of animals (n = 378), Rehfeldt et al. (2008) reported increased BW at weaning (28 d of age). Smith et al. (2007) evaluated nearly 2500 pigs in a U.S. multiplier herd; divided BIRTHWT into 9 categories based on SD and reported increased weaning weights, 15 or 20 d of age, due to heavier BIRTHWT. Schinckel et al. (2007) using over 1,000 animals, analyzed BIRTHWT as a continuous trait and reported increased BW at 20 d of age due to increased BIRTHWT. The authors reported a significant cubic effect; however, the effect of BIRTHWT on 20 d BW was similar to the study herein, as BIRTHWT increased, 20 d BW increased at a decreasing rate. Despite the use of different analyses, sample sizes, and facilities light BIRTHWT pigs were smaller at weaning compared to heavy BIRTHWT pigs. However, as reported in the study herein and Schinckel et al. (2007), incremental increases in BIRTHWT for pigs in the lighter portion of the BIRTHWT distribution compared to heavier portion, resulted in a much greater increase in BW at weaning.

One result of interest which has not been reported or discussed in other studies involving BIRTHWT was a cross foster status x BIRTHWT interaction. Regardless of litter size, Stewart and Diekman (1989) reported cross fostered pigs were lighter than non-cross fostered pigs at 21 d of age. The authors did not provide any explanation for the difference; however, Horrell and Bennett (1981) reported similar results and attributed the reduction in BW to teat order already being established and the fostered pigs experienced an interruption in their milk consumption while trying to compete for a teat. The study conducted by Horrell and Bennett (1981) carried out the fostering process at 7 d of age while in the present study cross fostering was completed within 24 h of birth. Even so, if interruption of milk consumption of cross fostered pigs due to an already established teat order on the foster dam is the main factor reducing BW and pre-weaning ADG then this could be the cause for the results reported herein. McBride (1963) concluded that teat order is established very early within a piglet's life often before the last pigs are born. Therefore, this disruption could still affect pigs ADG prior to weaning and BW at weaning. Especially considering the interaction is not present after weaning indicating cross fostered pigs are able to overcome this early life disadvantage. The difference in WWT between cross fostered vs. non-cross fostered pigs increased as BIRTHWT increased. This is likely due to a scaling effect; the difference in low BIRTHWT pigs is small; however, the difference in heavier BIRTHWT is greater due to the increased BW of the pigs.

Similar to the impact of BIRTHWT on BW at weaning, regardless of weaning age, BIRTHWT has also been shown to influence BW at various stages later in life. Dividing BIRTHWT into categories Powell and Aberle (1980) reported fewer days to 26 kg and 96 kg BW, Quiniou et al. (2002) reported increased BW at 63 d of age and fewer d to 105 kg, Smith et al. (2007) reported increased BW 42 d post weaning, and Rehfeldt et al. (2008) reported increased BW at 70, 133, and 180 (harvest) d of age due to increased BIRTHWT. While not discussed by the authors in Rehfeldt et al. (2008) it appears there was a numeric disparity in the difference between heavy vs. middle categories compared to the difference between middle vs. light categories where the difference between light vs. middle BIRTHWT was greater than the difference in middle vs. heavy category. This would agree with the findings herein of a greater difference in future BW for the lowest BIRTHWT pigs. Again, using a cubic model, Schinckel et al. (2007) reported BW at 126 and 168 d of age, increased at a decreasing rate as BIRTHWT increased.

Studies that have harvested pigs at a constant BW rather than a constant age reported no difference in HCW due to differences in BIRTHWT (Powell and Aberle, 1980; Gondret et al., 2005, 2006; Bérard et al., 2008). However, when pigs were harvested at similar ages within study, increased BIRTHWT resulted in increased HCW and were in agreement for the results of the current study (Nissen et al., 2004; Rehfeldt et al., 2008).

Once again regardless of the number of animals used and the type of analyses conducted increased BIRTHWT resulted in increased BW measured at various stages through harvest. However, it is important to look at differences in future BW across the BIRTHWT distribution and realize an increase in BIRTHWT from 0.8 to 1.0 kg does not have the same effect as an increase from 2.0 to 2.2 kg (Figs. 1, 2, 3). From these results, it is apparent BIRTHWT affects future BW. The major cause of this appears to be a difference in ADG. Based on results from the current study, BIRTHWT affects ADG during all phases of production; the difference is greatest for the lightest BIRTHWT pigs. The findings of differences in ADG are in agreement with Rehfeldt et al. (2008) for birth to harvest and Powell and Aberle (1980) for 26 to 96 kg BW. Not only do heavier pigs begin life with an advantage in weight but pigs at the lower end of the BIRTHWT distribution, due to reduced ADG, fall further behind in BW over time.

Several factors, both prenatal and postnatal, are likely responsible for this decrease in future growth due to reduced BIRTHWT. First, the difference in number of muscle fibers present in low BIRTHWT pigs compared to heavier BIRTHWT pigs. The number of muscle fibers is determined prenatally; however, the increase in the size of the muscle fiber impacts growth (Dwyer et al., 1993; Rehfeldt et al., 2000; Herfort Pedersen et al., 2001). Low BIRTHWT pigs have been shown to have fewer muscle fibers (Nissen et al., 2004; Gondret et al., 2005, 2006; Rehfeldt and Kuhn, 2006) and as a result reduced future growth. Secondly, colostrum from the sow provides the newborn piglet with vital energy and maternal antibodies (Le Dividich et al., 2005). Several studies have reported at least a minor relationship between increased BIRTHWT and the selection of anterior teats (McBride, 1963; Fraser, 1975; Hartsock et al., 1977) which have been shown to produce a greater amount of colostrum (Fraser and Lin, 1984) and pigs have reportedly gained more BW when nursing anterior teats (Kim et al., 2000). Other studies have measured colostrum intake and reported reduced intake due to low BIRTHWT (Devillers et. al., 2005, 2007). This difference in both colostrum intake and nursing more productive underline sections may contribute to the increase in pre-weaning ADG of pigs with heavier BIRTHWT. The increase in ADG prior to weaning leads to heavier BW at weaning which has been shown to result in increased post-weaning gain (Klindt, 2003). All of these factors contribute at varying levels to the reduced future BW and ADG due to reduced piglet BIRTHWT.

Results reported herein are in agreement with previous reports where it was concluded that increased BIRTHWT is associated with increased BW later in life. This affect of BIRTHWT on future BW is likely attributable to both prenatal and postnatal factors associated with differences in BIRTHWT. However, the relationship between birth weight and growth is not linear. There appears to be a threshold for BIRTHWT where once surpassed, further increase in BIRTHWT does not result in increased BW or ADG, especially later in life.

Real-time ultrasound backfat depth and longissimus muscle area

Another study in which pigs were fed ad libitum and harvested at a constant age, similar to the study herein, reported no difference in BF among pigs differing in BIRTHWT (Rehfeldt et al., 2008). No difference in fat thickness due to BIRTHWT was also reported for pigs harvested at a constant weight with restricted feeding (Gondret et al., 2005). Powell and Aberle (1980) reported no difference in fat thickness due to BIRTHWT for pigs fed ad libitum to a constant age, but adjusted BF to a common HCW. A study utilizing ad libitum feeding and measuring BF at constant BW reported increased BF in low BIRTHWT pigs (Gondret et al., 2006). Poore and Fowden (2004) measured BF at 12 months of age and reported increased BF in low BIRTHWT pigs; of note this particular study collected BF measures much later in life compared to the study herein, and other studies discussed. The effect of BIRTHWT on BF appears to be affected by the type of feeding and constraint, age or weight, used for BF collection. Pigs measured, either by real-time ultrasound or at harvest, at a constant age do not differ in BF due to BIRTHWT. However, when a constant weight is used as the constraint, low BIRTHWT pigs, which are older at similar BW, have greater BF depth. Based on the results of other studies, no difference in BF would be expected; however, this did not occur. Heavier BIRTHWT pigs had a tendency for increased BF. Pigs within weaned group for the most part were born within one week and therefore, were of similar age at time of real-time ultrasound. In addition to this, BF was adjusted for any age differences that were present. Typically BF is adjusted for BW at time of measure due to this impact of increased BF of pigs with greater BW. This relationship combined with heavier BIRTHWT pigs having increased BW at time of BF measurement is likely the explanation of increased BIRTHWT resulting in increased BF. It appears the impact of BIRTHWT on BW at time or real-time ultrasound resulted in a tendency for increased BF. Nissen et al. (2004) and Rehfeldt et al. (2008), again both harvesting at a constant age, reported heavier BIRTHWT pigs had increased muscle mass and LMA, respectively. Bérard et al. (2008), constant weight, and Powell and Aberle (1980), adjusted for HCW, did not differ between BIRTHWT classes. The studies harvesting or measuring muscle at a constant age without adjusting for BW or HCW reported similar results to the findings herein. It is commonly accepted that BW affects muscling specifically LMA and therefore, the effect of BIRTHWT on LMA appears to be caused by the effect of BIRTHWT on BW. If pigs are measured for muscling at a constant weight or measures are adjusted for weight prior to or during analysis, there is no difference in muscling due to differences in BIRTHWT.

Both BF and LMA are absolute measures used to predict the overall carcass composition. Previous studies reported no difference in a variety of percent muscle or percent lean estimates due to differences in BIRTHWT (Powell and Aberle, 1980; Nissen et al, 2004; Gondret et al., 2005; Bérard et al., 2008; Rehfeldt et al., 2008). Rehfeldt et al. (2008) reported a tendency for a BIRTHWT x sex interaction (P = 0.07) for lean meat percent where barrows did not differ across BIRTHWT while gilts in the heaviest BIRTHWT category had a greater percentage lean meat than gilts in either the middle or low BIRTHWT categories. Gondret et al. (2006) whom reported a difference in BF also reported reduced lean meat content for low vs. heavy BIRTHWT pigs. Both studies which reported differences in lean meat reported differences in gilts only, barrows were not used or did not differ. Numerous studies have reported gilts are leaner or have a greater percentage lean meat than barrows. Based on findings of Gondret et al. (2006) and Rehfeld et al. (2008), it appears gilts with heavier BIRTHWT have even greater lean meat yield than barrows across all BIRTHWT. Again when pigs are given access to ad libitum feed and fat thickness is measured at a constant BW, low BIRTHWT pigs ultimately have a carcass comprised of a greater proportion of fat.

While there was no significant difference in BF, only a tendency, due to BIRTHWT the effect of BIRTHWT on LMA appears to be similar to that of BIRTHWT on BW. Increased LMA due to increased BIRTHWT is greatest for lighter vs. heavier BIRTHWT pigs.

Within-litter variation

Other studies evaluating the effect of within litter variation of BIRTHWT on average pre-weaning gain or average BW at weaning found no effect (Milligan et al., 2001, 2002). However, the study herein evaluated partial correlations between the standard deviation of BIRTHWT and individual BW at weaning. Despite the difference in analysis, individual BIRTHWT and mean BIRTHWT, similar results were reported herein, within-litter variation did not impact future BW, ADG, BF, or LMA.

Conclusion

Birth weight of pigs in a commercial U.S. swine facility greatly impacts economically important traits. Pigs with low birth weights begin life smaller, gain less during all phases of production, and as result are lighter at fixed time points. Lighter birth weight pigs also have less longissimus muscle area. The incremental impact on growth and muscling is greatest for pigs at the lighter end of the birth weight distribution; the impact on the heavier end of the distribution in regards to growth, diminishes as pigs become older. Further research is needed to devise a selection strategy to reduce the incidence of low birth weight pigs or implement a management protocol to reduce the impact of birth weight on future growth and composition characteristics.

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Table 2.1. Descriptive statistics of birth weights for pigs used at different data collection points.

				Birth weight			
Production phase[a,b]	N	Males	Females	Mean, kg	SD, kg	Min, kg	Max, kg
Birth	5,727	2,880	2,847	1.43	0.352	0.32	2.77
Weaning	4,108	2,017	2,091	1.51	0.303	0.70	2.77
Non-cross fostered	3,423	1,686	1,737	1.53	0.294	0.70	2.68
Cross fostered	685	331	354	1.43	0.333	0.75	2.77
Finisher placement	3,439	1,655	1,784	1.53	0.299	0.75	2.68
7 wks into finisher	1,622	786	836	1.54	0.301	0.79	2.45
16 wks into finisher	1,586	767	819	1.54	0.300	0.79	2.45
Harvest	1,693	753	940	1.53	0.293	0.79	2.45

[a]All 4 weaned groups were used for birth, weaning, finisher placement, and harvest. Only groups 2 and 3 used of 7 wks and 16 wks into finishing.

[b]Cross foster status x birth weight interaction ($P < 0.01$).

Table 2.2. Birth litter descriptive statistics.

Item	Litters	Mean	SD	Minimum	Maximum
Parity	463	3.23	2.09	1	9
Number born alive	463	12.37	3.17	2	20
Stillborns	463	1.12	1.69	0	15
Mummified fetuses	463	0.24	0.577	0	4
Gestation length, d	463	114.5	1.38	108	119

Table 2.3. Unadjusted descriptive statistics for BW measures, ADG, longissimus muscle area, and backfat.

Item	Number of Pigs	Mean	SD	Min	Max
		Body weight			
Weaning[a,b], kg	4,108	4.92	1.170	1.56	9.25
Non-cross fostered	3,423	4.99	1.166	1.56	9.25
Cross fostered	685	4.58	1.128	1.61	8.55
Finisher placement[a], kg	3,439	23.17	4.516	9.07	37.10
7 wks into finishing[a], kg	1,622	58.53	9.275	30.66	85.73
16 wks into finishing[a], kg	1,586	103.12	13.595	50.35	140.62
Hot carcass weight[a], kg	1,693	94.63	11.804	64.86	129.28
		Average daily gain			
Pre-weaning[a], g/d	4,108	182.1	52.32	2.8	356.1
Nursery[a], g/d	3,421	323.3	72.50	74.1	541.1
Finisher[a], g/d	1,585	815.9	111.45	300.9	1096.0
Total[a], g/d	1,586	587.9	77.52	283.6	795.0
		Real-time ultrasound			
Longissimus muscle area[c], cm^2	1,585	38.07	0.163	15.00	59.48
Backfat[c], cm	1,586	1.66	0.011	0.60	3.22

[a]BW measures were collected at 18.7 ± 0.03 (weaning), 74.7 ± 0.03 (finisher placement), 120.8 ± 0.04 (7 wks into finishing), 172.8 ± 0.04 (16 wks into finishing), and 199.2 ± 1.2 (hot carcass weight) d of age. Average daily gain calculated for pre-weaning (birth to weaning), nursery (weaning to finisher placement), finisher (finisher placement to 16 wks into finishing), and total (birth to 16 wks into finishing).

[b]Cross foster status x birth weight interaction ($P < 0.01$).

[c]Longissimus muscle area and backfat measured using real-time ultrasound at the 10th and 11th rib interface at 172.8 ± 0.04 d of age.

Table 2.4. Effects, random, fixed, covariates, and interactions, included in the final model for the analysis of all traits.

	Random			Fixed		Birth weight		Interactions[b]			
Item	Birth	Nurse	Sex	Group	Cross	Linear	Quadratic	S x BIRTHWT	S x BIRTHWT^2	C x BIRTHWT	C x BIRTHWT^2
						Body weight					
WWT[a]	< 0.01[1]	< 0.01[1]	< 0.01[1]	0.67	0.23[1]	< 0.01[1]	< 0.01[1]	< 0.01[1]	< 0.01[1]	< 0.01[1]	0.07
FINP[a]	< 0.01[1]	0.27	0.02[1]	< 0.01[1]	< 0.01[1]	< 0.01[1]	< 0.01[1]	0.02[1]	0.02[1]	0.95	0.88
FIN7[a]	< 0.01[1]	0.88	0.04[1]	0.69	0.30	< 0.01[1]	< 0.01[1]	0.07	0.51	0.41	0.40
FIN16[a]	< 0.01[1]	0.57	< 0.01[1]	0.40	0.05[1]	< 0.01[1]	< 0.01[1]	0.82	0.90	0.42	0.66
HCW[a]	< 0.01[1]	0.44	< 0.01[1]	< 0.01[1]	0.08	< 0.01[1]	0.04[1]	0.59	0.43	0.82	0.94
						Growth					
PWADG[a]	< 0.01[1]	< 0.01[1]	< 0.01[1]	0.68	0.23[1]	< 0.01[1]	< 0.01[1]	< 0.01[1]	< 0.01[1]	< 0.01[1]	0.07
NADG[a]	< 0.01[1]	0.33	0.06[1]	< 0.01[1]	0.10	< 0.01[1]	< 0.01[1]	0.07[1]	0.05[1]	0.66	0.69
FADG[a]	< 0.01[1]	0.50	< 0.01[1]	0.89	0.05[1]	< 0.01[1]	< 0.01[1]	0.90	0.81	0.42	0.07
TADG[a]	< 0.01[1]	0.71	< 0.01[1]	0.42	0.05[1]	< 0.01[1]	< 0.01[1]	0.84	0.92	0.56	0.06
						Real-time ultrasound					
LMA[a]	< 0.01[1]	0.83	< 0.01[1]	< 0.01[1]	0.62	< 0.01[1]	< 0.01[1]	0.69	0.65	0.82	0.91
BF[a]	< 0.01[1]	0.48	< 0.01[1]	0.28	0.32	0.06[1]	0.32	0.45	0.49	0.81	0.55

[1]*P*-values with superscript were included in the final model for respective trait.

[a]WWT: adjusted 21 d BW (weaning); FINP: adjusted 75 d BW (finisher placement); FIN7: adjusted 121 d BW (7 wks into finishing); FIN16: adjusted 173 d BW (16 wks into finishing); HCW: carcass weight adjusted to 195 d; PWADG: ADG from BIRTHWT to WWT; NADG: ADG from WWT to FINP; FADG: ADG from FINP to FIN16; TADG: ADG from BIRTHWT to FIN16; LMA: 10th rib real-time ultrasound longissimus muscle area adjusted to 173 d of age; BF: 10th rib real-time ultrasound backfat depth adjusted to 173 d.

[b]Interactions: sex x BIRTHWT; sex x BIRTHWT x BIRTHWT; cross foster x BIRTHWT; cross foster x BIRTHWT x BIRTHWT.

Table 2.5. Estimates of intercepts, fixed effects, and birth weight for all traits due to a 1 kg increase in birth weight.

			Birth weight[c]									
Item	Intercept	SE	Linear	SE	Quadratic	SE	Sex[b]	SE[b]	Cross[c]	SE[c]	Group[d]	SE[d]
Body weight												
WWT[a], kg	0.62	0.372	3.98	0.462	-0.73	0.146	1.51	0.473	-0.22	0.182	-	-
FINP[a], kg	2.77	1.841	19.43	2.375	-4.29	0.749	5.77	2.481	0.86	0.222	0.26	0.138
FIN7[a], kg	25.05	4.296	34.03	5.599	-7.51	1.796	-0.79	0.384	-	-	-	-
FIN16[a], kg	60.79	6.600	43.35	8.679	-9.80	2.776	-3.61	0.597	1.99	1.032		
HCW[a], kg	74.78	4.321	19.45	5.617	-3.72	1.800	-2.37	0.389	-	-	0.11	0.484
Growth												
PWADG[a], g/d	29.7	17.73	142.0	22.99	-35.0	6.93	72.1	22.51	-10.4	8.65	-	-
NADG[a], g/d	42.8	32.57	288.4	41.67	-68.8	13.15	83.3	43.92	-	-	8.8	1.29
FADG[a], g/d	539.7	56.04	303.9	73.58	-75.4	23.50	-40.4	5.12	17.0	8.62	-	-
TADG[a], g/d	362.9	38.73	244.8	50.17	-56.6	16.05	-20.9	3.45	-11.5	5.96	-	-
Real-time ultrasound												
LMA[a], cm^2	21.81	3.123	19.10	4.402	-4.69	1.291	1.04	0.286	-	-	-2.15	0.205
BF[a], cm	1.70	0.062	0.07	0.038	-	-	-0.31	0.020	-	-	-	-

[a]WWT: adjusted 21 d BW (weaning); FINP: adjusted 75 d BW (finisher placement); FIN7: adjusted 121 d BW (7 wks into finishing); FIN16: adjusted 173 d BW (16 wks into finishing); HCW: carcass weight adjusted to 195 d; PWADG: ADG from BIRTHWT to WWT; NADG: ADG from WWT to FINP; FADG: ADG from FINP to FIN16; TADG: ADG from BIRTHWT to FIN16; LMA: 10^{th} rib real-time ultrasound longissimus muscle area adjusted to 173 d of age; BF: 10^{th} rib real-time ultrasound backfat depth adjusted to 173 d.

[b]Estimate for gilts; barrows = 0.

[c]Estimate for non-cross fostered pigs; cross fostered pigs = 0.

[d]Weighted average across groups.

Table 2.6. Estimates of significant interactions for all traits due to a 1 kg increase in birth weight.

Item	Sex x BIRTHWT[b]	SE[b]	Sex x BIRTHWT[2b]	SE[b]	Cross x BIRTHWT[c]	SE[c]
Body weight						
WWT[a,], kg	-1.94	0.614	0.61	0.196	0.50	0.120
FINP[a], kg	-7.20	3.192	2.34	1.007	-	-
Growth						
PWADG[a,], g/d	-92.3	29.24	29.2	9.31	24.0	5.71
NADG[a], g/d	-104.2	56.50	34.6	17.82	-	-

[a]WWT: adjusted 21 d BW (weaning); FINP: adjusted 75 d BW (finisher placement); PWADG: ADG from BIRTHWT to WWT; NADG: ADG from WWT to FINP.

[b]Estimate if for gilts; barrows = 0.

[c]Estimate for non-cross fostered pigs; cross fostered pigs = 0.

Table 2.7. Partial correlations between within-litter birth weight standard deviation and postnatal measures of body weight, average daily gain, muscling, and backfat thickness.

Item	SD	*P*-value
	Body weight	
WWT[a], kg	0.01	0.63
FINP[a], kg	0.02	0.36
FIN7[a], kg	0	0.93
FIN16[a], kg	0.01	0.53
HCW[a], kg	0.02	0.43
	Growth	
PWADG[a], g/d	0.01	0.63
NADG[a], g/d	0.02	0.30
FADG[a], g/d	0.02	0.47
TADG[a], g/d	0.01	0.56
	Real-time ultrasound	
LMA[a], cm^2	-0.02	0.47
BF[a], cm	-0.01	0.56

[a]WWT: adjusted 21 d BW (weaning); FINP: adjusted 75 d BW (finisher placement); FIN7: adjusted 121 d BW (7 wks into finishing); FIN16: adjusted 173 d BW (16 wks into finishing); HCW: carcass weight adjusted to 195 d; PWADG: ADG from BIRTHWT to WWT; NADG: ADG from WWT to FINP; FADG: ADG from FINP to FIN16; TADG: ADG from BIRTHWT to FIN16; LMA: 10th rib real-time ultrasound longissimus muscle area adjusted to 173 d of age; BF: 10th rib real-time ultrasound backfat depth adjusted to 173 d.

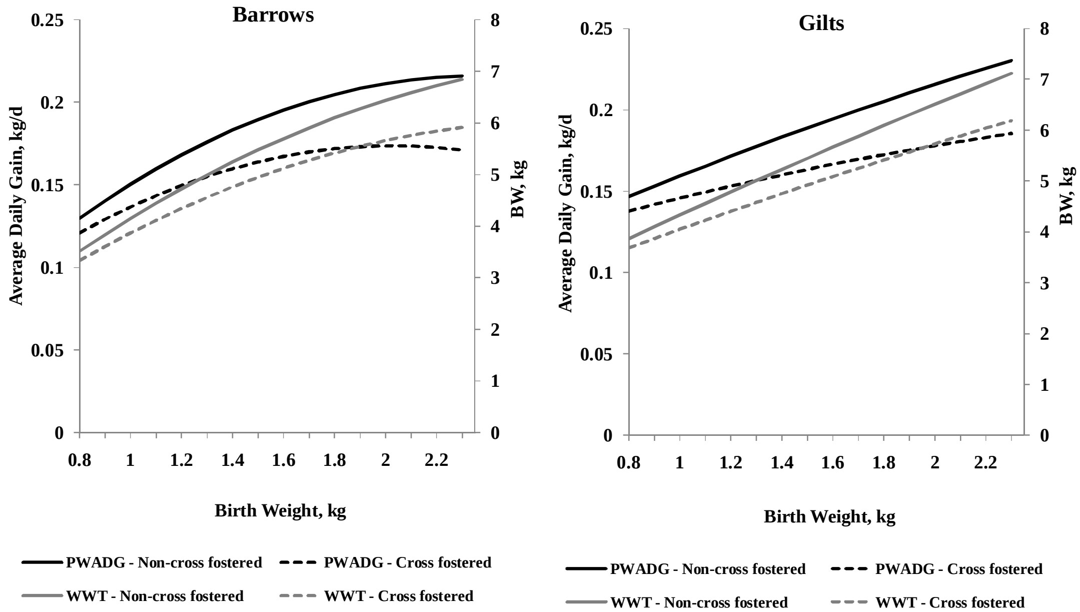

Figure. 2.1. Effect of birth weight on preweaning average daily gain (PWADG) and BW at weaning (WWT); separated into non-cross fostered pigs and cross fostered pigs and barrows and gilts.

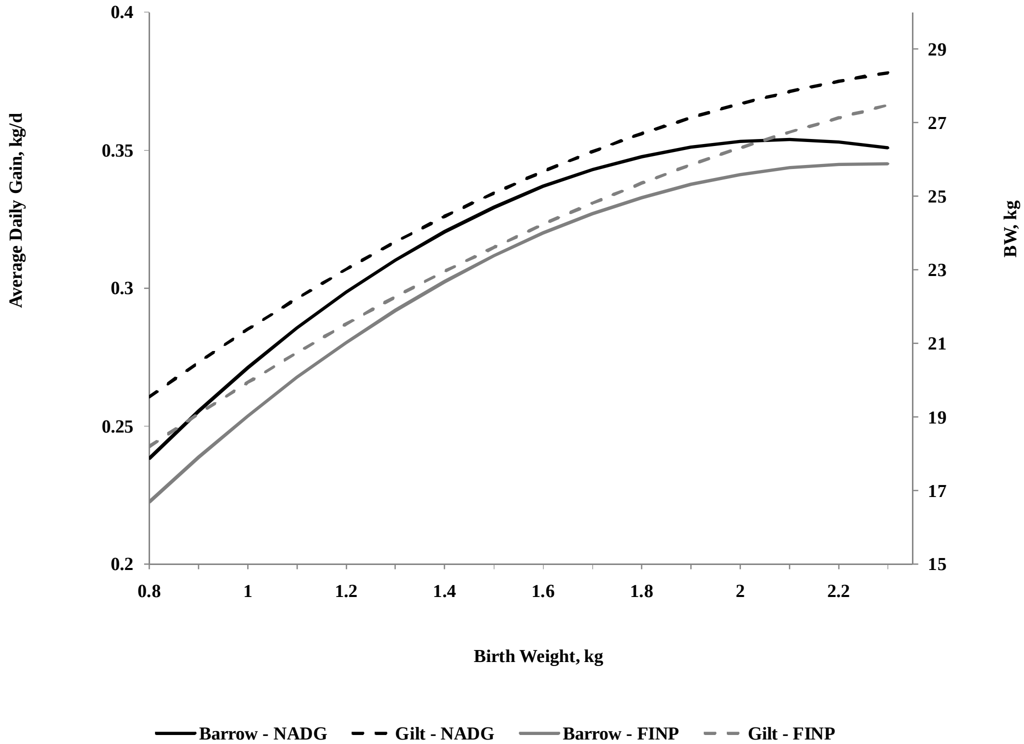

Figure. 2.2. Effect of birth weight on average daily gain during the nursery phase (NADG) and BW at finisher placement (FINP); separated in barrows and gilts.

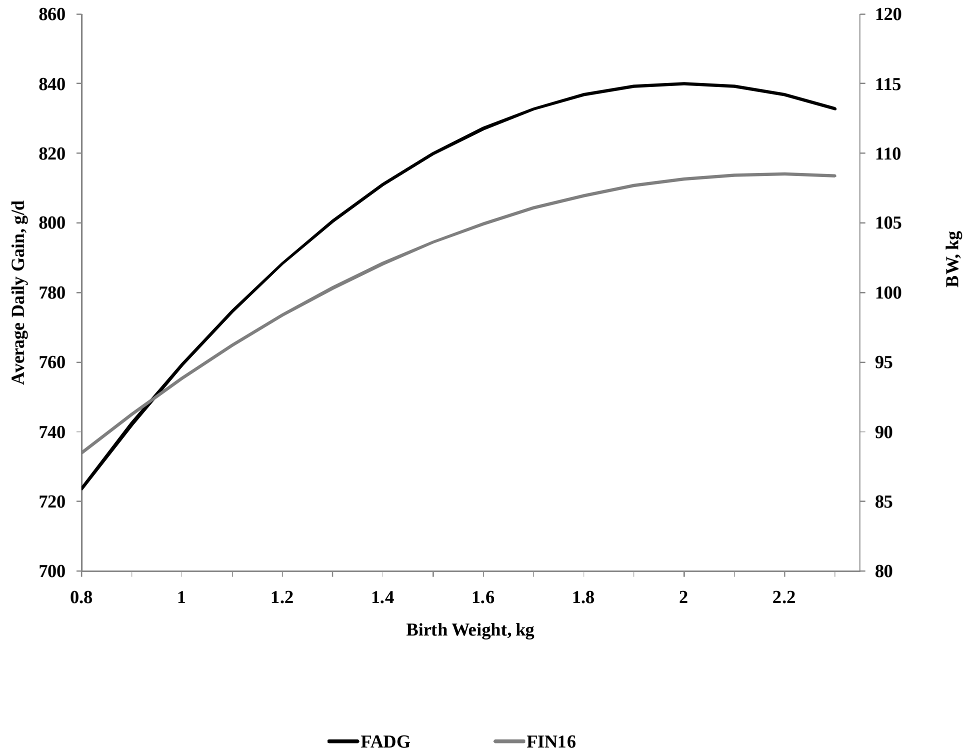

Figure. 2.3. Effect of birth weight on average daily gain during finishing phase (FADG) and BW 16 weeks (FIN16) in finishing phase.

Chapter 3: Effect of piglet birth weight on survival and the quality of commercial market swine.

ABSTRACT

The objective of this study was to determine the effect of individual piglet birth weight on mortality and pig quality in a U.S. commercial production system. Pigs used in this study were farrowed from Large White x Landrace sows (n = 463) bred to Duroc boars during a 4 week period at a commercial sow farm. Within 24 h of birth, all pigs (born alive = 5727 and stillborns = 513) were weighed (BWT) and individually indentified. A portion of pigs (16.7%) were cross-fostered to reduce variation in number of pigs nursed. Individual mortality was recorded daily during the suckling phase. Pigs were weighed 2 days prior to weaning (18.7 ± 2.1 days of age), finisher placement (74.8 ± 1.9 days of age), and 16 weeks into finishing (172.8 ± 1.8 days of age). During BW collections, an inventory of all live pigs was conducted, and pigs were given a quality score based on visual evaluation of BW and health (3 = healthy pig; 2 = slightly small and/or slightly unthrifty; 1 small and/or unthrifty). Survival was analyzed for 4 distinct time periods (prenatal, pre-weaning, nursery phase, and finishing phase). Data were analyzed using a logit (survival) or cumulative logit (quality score) function. Linear effects of birth weight on prenatal, pre-weaning, and nursery survival were observed; as birth weight decreased the probability of mortality increased. However birth weight did not impact the likelihood of survival during finishing. Lighter birth weight resulted in an increased likelihood of pigs being poorer quality, quality score (1 or 2), at weaning, finisher placement, and 16 weeks into finishing. As birth weight increased the likelihood of a pig being full value at the end of the finishing phase increased. Lower individual birth weight in pigs, resulted in reduced pig quality and likelihood of prenatal, pre-weaning, and nursery survival. Because of the negative impact of birth weight on pre-

weaning and nursery survival and pig quality in finishing, pigs with lighter birth weights were less likely to be full value.

Key words: birth weight, pigs, survival, quality

Introduction

From 1998 to 2008 the average number of pigs born alive per litter has increased over a full pig (10.2 to 11.35) (PIGCHAMP 1998, 2008). Studies have shown increases in litter sizes were associated with reductions in piglet birth weights (Roehe, 1999; Quiniou et al., 2002). With the continued emphasis on prolificacy in U. S. pig production from a genetic and management perspective, issues associated with birth weight, such as mortality and piglet quality, could be increasingly important as the prevalence of light birth weight pigs may be increasing.

The greatest proportion of mortality in commercial pig production occurs prior to weaning. A review of piglet survival during lactation reported pre-weaning mortality ranging between 10 and 20% of live born pigs (Alonso-Spilsbury et al., 2007). Similarly, pre-weaning mortality was estimated at 12.8% in U.S. commercial swine herds during 2008 (PIGCHAMP, 2008). A variety of causes lead to pre-weaning mortality; one of these causes is low individual piglet birth weight (Winters et al., 1947; Alonso-Spilsbury et al., 2007). Pigs with low birth weights have a greater chance of being stillborn (Quiniou et al., 2002; Zaleski and Hacker, 1993; Leenhouwers et al., 1999) or not surviving to weaning (Bereskin et al., 1973; Gardner et al., 1989; Quiniou et al., 2002). Pigs from litters with greater variation in birth weight have been reported to be more prone to pre-weaning mortality

(Milligan et al., 2002a; Milligan et al., 2002b). Roehe and Kalm (2000) reported a similar finding of increased pre-weaning mortality for litters with greater variation in birth weight, but also concluded individual birth weight accounted for more variation and thus, was a greater predictor of pre-weaning mortality.

Few studies have evaluated the impact of birth weight on survival during the nursery and finishing phases. Larriestra et al. (2006) reported lower birth weight led to increased chances of mortality during the nursery phase; however, once weaning weight was accounted for, the effect of birth weight was reduced. Weaning weight may be a more important determinant of nursery survival; however, birth weight accounts for a portion of the variation in weaning weight (Quiniou et al., 2002; Fix et al., 2010) which suggests birth weight impacts nursery survival through its impact on weaning weight. To the authors' knowledge no work has been published on the impact of birth weight on finishing survival.

While mortality may be of greater concern to producers due to its greater impact on profitability, pig quality also impacts production. Specifically, pigs that survive but are poorer quality (light weight, injured, etc.) are sent to alternative markets and consequently are reduced in value. Little research has been published estimating this potential impact of birth weight on pig quality at later points in production.

Therefore, the objective of this study was to characterize the relationship of piglet birth weight with survival and pig quality from farrowing to harvest in a commercial U.S. production system.

Materials and methods

All animal procedures were consistent with the Guide for the Care and Use of Agriculture Animals in Agriculture Research and Teaching (FASS, 1999).

Animal management

Detailed management of the pigs is described in Fix et al. (2010). Specifics to this portion of the trial will be described herein.

All fully formed pigs, both still births and born alive, were individually weighed and identified within 24 h of birth. During lactation all individual piglet mortalities were recorded on a daily basis. Pigs were weaned once per week into 4 groups. Every group was transported to a single commercial nursery facility for a 7 week nursery period. Each weekly placement was housed together and groups were placed in adjacent houses. All groups were then transported to a separate finishing site and placed wholly in a sequential order of barns at the site. To determine survival beyond weaning, inventories of all live pigs were conducted at nursery placements and all subsequent BW collections (weaning: 18.7 ± 2.1 days of age; placement in finisher: 74.8 ± 1.9 days of age; 16 weeks into finishing 172.8 ± 1.8 days of age). All pigs were tracked through placement in the finisher; however, data were collected on weaned groups 2 and 3 only, after placement in the finisher.

Survival was evaluated for 4 time periods: prenatal, pre-weaning, nursery, and finishing. A summary of the number of pigs used for each mortality analysis is provided in Table 3.1. Prenatal survival included all pigs born alive and stillborns. Classification of stillborns followed on-farm protocol. Pre-weaning survival included only pigs born alive and weighing greater than 0.7 kg.

During the BW collections pigs were given a quality score based on visual evaluation with respect to health and BW (3 = healthy and/or acceptable BW; 2 = minor health issue and/or somewhat small BW; 1 = major health issue and/or extremely small). Examples of health issues associated with a quality score 2: rough hair coat and minor leg or body injuries. Majority of health issues associated with a quality score 1 were belly ruptures, scrotal hernia, and leg or body injuries. Descriptive statistics of the BW associated with each quality score measure separated into quality scores 1, 2, and 3 are in presented in Table 3.2. Similar to survival analysis, after finishing placement only 2 weaned groups, 2 and 3, were evaluated for BW or given quality scores.

Of great interest to swine producers is the likelihood of a pig being full value at finishing barn closeout. The ability of a pig to reach full value is dependent on mortality, sufficient growth to reach minimum weight requirements, and pig quality. At the conclusion of finishing, light weight pigs (BW < 100 kg) and pigs with injuries, belly rupture, poor health, etc. were sent to an alternative harvest facility. The combination of pigs sent to the alternative market along with pre-weaning, nursery and finishing mortalities were classified as non-full value. All pigs sent to primary harvest facility were classified as full value (FV). Only pigs from 2nd and 3rd weeks of farrowing, weaned groups, were used for the analysis of FV.

Statistical analyses

All data were analyzed using the GLIMMIX procedure of SAS (SAS Inst. Inc., Cary, NC). Kenward-Roger adjustments for degrees of freedom were used for all models. For survival and FV models, the binary distribution option was used with a logit link function while quality score was analyzed with a multinomial distribution option with a cumulative logit link function.

To determine effect of birth weight on measures of survival and quality scores, a covariate of birth weight was included in all models. Because within-litter variation in individual birth weight has been shown to affect pre-weaning survival, a covariate of within litter birth weight CV was tested and found non-significant in all models. Consequently, within litter birth weight CV was removed from all final models (Table 3.3). All models included fixed effects of sex and farrowing week, covariates of gestation length, sow parity, and number of fully formed pigs (linear and quadratic). Models for nursery and finishing mortality included an additional fixed effect of cross foster status and covariate of age at weaning weight collection. All quality score analyses included an additional fixed effect of cross foster status and were adjusted for linear and quadratic effects of age.

Effects and their P-values for each model are provided in Table 3.3. All appropriate interactions between fixed effects and covariates were included; however, no interactions were significant $P > 0.10$ and as such were removed from models. Significance was declared at $P < 0.05$.

Results and discussion

Effects included in the final models and their respective *P*-values are presented in Table 3.3. Estimates and standard errors of the estimates for all effects included in the final model are provided in Tables 3.4 and 3.5.

Within-litter variation in birth weight as measured by CV did not ($P > 0.05$) impact survival or pig quality during any portion of this trial Although the measure of within-litter variation differs across reported studies as CV or mean and standard deviation of birth weight; interpretations are similar using either measure. Findings herein are in agreement with other studies for prenatal survival (Zaleski and Hacker, 1993; Leenhouwers et al., 1999; Le Cozler et al., 2002 Wolf et al., 2008) and pre-weaning survival (Pettigrew et al., 1986; Gardner et al., 1989; Knol et al., 2002). In contrast, pre-weaning mortality results herein differed from Milligan et al. (2001) and Wolf et al. (2008) whom reported a tendency and small (0.05) phenotypic correlation for increased pre-weaning mortality in more highly variable litters, respectively. Milligan et al. (2002a) and Milligan et al. (2002b) both reported increased pre-weaning mortality in litters with greater within-litter variation in birth weight. For the study herein, pigs born to litters with greater within-litter variation were more likely ($P < 0.01$) to suffer prenatal and pre-weaning mortality; however, once individual birth was included in the model within-litter variation was no longer significant ($P > 0.35$). Similar to the findings of Roehe and Kalm (2000) increased within-litter variation was associated with increased risk of mortality but individual birth weight was a better predictor and the non-significance of within-litter variation may be partly due to the shared variation with individual birth weight.

Stillbirths

A linear effect ($P < 0.01$) of birth weight on likelihood of a pig being born alive was identified (Tables 3.3 and 3.4). As birth weight increased, the likelihood of pigs being born alive increased (Fig. 3.1) and was in general agreement with other studies (De Roth and Downie, 1976; Quiniou et al., 2002; Canario et al., 2006). Zaleski and Hacker (1993) reported increased likelihood of stillbirth from low average birth weight litters but conversely reported no relation between stillbirth and individual birth weight. One of the leading causes of stillbirths in pigs is asphyxia during parturition (Sprecher et al., 1974; Alonso-Spilsbury et al., 2007). Herpin et al. (1996) found pigs subject to greater levels of asphyxia were less viable at birth than pigs subject to less asphyxia. De Roth and Downie (1976) reported low birth weight pigs had lower viability scores. Therefore, lower birth weight pigs may be more susceptible to asphyxia during parturition and as a result are more prone to being a stillborn (Leenhouwers et al., 1999; Quiniou et al., 2002).

Linear and quadratic effects of number of fully formed pigs ($P < 0.01$; $P < 0.01$) and gestation length ($P < 0.05$; $P < 0.05$) were associated with prenatal survival (Tables 3.3 and 3.4). Prenatal mortality was minimized at intermediate gestation lengths and fully formed pigs (Fig. 3.2). Similar effects of reduced prenatal survival through birth in small and large litters were reported in Knol et al. (2002) and Canario et al. (2006); however, in both studies there appeared to be a greater impact on stillborns of larger litters compared to the study herein. Also, Leenhouwers et al. (1999) reported an increased number of stillborns in large litters. A potential cause for the discrepancy in the effect of large litters on likelihood of prenatal mortality is the difference in maximum number of fully formed pigs. Canario et al.

(2006) reported results from litters with 2-3 more pigs than the study herein. Another potential explanation is the number of observations contained in the extremes of the distribution; specifically 1.7% of litters farrowed were ≥ 20 fully formed pigs. Therefore, the predictive ability on the extremes is reduced which suggests the significance of impact of the smallest and largest litters could vary between datasets. Similar to other studies (Zaleski and Hacker, 1993; Leenhouwers et al., 1999; Rydhmer et al., 2008) shorter gestation lengths lead to increased prenatal mortality. Authors of these studies attributed this loss to reduced physiological development associated with reduced gestation length. In contrast, none of these studies reported increased stillborns associated with extended gestation length. While it is difficult to determine the causes of increased gestation, survival of pigs was unfavorably affected in the study herein.

Increasing sow parity was associated with increased levels of stillbirth (Tables 3.3 and 3.4) and was in agreement with other studies (Zaleski and Hacker, 1993; Leenhouwers et al., 1999; Knol et al., 2002; Canario et al., 2006). Canario et al. (2006) suggested this association was possibly attributable to increased farrowing duration coupled with reduced muscle tone of the uterus (Canario et al., 2006).

Pre-weaning mortality

Increased birth weight was associated with a reduced ($P < 0.01$) chance of mortality prior to weaning (Tables 3.3 and 3.4). The greatest incremental impact of birth weight on pre-weaning survival was for pigs with the lowest birth weights (Fig. 3.1). These findings are in agreement with other studies (Bereskin et al., 1973; Pettigrew et al., 1986; Gardner et al., 1989; Roehe and Kalm, 2000; Quiniou et al., 2002). Increased pre-weaning mortality due to reduced birth weight could be attributable to a variety of prenatal developmental and postnatal environmental factors. Two postnatal factors which have been reported in the literature are vitality and energy consumption. De Roth and Downie (1976) reported lower birth weight pigs were given lower, or poorer, viability scores immediately following birth, and were more likely to suffer pre-weaning mortality. Lower birth weight pigs consume less colostrum and are more likely to suffer pre-weaning mortality (Devillers et al., 2005; Devillers et al., 2007). Other than crushing of piglets by the sow, early life mortality is most likely attributable to insufficient colostrum consumption (Le Dividich et al., 2005). While most pre-weaning mortality occurs early in lactation (Roehe and Kalm, 2000), there is also the potential for pigs to fall behind due to reduced milk consumption. Lighter birth weight pigs have been shown to be at a competitive disadvantage and subject to less milk consumption (Hartsock and Graves, 1976). Milk intake is vital to the survival of the piglet. Despite the availability of creep feed, pigs are mostly dependent on the sow to meet their nutrient and energy requirements prior to weaning (Sørensen et al., 1998).

Significant effects of sow parity ($P < 0.01$) and gestation length (linear: $P < 0.05$; quadratic: $P < 0.05$) were observed (Tables 3.3 and 3.4). Increased sow parity and reduced gestation length (Fig. 3.2) resulted in greater pre-weaning mortality. Other studies have shown increased pre-weaning mortality in older sows (Gardner et al., 1989; Roehe and Kalm, 2000; Knol et al., 2002). This could be attributable to reduced litter size on younger sows; number of fully formed pigs was not significant which could be somewhat attributable to parity accounting for a portion of the variation associated with litter size. Another explanation may be the increased farrowing duration of older parity sows described previously (Canario et al., 2006). The extended parturition of older sows could also lead to weaker pigs that survive through birth, but are compromised and consequently susceptible to pre-weaning mortality. A sharp increase in pre-weaning mortality as gestation moved below 111 d (Fig. 3.2) was estimated and was in agreement with Roehe and Kalm (2000) and Rydhmer et al. (2008). Reduced gestation interval may result in less physiologically mature pigs being born and are more susceptible to pre-weaning mortality. Colostrum production has also been associated with sow age and induced litters with short gestation lengths. The reduction in colostrum production led to reduced consumption by the piglets and adversely affected pre-weaning mortality (Devillers et al., 2005; Devillers et al., 2007).

Nursery and finishing mortality

A linear effect of birth weight was significantly associated with nursery mortality; however, birth weight was not associated with finishing mortality (Tables 3.3 and 3.4). Lighter birth weight pigs had greater nursery mortality (Fig. 3.1). While the impact of birth weight on pre-weaning performance has been more detailed, few studies have published birth weight effects on survival of piglets post-weaning. Larriestra et al. (2006) and de Grau et al. (2005) reported lower weaning weight pigs had lower nursery survival rates. As discussed in Fix et al. (2010) birth weight is a significant indicator of future BW measures, especially weaning weight. Therefore, it is plausible that the association between weaning weight and nursery mortality may be partly due to birth weight. Smith et al. (2007) divided birth weights into categories and reported varying results for post-weaning survival; however, pigs in the lightest birth weight group experienced the highest rate of mortality during the nursery phase. While the magnitude of the impact of birth weight on nursery survival was not as large as pre-weaning mortality (Fig. 3.1), lower birth weights continue to lead to increased chances of mortality. Cumulatively, the effect of birth weight on pre and post-weaning mortality is highly significant; However, 18% light weight pigs ($\leq$ 1 kg) born alive survived to finisher placement compared to 66% of pigs > 1 kg. Thus, fewer light birth weight pigs were placed in the nursery and subsequently the finisher, causing censoring of the data. Therefore, although birth weight was not significantly associated directly with finisher mortality, birth weight was associated with cumulative pig mortality ($P < 0.01$). Since not all light weight pigs were available in the finisher, the impact of birth weight on mortality during finishing may be under estimated.

Longer lactation length ($P < 0.01$) and older parity dams ($P < 0.01$) were associated with reduced nursery mortality. Main et al. (2004) reported similar findings for increased weaning age. Davis et al. (2006) also reported increased nursery mortality of pigs weaned at younger ages and attributed this effect to an unfavorable impact on immunity. Larriestra et al. (2006) compared gilts to sows and reported no difference in nursery piglet survival. Gilts, compared to sows, have been reported with reduced individual weaning weights (Smith et al., 2007). The combination of these factors could be an explanation of reduced mortality due to increased sow parity.

Quality scores

Lower birth weight was associated with lower quality scores at weaning ($P < 0.01$), finishing placement ($P < 0.01$), and 16 weeks into finishing ($P < 0.01$). The estimated effects of birth weight on quality score decreased in magnitude after weaning. This was similar to what was observed with pre and post-weaning mortality; once again, few light birth weight pigs survive past weaning. Those that do survive past weaning, appear to be a greater risk of being poorer quality than their heavier birth weight cohorts.

Morrow et al. (2006) evaluated the economic and welfare implications of euthanasia decisions for compromised pigs during the nursery phase. The authors reported that pigs which had low BW or other health issues during the nursery phase had a lower economic value compared to their healthy cohorts. Similarly, quality scores given herein were strongly influenced by BW at time of evaluation (Table 3.2) and as summarized in Fix et al. (2010) reduced birth weight was associated with reduced BW later in life. Therefore, the relationship between birth weight and quality was expected. No other studies appear to have evaluated the impact of birth weight on pig quality.

To keep the scoring system practical from a time perspective, the system was limited to three levels which did not differentiate between causes, only severity. This differed from the technique used in Morrow et al. (2006), which entailed a more detailed evaluation for the causes of low quality pigs.

Full value at harvest

Lower birth weight pigs were less ($P < 0.01$) likely to be full value at harvest than heavier birth weight pigs (Tables 3.3 and 3.4). This was especially true for pigs with the lightest birth weights (Fig. 3.5). The non-full value pigs consisted of two groups, dead pigs and pigs with low quality scores due to weight or health issues. The impact of birth weight on the ability to reach full value was a combination of its negative impact on survival, quality, and growth.

Conclusion

As birth weight decreased pigs were more likely to suffer mortality prior to weaning and during the nursery phase. Additionally, decreased birth weight resulted in poorer quality pigs at weaning, finisher placement, and near the conclusion of finishing. This effect of pig quality decreased with age but was still important throughout production.

The combination of these effects due to birth weight leads to a dramatic impact on the ability of a pig to be full value at harvest which in turn impacts the profitability of commercial pig producers. To determine the total economic impact of low birth weight pigs on commercial pig production, an economic analysis of the data presented herein along with performance data is planned by the authors.

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Table 3.1. Number of animals used for each analysis along with means and standard deviation for birth weight and litter traits.

	Number of animals[a]				Sex		Birth weight		CV		Covariates[b]					
											FFP		Gestation		Parity	
Phase[c]	Total	Alive	Dead	Culls	B	G	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Survival																
Prenatal	6,240	5,727	513	-	3,160	3,080	1.41	0.36	20.6	6.7	13.2	3.0	114.4	1.4	3.3	2.1
Pre-weaning	5,408	4,108	1,300	-	2,719	2,689	1.46	0.33	20.2	6.6	13.4	2.9	114.4	1.3	3.2	2.0
Nursery	3,943	3,420	523	-	1,935	2,008	1.52	0.30	19.8	6.7	13.2	2.9	114.4	1.3	3.1	2.0
Finishing	1,815	1,572	243	-	893	922	1.54	0.30	19.6	6.6	13.2	2.8	114.4	1.2	3.2	2.1
Full Value																
Birth to harvest	2,914	1,436	1,355	123	1,480	1,434	1.45	0.33	20.1	6.5	13.2	2.8	114.4	1.2	3.2	2.1

[a]Total number of pigs used for analysis of mortality during different phases of production and likelihood of being full value at harvest.

[b]Means and standard deviations for covariates included in the models for analysis of mortality and quality score; FFP: number of fully formed pigs; Gestation: gestation length.

[c]Prenatal: within 24 h of birth pigs were classified as born alive or stillborn (dead), mummies were not used; Pre-weaning: live pigs were recorded at 18.7 ± 2.1 days of age and live born pigs with BW > 0.7 kg were used; Nursery: pigs alive at nursery placement (20.7 ± 2.1 days of age) were used and survival to finisher placement was recorded via inventory at finisher placement (74.8 ± 1.9 days of age); Finishing: pigs alive at finisher placement that survived through 16 weeks into finishing (172.8 ± 1.8 days of age); Birth to harvest: pigs born alive to harvest.

Table 3.2. Descriptive statistics of body weights for each quality score at weaning, finisher placement, and 16 weeks into finishing.

Quality Score	BW at weaning, kg				
	N	Mean	Min	Max	SD
1	198	2.9	1.6	6.0	0.7
2	376	3.4	2.3	6.5	0.4
3	3,534	5.2	2.6	9.3	1.0
Quality Score	BW at finisher placement, kg				
	N	Mean	Min	Max	SD
1	232	20.5	9.1	34.0	5.7
2	386	17.1	9.7	28.8	2.7
3	2,802	24.2	13.2	37.1	3.8
Quality Score	BW 16 weeks into finishing, kg				
	N	Mean	Min	Max	SD
1	66	85.4	50.4	129.7	22.1
2	137	80.9	63.3	90.7	6.0
3	1,365	106.3	83.5	140.6	10.5

Table 3.3. List of fixed effects and covariates for all models.

	Covariates[c]								Fixed Effects		
Item[a]	BWT	CV	FFP	FFP*FFP	Parity	Lact	Gest	Gest*Gest	Sex	Group	Cross
Survival											
Prenatal	< 0.01[d]	0.68	0.03[d]	0.04[d]	< 0.01[d]	-	< 0.01[d]	< 0.01[d]	0.02[d]	0.08[d]	-
Pre-weaning	< 0.01[d]	0.21	0.26	0.10	< 0.01[d]	-	0.03[d]	0.03[d]	< 0.01[d]	< 0.01[d]	-
Nursery	< 0.01[d]	0.18	0.37	0.34	< 0.01[d]	< 0.01[d]	0.80	0.40	< 0.01[d]	0.51	< 0.01[d]
Finishing	0.57	0.19	0.59	0.21	0.20	0.20	0.73	0.91	0.10	0.39	0.71
Full Value											
Birth to harvest	< 0.01[d]	0.12	0.29	0.68	0.13	-	0.01[d]	0.01[d]	< 0.01[d]	0.08	-
Quality Scores											
	Covariates[c]								Fixed Effects		
Item[b]	BWT	CV	FFP	FFP*FFP	Parity	Lact	Age	Age*Age	Sex	Group	Cross
Weaning	< 0.01[d]	0.09	0.02[d]	0.43	0.03[d]	-	< 0.01[d]	< 0.01[d]	0.16[d]	< 0.01[d]	< 0.01[d]
Finisher Placement	< 0.01[d]	0.27	0.47	0.16	0.01[d]	-	0.02[d]	0.03[d]	< 0.01[d]	< 0.01[d]	0.68
16 weeks into finishing	< 0.01[d]	0.85	0.85	0.13	0.24	-	< 0.01[d]	0.96	0.10[d]	0.61	0.25

[a]Prenatal: within 24 h of birth pigs were classified as born alive or stillborn (dead), mummies were not used; Pre-weaning: live pigs were recorded at 18.7 ± 2.1 days of age and live born pigs with BW > 0.7 kg (n = 132; < 0.7 kg) were used; Nursery: pigs alive at nursery placement (20.7 ± 2.1 days of age) were used and survival to finisher placement was recorded via inventory at finisher placement (74.8 ± 1.9 days of age); Finishing: pigs alive at finisher placement that survived till FIN16 (172.8 ± 1.8 days of age); Birth to harvest: pigs that were full value at harvest from pigs born alive.

[b]Quality scores at weaning, placement in the finisher, and 16 weeks into finishing.

[c]BWT: individual pig birth weight; CV: coefficient of variation for individual birth weights within a litter; FFP: number of fully formed pigs in a litter, born alive + stillborns; Lact: lactation length measured as age at time of weaning weight; Gest: gestation length, no sows were induced to farrow; Age: age at the time of quality score evaluation.

[d]*P*-values for effects in the final model.

Table 3.4. Estimates and standard errors for likelihood of pig surviving, in Logit scale, for all covariates and fixed effects included in the model due to a 1 kg increase in birth weight.

			BWT[a]		FFP[a]				Gestation length													
Item[c]	Int	SE	Lin	SE	Lin	SE	Quad	SE	Linear	SE	Quad	SE	Lact	SE	Parity	SE	Cross[b]	SE	Sex[b]	SE	Group[b]	SE
										Survival												
Prenatal	-646.1	137.6	2.10	0.14	0.23	0.10	-0.007	0.004	11.3	2.4	-0.05	0.01	-	-	-0.21	0.02	-	-	0.22	0.10	0.04	0.49
Pre-wean	-265.9	120.5	2.59	0.12	-	-	-	-	4.6	2.1	-0.02	0.01	-	-	-0.05	0.02	-	-	0.28	0.07	-0.53	0.50
Nursery	-2.8	0.5	1.09	0.17	-	-	-	-	-	-			0.14	0.03	0.15	0.03	-0.54	0.13	0.35	0.10	-	-
Finishing	-	-	-	-	-	-	-	-	-	-					-	-	-	-	-	-	-	-
										Full Value												
Birth to harvest	-512.1	207.8	1.93	0.13	-	-	-	-	8.98	3.63	-0.04	0.02	-	-	-	-	-	-	0.27	0.08	-	-

[a]BWT: individual birth weight, linear; FPP: number of fully formed pigs within a litter (stillborns + born alive), linear and quadratic.

[b]Cross: cross foster status, estimate for cross fostered pigs, non-cross fostered pigs = 0; Sex: estimate for gilts, barrows = 0; Group: weighted average for contemporary groups, wean week or nursery/finishing house.

[c]Prenatal: within 24 h of birth pigs were classified as born alive or stillborn (dead), mummies were not used; Pre-weaning: live pigs were recorded at 18.7 ± 2.1 days of age and live born pigs with BW > 0.7 kg (n = 132; < 0.7 kg) were used; Nursery: pigs alive at nursery placement (20.7 ± 0.03 days of age) and survival to finisher placement was recorded via inventory at finisher placement (74.8 ± 1.9 days of age); Finishing: pigs alive at finisher placement that survived through 16 weeks into finishing (172.8 ± 1.8 days of age); Birth to harvest: pigs that were full value at harvest from pigs born alive.

Table 3.5. Estimates and standard errors for likelihood of pig being a numerically higher or superior quality score, in Cumulative Logit scale, for all covariates and fixed effects included in the model due to a 1 kg increase in birth weight.

											Age[a]									
Item	Int 1[a]	SE	Int 2[a]	SE	BWT[a]	SE	FFP[a]	SE	Parity	SE	Lin	SE	Quad	SE	Cross[a]	SE	Sex[a]	SE	Group[a]	SE
Weaning	-17.9	1.9	-16.6	1.9	3.0	0.2	0.05	0.02	0.06	0.03	1.3	0.2	-0.029	0.005	-0.63	0.13	0.13	0.10	-0.15	0.11
Finisher placement	-91.5	36.8	-90.4	36.9	1.4	0.2	-	-	0.06	0.02	2.3	1.0	-0.014	0.007	-	-	0.43	0.09	-0.35	0.10
16 weeks into finishing	-21.8	7.6	-20.6	7.6	1.4	0.3	-	-	-	-	0.13	0.04	-	-	-	-	-0.25	0.15	-	-

[a]Int 1: intercept for likelihood of score quality score of 3; Int 2: intercept for likelihood of quality score 2 or 3; BWT: linear estimate for individual birth weight; FPP: linear estimate for number of fully formed pigs within a litter (stillborns + born alive); Age: covariates (linear and quadratic) for age at time of quality score; Cross: cross foster status, estimate for cross fostered pigs, non-cross fostered pigs = 0; Sex: estimate for gilts, barrows = 0; Group: weighted average for contemporary groups, wean week or nursery/finishing house.

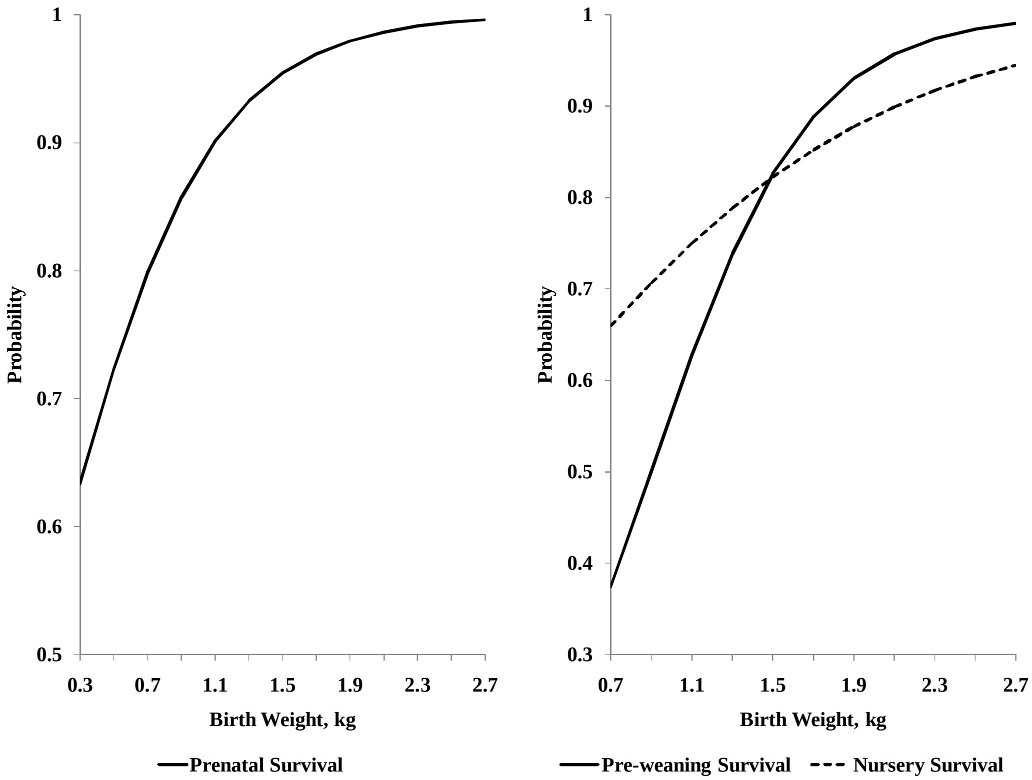

Figure. 3.1. Effect of birth weight on prenatal, pre-weaning, and nursery survival.

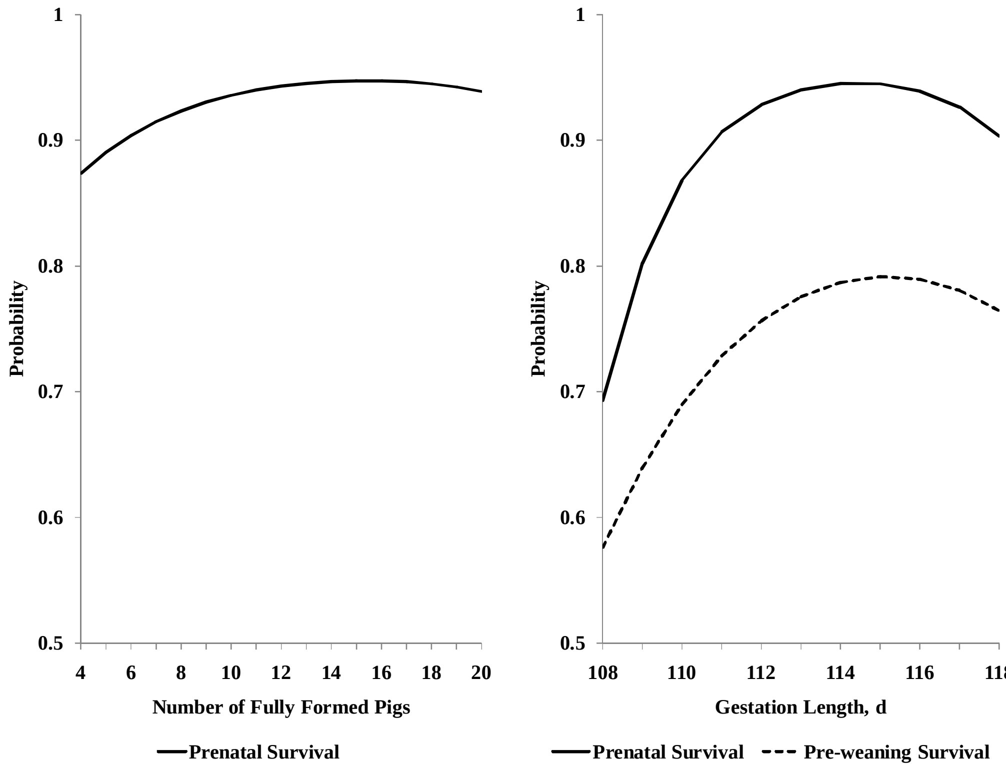

Figure. 3.2. Effect of number of fully formed pigs and gestation length on prenatal survival and gestation length on pre-weaning survival.

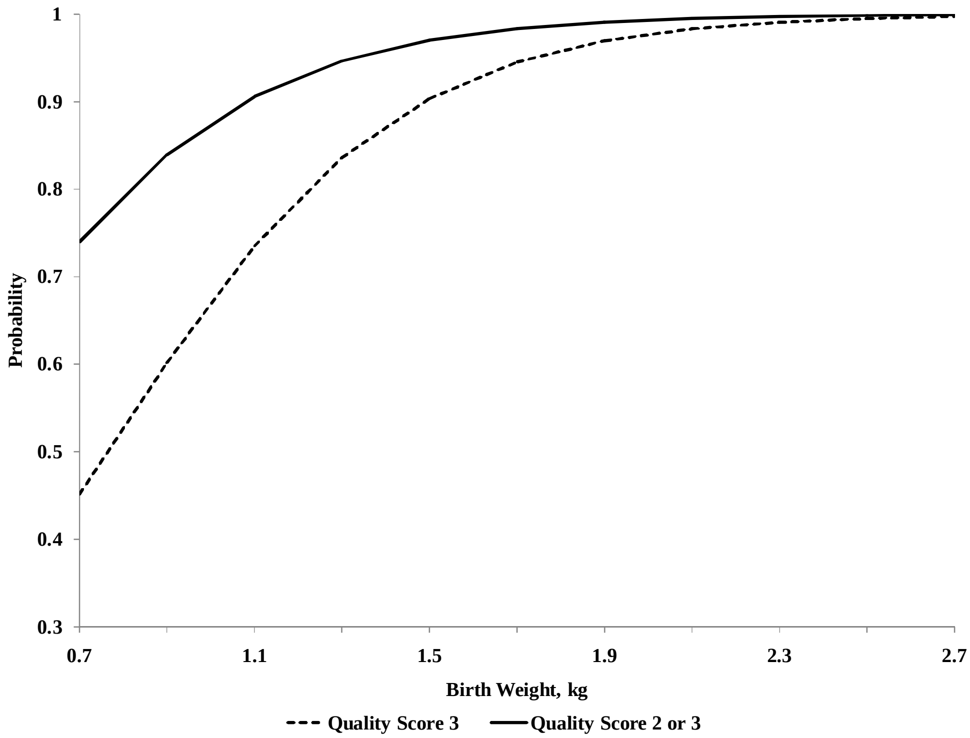

Figure. 3.3. Effect of birth weight on pig quality at weaning.

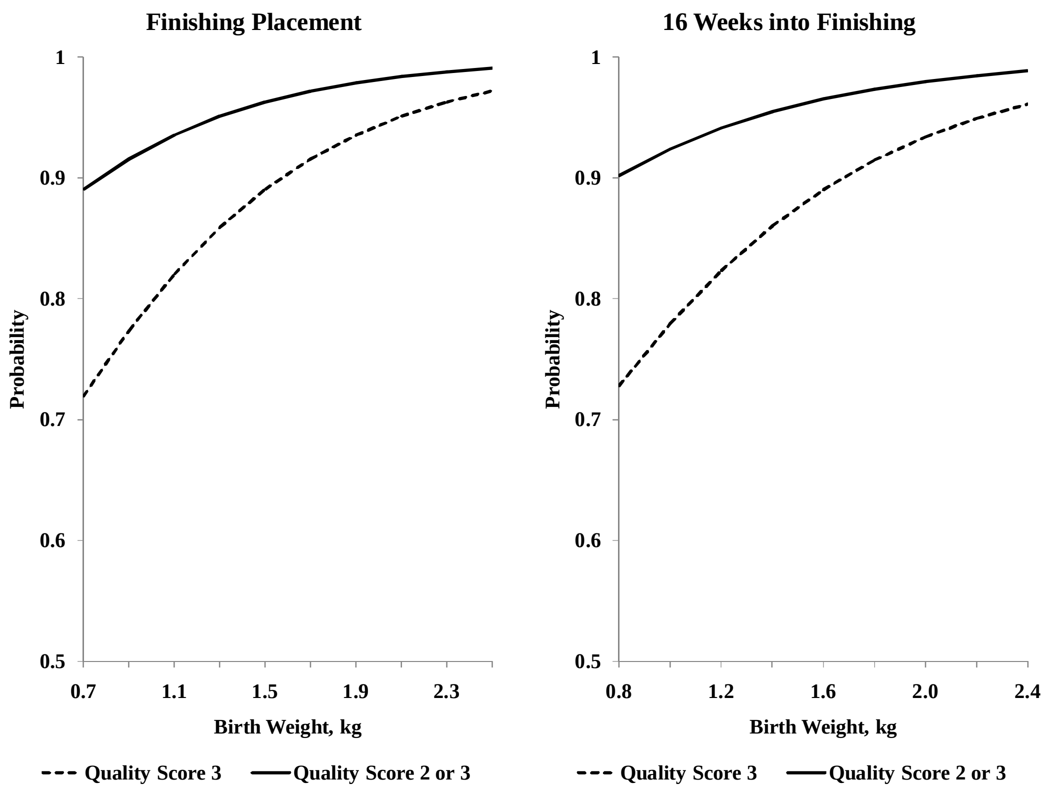

Figure. 3.4. Effect of birth weight on pig quality at placement and 16 weeks into the finishing phase.

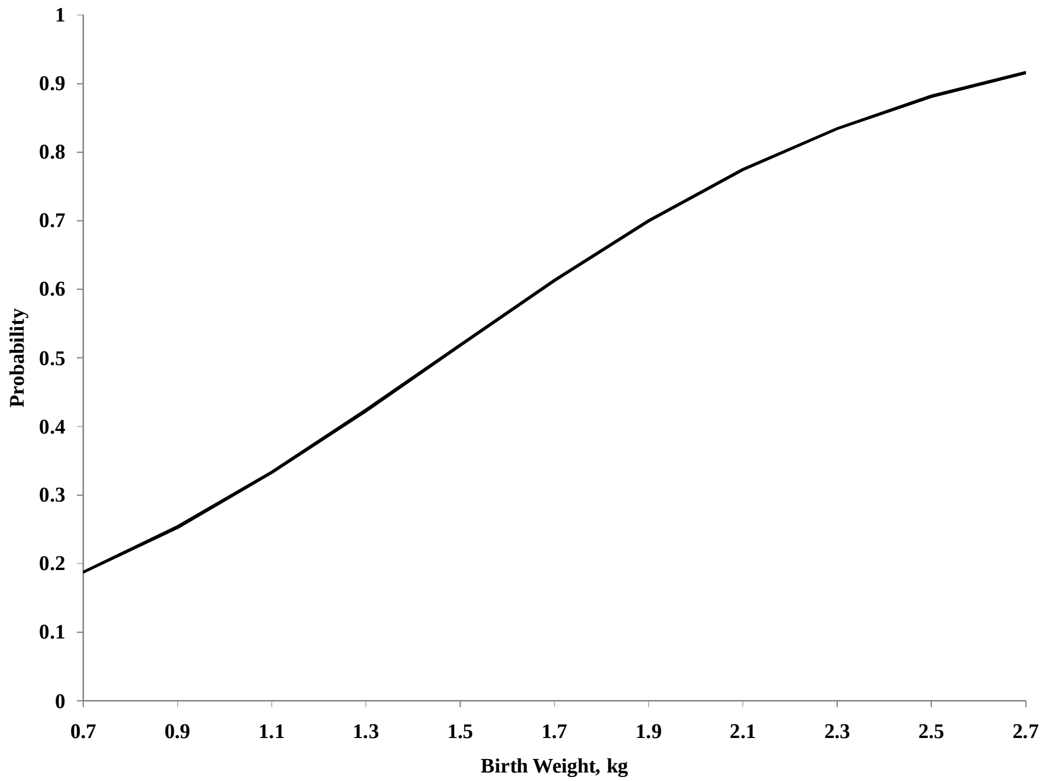

Figure. 3.5. Estimated effect of birth weight on likelihood of live born pigs being full value at harvest.

Chapter 4: Effect of piglet birth weight on efficiency of commercial market swine.

ABSTRACT

The objective of this study was to determine the impact of birth weight, as a continuous trait, on efficiency of commercial market swine from weaning through harvest. During a 5 day period at a commercial sow farm, all pigs were individually weighed and identified within 24 hours of birth. At weaning 440 pigs were selected to represent the entire birth weight distribution. These pigs were transferred to a research facility and placed in pens of ten by birth weight and sex. After a 6 week nursery phase all pens were split into two pens of five by birth weight. Feed allotment was recorded daily. Individual pig BW and feed weigh back were completed in 3 week increments, except for the final collection of 26 days. During the final 3 BW collections all pigs were measured for backfat depth and longissimus muscle area at the 10th rib using real-time ultrasound. Average daily gain, average daily feed intake, and gain to feed were calculated for a nursery phase, finishing phase, and total test period. Also, lean average daily gain and lean gain to feed were calculated for the final 68 days of test. Increased birth weight was associated with heavier BW at weaning, beginning of finishing phase, and conclusion of the test period, increased average daily gain during the nursery phase, finishing phase, and total test period, and increased lean average daily gain. All were linear associations except final BW, total average daily gain, and BW at beginning of finishing (P = 0.08) which also included quadratic associations. Negative linear effects of birth weight on gain to feed during the nursery and finishing phases and lean average daily gain were estimated. Linear and quadratic effects were estimated for birth weight on total gain to feed and lean gain to feed. For all efficiency measures, lighter birth weight pigs were more efficient during the respective phase of the testing period. However, if phases were

adjusted for the final pig BW, effects of birth weight were no longer significant ($P > 0.05$). Heavier birth weight pigs were heavier through harvest, gained faster per day, consumed more feed per day and were less efficient to a constant age than their lighter birth weight contemporaries.

Key Words: Pigs, Birth Weight, Efficiency, Performance

Introduction

Light birth weight pigs grow slower and are less likely to survive than their heavier contemporaries (Quiniou et al., 2002, Fix, et al., 2010ab). The impact of birth weight on muscling, fatness, or composition varies between studies; however, when provided ad-libitum feed and measured at a constant weight, low birth weight pigs were fatter (Poore and Fowden, 2004; Gondret et al., 2006) but did not differ from heavier birth weight pigs when measured at a constant age or adjusted for weight (Powell and Aberle, 1980; Rehfeld et al., 2008). Birth weight was not associated with muscling when pigs were fed to a constant weight or muscling was adjusted for BW (Powell and Aberle, 1980; Bérard et al., 2008) In contrast, at a constant age heavier birth weight pigs have increased muscling (Nissen et al., 2004; Rehfeldt et al., 2008; Fix et al., 2010a).

Few studies evaluated the impact of piglet birth weight on efficiency from weaning to harvest. Two studies, testing pigs in individual pens fed to a constant BW reported increased G:F for heavy compared to light birth weight pigs (Gondret et al., 2006; Bérard et al., 2008). Powell and Aberle (1980) reported no difference in F:G between high, medium, and low birth weight pigs but did find “runt” pigs were less efficient than their “larger” littermates.

Finally, Wolter et al. (2002) reported increased G:F for pens of heavy vs. light birth weight pigs fed to a constant weight. Schinckel et al. (2010) analyzed birth weight as a continuous effect and reported light birth weight pigs had greater feed to gain. All of these studies evaluated the impact of birth weight on efficiency during the nursery or nursery and finishing phases with a constant BW as the determinant for off-test.

Studies measuring the association between birth weight and efficiency have analyzed birth weight as a categorical trait, heavy vs. light, etc. However, as reported in Schinckel et al. (2007, 2010) and Fix et al. (2010a) the estimated effect of birth weight on future growth is not linear. Therefore, the objective of this study was to estimate the effect of birth weight, analyzed as a continuous trait, on efficiency of commercial market swine in a situation similar to current production practices.

Materials and methods

All animal procedures were approved by the Institutional Animal Care and Use Committee of North Carolina State University, Raleigh, NC (IACUC # 09-066-A).

Animals

All live born pigs (n = 1,052) farrowed from May 4, 2009 to May 8, 2009 at a commercial sow farm were used for this study. Pigs were farrowed from Large White x Landrace (n = 82) sows bred to Duroc sires. Within 24 hours of birth, all pigs were individually weighed, identified, and cross-fostered to balance the number of pigs nursed per litter. At approximately 5 days of age all pigs were processed and male pigs were castrated. By 12 days of age all litters were provided access to creep feed.

Immediately prior to weaning (20.5 ± 1.1 days of age), individual weaning weights were collected on 440 pigs (220 barrows and 220 gilts). To achieve a balanced number across sex and a complete representation of birth weight; pigs were randomly selected within sex across the entire birth weight distribution of the remaining live pigs at weaning. After weaning pigs were transferred to the North Carolina Swine Evaluation Station (Clayton, NC). All pens at the research facility were 1.52 x 3.66 m with solid concrete flooring.

Pigs were assigned to pens of 10 (0.56 m^2/pig) within sex from the lightest to heaviest birth weight. Individual BW collections and feed weigh backs were conducted at 3 weeks and 6 weeks into nursery phase. Finishing phase began after week 6 BW collection; immediately following week 6 BW collection, all pens were divided into 2 pens of 5 pigs (1.12 m^2/pig) from lightest to heaviest birth weights. During the finishing phase individual BW and feed weigh backs were collected every 3 weeks except for the final (off-test) BW collection which was conducted 26 days after previous BW collection. Individual BW were collected for all pigs that died or were removed from test during the trial.

During the final 3 BW collections (104.5 ± 1.1, 125.5 ± 1.1, 150.5 ± 1.1 days of age) all pigs were individually measured for 10^{th} rib backfat depth and longissimus muscle area using real-time ultrasound (Aloka 500; Corometrics Medical Systems, Wallingford, CT). Estimated percent lean was calculated using the NPPC (2000) equation. Lean gain and lean gain to feed were calculated from 104.5 to 150.5 days of age.

Pigs were provided ad-libitum access to feed and water. Pigs were fed a standard pelleted commercial 7 phase feeding program formulated to meet NRC 1998 requirements (NRC, 1998). Diet specifics follow (amount budgeted per pig (kg), crude protein (%), crude fat (%), metabolizable energy (Kcal/kg)): early wean (2.3, 23.6, 7.9, 3433.7); prestarter 2 (8.2, 21.9, 9.7, 3564.5); starter (18.1, 22.2, 10.1, 3584.2); grower 1 (29.5, 19.0, 9.5, 3553.3); grower 2 (34.0, 17.4, 9.6, 3571.4); developer (61.7, 16.3, 9.7, 3578.5); finishing 1 (through harvest, 13.3, 5.4, 3397.1).

Statistical analysis

For all analyses pen was used as the experimental unit. Dependent variables analyzed were, average daily gain, average daily feed intake, and gain to feed for nursery phase (first 6 weeks), finishing phase (final 89 days), and overall. In all instances variables were fit to a model with a fixed effect of sex, regression covariates of birth weight (linear and quadratic), and all appropriate interactions.

To determine the total impact of birth weight on backfat and longissimus muscle area, neither measure was adjusted for BW at time of measurement, due to the known impact of birth weight on future BW (Fix et al., 2010a); however, both backfat and longissimus muscle area were individually adjusted to a common age (105, 125, and 150 days of age, respectively) prior to analysis. Values of backfat and longissimus muscle area for percent lean calculations were unadjusted. All 3 measures (105, 125, and 150 d of age) for backfat, longissimus muscle area, percent lean, lean average daily gain, and lean gain to feed were fit to models with a fixed effect of sex, and regression covariates of birth weight (linear and quadratic).

Interactions between sex and birth weight (linear and quadratic) were found to be not significant, $P > 0.05$, and were removed from all models.

Results and discussion

Descriptive statistics and estimates for all effects are provided in Tables 4.1 and 4.2, respectively.

Body weight, gain, and feed intake

A linear relationship ($P < 0.01$) was identified between birth weight and weaning weight; as birth weight increased, pigs were heavier at weaning. A significant ($P < 0.01$) linear and a tendency ($P < 0.10$) for a quadratic relationship were estimated between birth weight and BW at the beginning of the finishing phase; however, significant ($P < 0.01$) linear and quadratic effects of birth weight on off-test weight were estimated. As birth weight increased, BW at the beginning and ending of the finishing phase increased at a decreasing rate (Fig. 4.1). These findings are in agreement with many studies that have shown increased birth weight to be associated with heavier BW later in life (Powell et al., 1980; Quiniou et al., 2002; Smith et al., 2007). While still in agreement for increased BW due to heavier birth weights, two other studies reported nonlinear relationships between birth weight and future BW measures (Schinckel et al., 2007; Fix et al., 2010). Quiniou et al. (2002) also fit a quadratic effect of birth weight and reported similar relationship between birth weight and future BW. In all studies utilizing nonlinear models, an incremental increase in birth weight, for the lightest pigs at birth, resulted in the greatest increase in future BW. These studies utilized a large number of animals with individual animal as the experimental unit, whereas the study herein used pens, this might lead to the inability to detect a nonlinear relationship between birth weight and weaning weight.

Significant ($P < 0.01$) estimates for a linear effect of birth weight on average daily gain during the nursery and finishing period were identified. Linear and quadratic effects ($P < 0.01$) of birth weight on overall gain were also estimated. Increased birth weight was associated with faster growth during the nursery and finishing phase (Fig. 4.1). These relationships coincided with increased BW at the beginning and end of the finishing phase and are in agreement with other published findings (Wolter et al., 2002; Grondret et al., 2006; Rehfeldt et al., 2008). The relationship between birth weight and total average daily gain was similar to findings reported in Fix et al. (2010a) where the impact of birth weight increased as birth weight decreased.

Prenatal and postnatal causes of differences in BW and average daily gain have been covered in detail in Fix et al. (2010a); however, a general summary will be provided herein. A reduced number of muscle fibers have been associated with lighter birth weight pigs (Nissen et al., 2004; Gondret et al., 2005, 2006; Rehfeldt and Kuhn, 2006). Number of muscle fibers is believed to be determined prenatally and has been reported to impact pig growth (Dwyer et al., 1993; Rehfeldt et al., 2000; Herfort Pedersen et al., 2001). Growth of light birth weight pigs has been reported to be negatively impacted by several postnatal environmental factors: reduced colostrum intake (Devillers et. al., 2005, 2007); selection or more appropriately forced selection of more posterior or poorer producing teats (McBride, 1963; Fraser, 1975; Hartsock et al., 1977), which have been associated with slower growing pigs (Kim et al., 2000). It is difficult to determine the complete impact of each factor, but some combination is likely the cause of lighter birth weight pigs to be slower growing and have reduced BW measured later in life.

Increased birth weight was associated with increased average daily feed intake during the nursery, linear ($P < 0.01$), finishing, linear ($P < 0.01$) and quadratic ($P < 0.01$), and overall, linear ($P < 0.01$) and quadratic ($P < 0.01$) (Fig. 4.2). While other studies divided birth weight into categories for analysis or experimental design, similar findings of heavier birth weight pigs consuming more feed per day during the finishing period were reported (Wolter et al., 2002; Bérard et al., 2008); however, both of these studies reported no differences in average daily feed intake during a period similar to the nursery period herein. Also, Gondret et al. (2006) and Schinckel et al. (2010) reported no association between piglet birth weight and average daily feed intake.

Heavier pigs have increased energy requirements and consequently consume more feed (NRC, 1998). In the study herein, heavier birth weight pigs were heavier at the beginning and continued to get heavier through the end of the trial; subsequently, this increase in BW is likely the basis for an association between birth weight and average daily feed intake.

Gain to feed

Linear effects of birth weight (*P* < 0.05) on gain to feed during the nursery and finishing periods were indentified. In both instances increased birth weight was associated with reduced gain to feed. Over the entire test period, linear (*P* < 0.01) and quadratic (*P* < 0.01) effects of birth weight on gain to feed were estimated. As birth weight increased, gain to feed decreased at a decreasing rate (Fig. 4.3). Recall from previous discussion on the impact of birth weight on BW later in life; heavier birth weight pigs were heavier throughout the trial. Increased BW requires more energy for maintenance (NRC, 1998); consequently, heavier birth weight pigs required more energy or feed to maintain their heavier BW. This leads to reduced gain to feed of heavier birth weight pigs. This nonlinear association between birth weight and gain to feed mirrored that of birth weight and total average daily gain; incremental changes for the lightest birth weight pigs were associated with a greater differences compared to their heavier contemporaries. Published results from other studies differed from those herein; heavier birth weight pigs had greater gain to feed during the finishing period (Wolter et al., 2002; Gondret et al., 2006; Bérard et al., 2008). All three of these studies either began or concluded test periods based on the animals reaching a predetermined BW which differs from an age constraint used herein. In each situation of pigs being removed from test once a specified BW was reached, lighter birth weight pigs required 7 to 12 days more to reach final BW. Reduced gain to feed for lighter birth weight pigs may be attributed to more feed consumed on maintenance during the extra days required. Schinckel et al. (2010) used nearly 2000 pigs housed in pens with individual feed intake recorded with FIRE® feeders, reported feed to gain increased as birth weight decreased.

Birth weight was analyzed as a continuous variable, similar to the current study; however, similar to other studies, pigs were removed from test based on a predetermined BW, not age.

Other research has shown no impact of birth weight on efficiency; either for various test periods or the whole trial. Wolter et al. (2002) did report increased gain to feed from weaning to 14 kg BW for heavier birth weight pigs but no difference from 25 to 54 kg BW, which is in agreement for Bérard et al., (2008) during the postweaning and growing periods. Similarly, Powell and Aberle (1980) reported no difference in feed to gain during any phase of the trial.

In the current study, the conclusion of the testing period was based on age not BW; however, if gain to feed was adjusted for the BW at conclusion of the test period, there was no longer a significant ($P > 0.05$) association between birth weight and gain to feed. This would seem to agree with the discussion concerning the relationship between birth weight and average daily feed intake; the heavier birth weight pigs consumed more feed due to their additional energy requirements.

Real-time ultrasound backfat, longissimus muscle area, and fat free lean

Increased birth weight was associated ($P < 0.01$) with increased longissimus muscle area at all three measurements. Effects of birth weight on first (linear; $P < 0.05$) and third (linear: $P < 0.01$; quadratic: $P < 0.01$) backfat measurements were indentified. In both instances increased birth weight was associated with increased backfat. In general, these findings are in agreement with Fix et al. (2010a); however, the authors reported a quadratic effect of birth weight on longissimus muscle area and a tendency for a linear association between birth weight and backfat. Both backfat and longissimus muscle area were adjusted for age, not BW, therefore, much of the association could be attributable to the impact of birth weight on future BW. Heavier birth weight pigs were heavier at the time of ultrasound measurement. Increased BW is commonly associated with increased backfat and longissimus muscle area.

Studies measuring muscling at a constant age, similar to the current study, reported findings of increased muscling for heavier birth weight pigs (Nissen et al., 2004; and Rehfeldt et al. 2008). Although, adjusted to a common weight, Schinckel et al. (2010) reported increased muscling in heavier birth weight pigs.

Studies with similar ad libitum feeding programs but either adjusting to or measuring backfat and longissimus muscle area at a constant weight reported findings different than those herein. Poore and Fowden (2004), Gondret et al. (2006), and Schinckel (2010) reported lighter birth weight pigs had increased fat depth. Also, no association between backfat and birth weight has been shown (Rehfeldt et al., 2008). Bérard et al. (2008) and Powell and Aberle (1980), reported no difference in muscling due to birth weight.

While relationships of birth weight with backfat and muscling appear to differ between adjustment methods, trial design, and feeding techniques; trials with similar designs report similar findings.

Backfat and longissimus muscle area are measures used for prediction of carcass composition; therefore, it is also important to examine the impact of birth weight on estimated percent lean. Birth weight was not associated with estimated percent lean at first or second real-time ultrasound; however, linear and quadratic effects ($P < 0.05$) of birth weight on estimated percent lean at off-test were identified. Estimated percent lean was lowest for intermediate birth weight pigs and increased for both heavier and lighter birth weight pigs. Findings for estimated percent lean are based on a combination of the effects of birth weight on backfat and longissimus muscle area. Heavier birth weight pigs were heavier muscled but fatter while light birth weight pigs were leaner but lighter muscled. Once these are combined into an estimated percent lean muscling in the heavier birth weight pigs and leanness of light birth weight pigs lead to greater percent lean than pigs of intermediate birth weight. The estimated effect of birth weight on estimated percent lean reported herein are not in agreement with any other studies.

Many studies detailing the effects of birth, reported no association between birth weight and carcass composition, regardless of trial design (Powell and Aberle, 1980; Nissen et al, 2004; Gondret et al., 2005; Bérard et al., 2008; Rehfeldt et al., 2008). Two studies did report an association between birth weight and composition of harvest age gilts; in both studies heavier birth weight gilts had increased lean (Gondret et al., 2006; Rehfeldt et al., 2008). While effects were different between sexes, Schinckel at al. (2010) reported the lightest birth weight pigs had reduced predicted lean compared to heavier birth weight pigs.

Birth weight was associated with lean average daily gain (linear: $P < 0.01$) and lean gain to feed (linear $P < 0.01$; quadratic: $P < 0.05$) (Fig. 4.3). Heavier birth weight pigs had greater lean average daily gain. As birth weight increased, lean gain to feed decreased at decreasing rate. While estimated composition is taken into account, it appears the impact of birth weight on average daily gain and average daily feed intake played a large role; as the associations are quite similar for birth weight with average daily gain and gain to feed previously. As with gain to feed, if lean gain to feed is adjusted for the BW at the end of the test period, birth weight was no longer associated with lean gain to feed.

Conclusion

Birth weight has dramatic impacts on the growth of pigs from weaning till harvest, over the entire nursery to finishing time period this relationship is not linear. There appears to be a threshold where an increase in birth weight does not result in improved gain. Birth weight also impacts composition, feed intake, and efficiency of commercial market hogs; however, much of this appears to be due to the association between birth weight and gain. Heavier birth weight pigs are heavier at a given age which translates to increased muscling, fat, feed intake, and reduced gain to feed. If the difference in BW is accounted for many of these effects are no longer significant. When light birth weight pigs are given the extra days required to reach a predetermined final BW, their advantage in efficiency is lost and based on results of other studies may in fact become a disadvantage.

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Table 4.1. Descriptive statistics.

Item	Pens	Mean	Standard Dev.	Min	Max
Birth weight, kg					
Nursery	44	1.54	0.366	0.81	2.39
Finishing	88	1.54	0.366	0.80	2.47
Body weight, kg					
Weaning	44	5.93	0.87	4.23	7.82
Beginning of finishing	88	43.2	4.18	32.1	51.1
Off-test	88	115.2	8.88	94.0	133.4
Average daily gain, kg/d					
Nursery, days 1-42	44	0.44	0.05	0.32	0.55
Finishing, days 43-129	88	1.00	0.09	0.63	1.16
Overall, days 1-129	44	0.83	0.06	0.69	0.95
Average daily feed intake, kg/d					
Nursery, days 1-42	44	0.58	0.08	0.39	0.71
Finishing, days 43-129	88	2.20	0.22	1.66	2.61
Overall, days 1-129	44	1.67	0.16	1.34	2.00
Gain to feed					
Nursery, days 1-42	44	0.78	0.03	0.71	0.86
Finishing, days 43-129	88	0.46	0.03	0.34	0.51
Overall, days 1-129	44	0.50	0.01	0.47	0.53
Real-time ultrasound[1]					
Backfat 1, cm	88	1.17	0.16	0.88	1.65
Backfat 2, cm	88	1.46	0.18	1.09	2.05
Backfat 3, cm	88	1.92	0.28	1.38	2.43
Longissimus muscle area 1, cm^2	88	26.91	2.36	22.19	33.22
Longissimus muscle area 2, cm^2	88	33.23	2.45	27.95	38.78
Longissimus muscle area 3, cm^2	88	42.13	2.86	35.79	49.96
Fat free lean, %[1]					
Measurement 1	88	0.40	0.01	0.37	0.44
Measurement 2	88	0.40	0.01	0.36	0.42
Measurement 3	88	0.39	0.01	0.35	0.42
Lean gain day 84-129, kg/d	85	0.40	0.03	0.34	0.46
Lean gain to feed day 84-129	85	0.15	0.01	0.13	0.18

[1]Backfat and longissimus muscle area were individually adjusted prior to analysis to a constant age of 105, 115, and 150 d for measurement 1, 2, and 3, respectively. Fat free lean values were individually calculated with unadjusted backfat and longissimus muscle area real-time ultrasound measurements collected at the 10th rib.

Table 4.2. Impact of birth weight on average daily gain, average daily feed intake, gain to feed, real-time ultrasound backfat and longissimus muscle area, and fat free lean due to a 1 kg increase in birth weight.

			Birth Weight					
Item	Intercept	SE	Linear	SE	Quadratic	SE	Sex	SE
Body weight								
Weaning	2.60[a]	0.24	2.16[a]	0.15	-0.03	0.33	0.07	0.11
Beginning of finishing	22.94[a]	4.23	16.28[a]	4.92	-2.43[c]	1.39	0.45	0.59
Off-test	67.22[a]	7.30	37.74[a]	8.44	-6.81[a]	2.39	9.32[a]	1.01
Average daily gain, kg/d								
Nursery, days 1-42	0.30[a]	0.03	0.10[a]	0.02	-0.05	0.04	0.01	0.01
Finishing, days 43-129	0.80[a]	0.03	0.10[a]	0.02	-0.07	0.04	0.10[a]	0.01
Overall, days 1-129	0.49[a]	0.07	0.30[a]	0.09	-0.07[a]	0.03	0.08[a]	0.01
Average daily feed intake, kg/d								
Nursery, days 1-42	0.34[a]	0.03	0.15[a]	0.02	-0.07	0.05	0.00	0.02
Finishing, days 43-129	1.02[a]	0.18	1.09[a]	0.23	-0.25[a]	0.07	0.29[a]	0.03
Overall, days 1-129	0.73[a]	0.17	0.87[a]	0.22	-0.20[a]	0.07	0.21[a]	0.02
Gain to feed								
Nursery, days 1-42	0.84[a]	0.02	-0.04[b]	0.02	0.02	0.04	0.00	0.00
Finishing, days 43-129	0.49[a]	0.01	-0.01[b]	0.01	0.02	0.02	-0.01[a]	0.01
Overall, days 1-129	0.57[a]	0.02	-0.08[a]	0.02	0.02[b]	0.01	-0.02[a]	0.00
Real-time ultrasound[1]								
Backfat 1, cm	0.98[a]	0.07	0.10[b]	0.04	-0.14	0.09	0.08[b]	0.03
Backfat 2, cm	1.27[a]	0.07	0.06	0.05	-0.05	0.10	0.20[a]	0.03
Backfat 3, cm	0.80[a]	0.30	1.14[a]	0.38	-0.33[a]	0.12	0.39[a]	0.04
Longissimus muscle area 1, cm^2	21.36[a]	0.91	3.60[a]	0.58	-1.29	1.20	-0.39	0.42
Longissimus muscle area 2, cm^2	26.80[a]	0.90	4.18[a]	0.56	-0.94	1.18	-0.42	0.41
Longissimus muscle area 3, cm^2	36.20[a]	1.16	3.84[a]	0.74	-1.65	1.53	-0.59	0.54
Fat free lean, %[1]								
Measurement 1	0.41[a]	0.01	0.00	0.00	0.01	0.01	-0.02[a]	0.00
Measurement 2	0.40[a]	0.01	0.00	0.00	0.01	0.01	-0.02[a]	0.00
Measurement 3	0.43[a]	0.01	-0.04[b]	0.02	0.01[b]	0.01	-0.02[a]	0.00
Lean gain, kg/d								
Day 84-129	0.34[a]	0.01	0.03[a]	0.01	-0.02	0.01	0.02[a]	0.01
Lean gain to feed								
Day 84-129	0.20[a]	0.01	-0.05[a]	0.02	0.01[b]	0.01	-0.02	0.00

[a]$P < 0.01$
[b]$P < 0.05$
[c]$P < 0.10$

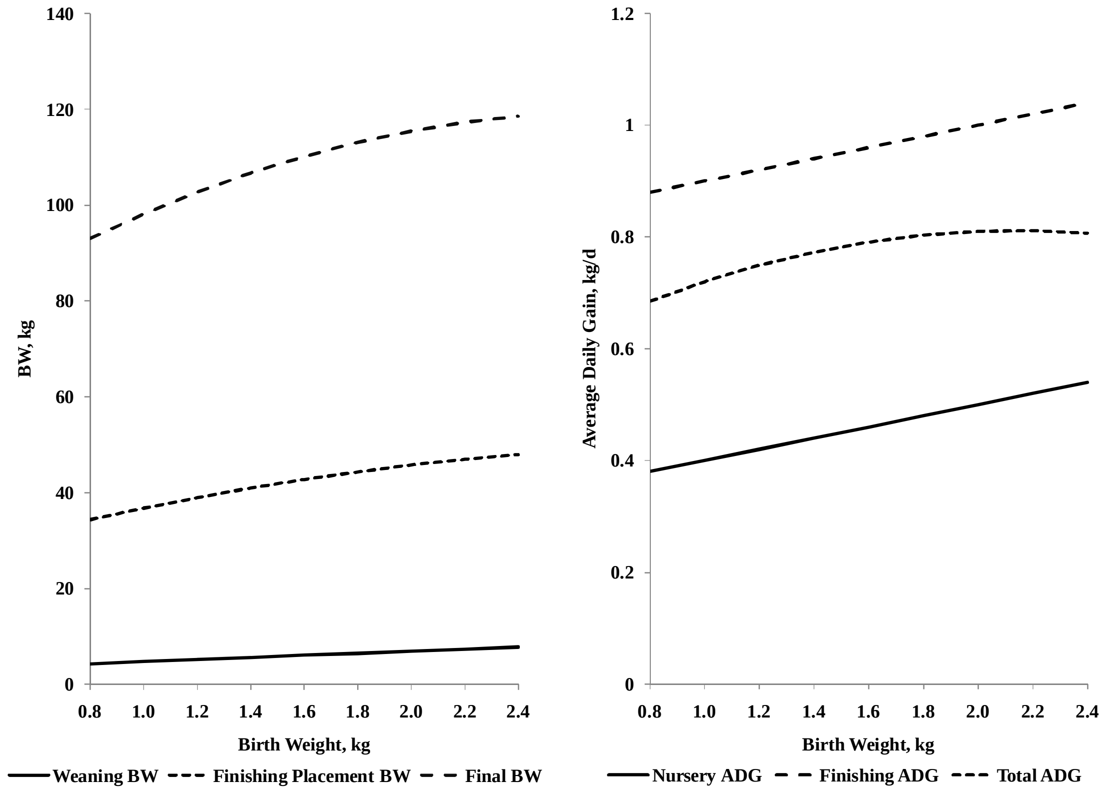

Figure. 4.1. Effect of birth weight on body weights and average daily gain.

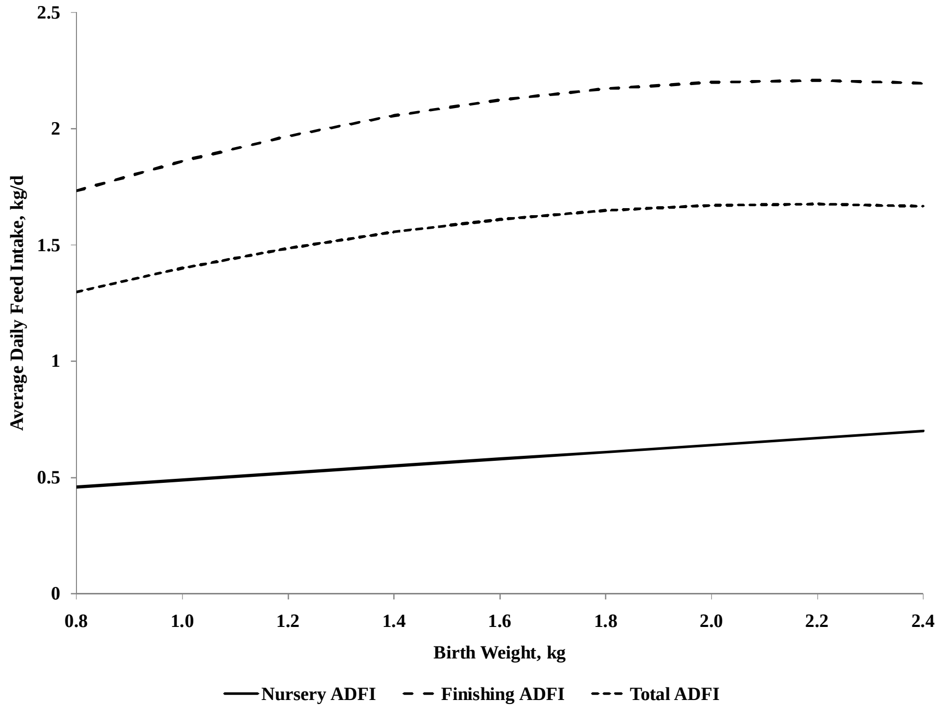

Figure. 4.2. Effect of birth weight on average daily feed intake.

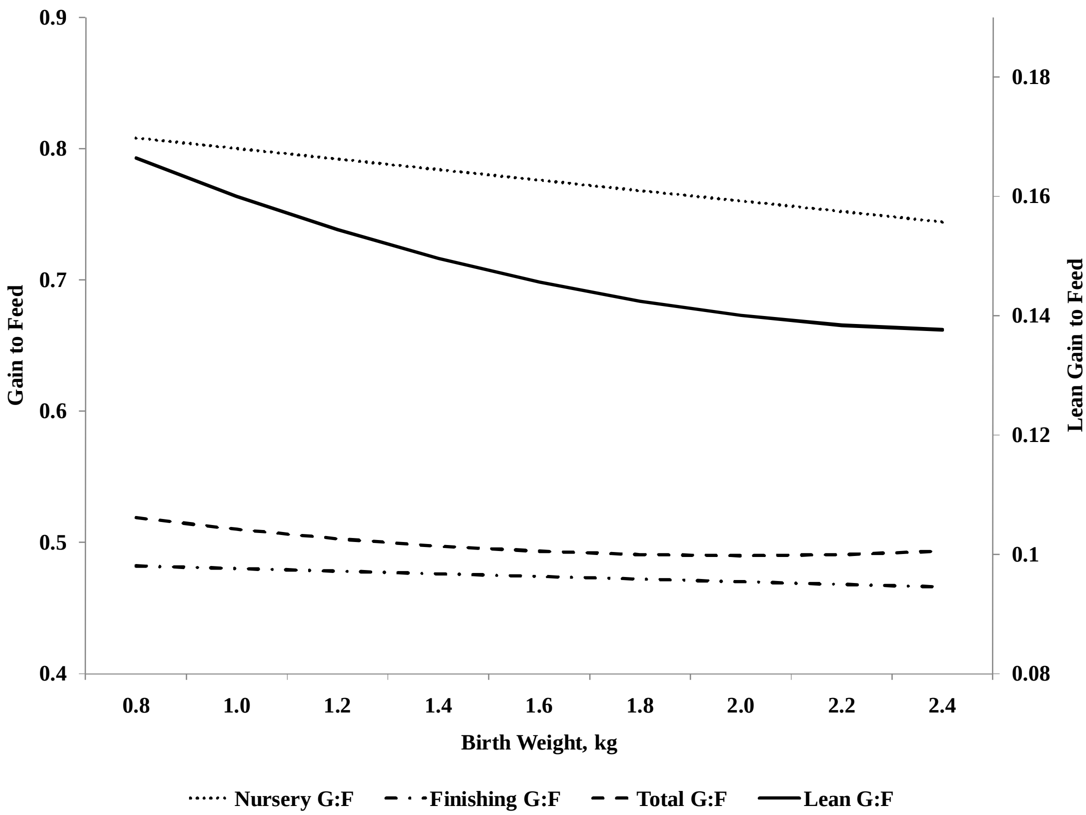

Figure. 4.3. Impact of birth weight on gain to feed and lean gain to feed.

Chapter 5: Genetic Relationship between Individual Piglet Birth Weight and Performance Traits.

ABSTRACT: The objective of this study was to estimate the heritability of birth weight and its genetic relationship with economically important performance traits in two U.S. swine populations. Data from Large White (LW) and Landrace (LR) populations for birth weight (127,188; 93,273), weaning weight (105,760; 78,131), off-test BW (45,278; 42,407), ADFI (2,959; 1,914) backfat depth (26,842; 25,858) and LM depth (26,789; 25,840) data were provided by Smithfield Premium Genetics and used to estimate (co)variances. Breed specific 6 trait models with birth dam maternal effects were used. Analyses were conducted using GIBBS2F90 and POSTGIBBSF90 with 100,000 cycles, burn-in period of 20,000 and every 20th sample stored thereafter. Direct heritability estimates (Large White, Landrace): birth weight (0.06, 0.06), weaning weight (0.11, 0.08), off-test weight (0.25, 0.29), backfat depth (0.52, 0.45), LM depth (0.33, 0.25), and ADFI (0.30, 0.31). Maternal heritability estimates (Large White, Landrace): birth weight (0.12, 0.11), weaning weight (0.10, 0.08), off-test weight (0.09, 0.09), backfat depth (0.08, 0.08), LM depth (0.07, 0.07), and ADFI (0.17, 0.16). Direct genetic correlations (LW, LR) between birth weight and weaning weight, off-test weight, backfat depth, LM depth, and ADFI: (0.54, 0.54), (0.48, 0.55), (-0.23, -0.16), (-0.19, -0.01) and (0.11, 0.24), respectively. Based on the low estimates for direct heritability, regardless of breed, response to direct selection to change birth weight would be slow; however, given the moderate to high genetic correlations between birth weight and BW at weaning and off-test, an opportunity exists to increase birth weight through indirect selection for increased BW at later points in life.

Key Words: Pigs, genetic parameters, birth weight, performance

Introduction

In the U.S. swine industry there is strong desire to reduce variation at finishing barn closeout, or more specifically to reduce or eliminate the number of light weight pigs. Phenotypic studies have reported associations between birth weight and BW at or near the time of harvest (Quiniou et al., 2002; Fix et al., 2010a; Schinckel et al., 2010). Fix et al. (2010b) estimated effects of birth weight on the likelihood of pigs reaching full value; a combination of adequate growth, survival, and pig quality. In each study, increased birth weight was associated with the favorable outcome. Unlike BW, associations between birth weight and other economically important traits are not consistent in direction or significance across experimental designs; birth weight has been shown to impact muscling (Nissen et al., 2004; and Rehfeldt et al., 2008; Fix et al., 2010a), leanness (Poore and Fowden, 2004; Gondret et al., 2006 Schinckel et al., 2010), and feed intake (Wolter et al., 2002; Bérard et al., 2008).

Due to these known phenotypic effects of birth weight on economically important traits, it is important to estimate the genetic relationships amongst birth weight and these traits to determine the potential for selection to eliminate or reduce the incidence of low birth weight pigs. Other studies have estimated heritabilities for individual birth weight but few have estimated genetic correlations with traits beyond individual weaning weight. Direct heritability estimates for birth weight across breeds and studies have been similar, < 0.10 (Roehe et al., 1999; Kaufmann et al., 2000; Knol et al., 2002) except for 0.16 reported by

Kerr and Cameron (1996); maternal heritability for birth weight in these studies was higher, near 0.20. One study, reported a much higher, 0.36, direct heritability for individual birth weight (Roehe et al., 2009); however, that study utilized outdoor production while the others were some form of conventional swine production. Another study using a portion of the data set utilized herein, reported direct heritabilities between 0.03 and 0.06 (Arango et al., 2006).

Several studies have estimated the genetic relationship between birth weight and pre-weaning survival (Arango et al., 2006; Roehe et al., 2009); however, to the authors' knowledge only a few studies have estimated genetic correlations between individual birth weight and BW later in life. Kerr and Cameron (1996) and Kaufmann et al. (2000) reported moderate to strong (0.67 and 0.59, respectively) positive and favorable genetic correlation between BW at birth and weaning. To the authors' knowledge there are no published estimates of genetic correlations between birth weight and performance traits after weaning.

Therefore, the objective of this study was to estimate the heritability of birth weight and its genetic relationship with economically important performance traits in two U.S. swine populations.

Materials and Methods

Data

Both Large White and Landrace datasets were provided by Smithfield Premium Genetics Group (Rose Hill, NC) from five nucleus farms located in North Carolina and Texas. During farrowing, nursery, and finishing phases all pigs were housed in confinement facilities typical of U.S. swine production and management followed standard U.S. protocol.

All live born pigs were individually weighed and identified within 24 h of birth. Cross-fostering (12.6%) to balance number of pigs nursed was completed within 24 h of birth; nurse dam was recorded if piglets were fostered. All male pigs used in the analysis were left intact. Individual BW was recorded on all live pigs at weaning (Large White: 21.5 ± 2.7 d; Landrace: 21.8 ± 2.8 d). A select number of pigs were tracked through conclusion of a finishing phase. At the end of the test period (Large White: 172.8 ± 4.5 d; Landrace: 171.5 ± 4.6 d) pigs were individually weighed and real-time ultrasound backfat and LM depth were measured at the 10th rib. A portion of the male pigs had ADFI intake recorded during the final stages of the testing period using FIRE® feeding system.

Data was available from 128,074 Large White (63,460 females and 64,614 males) and 93,732 Landrace (46,278 males and 47,454 females) pigs. The numbers of animals with observations for a given trait are presented in Table 5.1.

Statistical Analysis

Prior to genetic analysis, inclusion of fixed effects and covariates (linear and quadratic) was determined using the Mixed procedure of SAS (SAS Institute Inc., Cary, NC). For these analyses, single trait models within breed were utilized; effects were used in the genetic analysis if $P < 0.05$. Also, to determine which random litter effect (birth or nurse) to include for each trait, model comparisons were completed using AIC and BIC fit statistics.

Variance component estimation was completed using breed specific 6 trait animal models with maternal effects of the birth dam. Effects included in the final model for each breed are presented in Tables 5.2 and 5.3 for Large White and Landrace, respectively.

Estimation of variance components was accomplished using GIBBS2F90 (Misztal et al., 2002). A single chain of 100,000 cycles with a burn in period of 20,000 was used. Every 20th sample was stored and for Post-Gibbs analysis using POSTGIBBSF90 (Misztal et al., 2002). Estimates for fixed effects generated from GIBBS2F90 are provided in Tables 5.4 and 5.5.

Results and Discussion

Variance and covariance estimates are presented in Tables 5.6 and 5.7 for Large White and Landrace, respectively. Tables 5.8 and 5.9 contain the variances of the estimated (co)variances provided in Tables 5.6 and 5.7. Heritabilities (diagonal) and genetic correlations (off-diagonal) are provided in Tables 5.10 and 5.11.

Direct Heritability

While not the focus of the study herein, heritability estimates of the performance traits were in agreement with other studies. Specifically, Stewart and Schinckel (1991), calculated weighted averages for growth (days to 230; 0.25), backfat (0.41 and 0.52), muscling (longissimus muscle area; 0.47) and average daily feed intake (0.24). Traits were not measured exactly the same across studies; however, traits that measured similar biological factors were in agreement for heritability estimates. Similar to birth weight, weaning weight heritability estimates are limited; however, two studies Kerr and Cameron (1995) and Kaufman et al. (2000) both reported estimates of 0.08 which are in agreement with results of the present study.

Direct heritability estimates for individual birth weight were low regardless of breed. In general these estimates were in agreement with published reports (Roehe et al., 1999; Kaufmann et al., 2000; Cassady et al., 2002; Knol et al., 2002). In all of these studies estimates were less than 0.10. Rosendo et al. (2007) estimated direct heritability to be, 0.10 which would still be considered lowly heritable. One study, Kerr and Cameron (1996), did report a slightly higher heritability, 0.16, but this still could be classified as lowly heritable. Arango et al. (2006) used a smaller portion of this dataset and focused on pre-weaning survival but did publish similar estimated heritabilities (0.03-0.06) to those presented herein. Roehe et al. (2009) used a population of outdoor swine and reported a considerably higher estimate (0.36). The authors suggested a variety of reasons for their higher estimates of heritability in comparison to other published reports. One such explanation was the populations used had been selected for traits of interest or highly correlated traits, which may have led to increased direct additive variation. However, another possibility may be the crossbred populations used therein; the increased variation due to additive effects could be the result of the crossbreeding.

Maternal Heritability

The proportion of phenotypic variation accounted for by the maternal effect was similar across breeds with respect to each trait. Also, as would be expected for traits other than average daily feed intake, the maternal variation was proportionately less than birth weight. Which would be expected for traits measured later in life compared to early life measures.

For the study herein, the only maternal effect of concern was that for birth weight; estimates of maternal heritability for individual birth weight were slightly higher (0.11 and 0.12) than estimates for direct heritability, which is in agreement with other studies. However, other than Arango et al. (2006), 0.14-0.19, and Rosendo et al. (2007), 0.17, reported maternal heritabilities were > 0.20 (Kaufman et al., 1995; Roehe, 1999; Knol et al., 2002; Roehe et al., 2009). As previously mentioned Arango et al., (2006) included a portion of the data used herein, the closer proximity of those results with the current study was understandable. Despite minor differences in values, the proportion of phenotypic variation explained by the maternal effect was, in general, similar across all studies. Similarly, maternal effects accounting for a greater portion of phenotypic variation than the direct effects was in agreement across studies, which included a maternal effect in the model.

Genetic Correlations

To the author's knowledge, genetic correlations between birth weight and future growth and grow-finish performance traits are limited to estimates with weaning weight in a limited number of studies. Kerr and Cameron (1995) and Kaufmann et al. (2000) both reported moderate, positive, favorable estimates of genetic correlations between birth weight and weaning weight; 0.59 and 0.46, respectively. These estimates are similar to those reported herein. Genetic correlations between birth weight and BW or growth beyond weaning are unknown; however, the similarity between birth weight and weaning with birth weight and off-test weight genetic correlations estimated is not unexpected. While estimates of genetic correlations are limited, these results are similar to phenotypic associations, between increased birth weight and increased BW later in life, reported in various studies (Quiniou et al., 2002; Fix et al. 2010a; Schinckel et al., 2010).

Studies estimating genetic correlations between birth weight and composition, more specifically real-time ultrasound backfat and loin depth are unknown to the authors. However, phenotypic studies estimating associations are available. Specifically, when backfat and muscling, loin depth or area, are measured at a constant weight or adjusted to a constant weight comparable to the methods here, reported phenotypic associations are in similar directions to the genetic correlations reported. Specifically, Poore and Fowden (2004), Gondret et al. (2006), and Schinckel et al. (2010) all reported increased backfat in lighter birth weight pigs when measured at or adjusted to a common BW. This is in agreement with the negative genetic correlations between birth weight and backfat depth estimated for the present study. Genetic correlations between birth weight and loin depth were somewhat different between the Large White and Landrace populations in the current study. Estimates for Landrace were nearly 0, which is similar to the phenotypic associations or lack of reported in Powell and Aberle (1980) and Bérard et al. (2008). However, negative genetic correlations estimated for the Large White population are surprising and difficult to explain.

Estimates of genetic correlations between birth weight and ADFI are limited; however, based on genetic correlations between birth weight and off-test BW provided herein, the positive genetic correlation between birth weight and ADFI was not unexpected. In a review by Stewart and Schinckel (1991) average daily gain and ADFI were strongly and positively correlated. Consequently, it is likely the genetic correlation between birth weight and off-test weight that is the cause of the genetic correlation between birth weight and ADFI. Heavier birth weight pigs are genetically heavier at off-test which contributes to the positive genetic correlation with ADFI.

Genetic Correlations: Direct and Maternal Effects for Birth Weight

Interest in estimated genetic correlations between direct and maternal effects was limited to birth weight for the current study. However, similar genetic correlations between direct and maternal effects within trait were estimated across traits and populations. While not the same values, estimates herein were similar across populations; low and negative. These findings are in agreement with other published reports (Roehe, 1999; Rosendo et al., 2007; Roehe et al., 2009). Robinson (1996) suggested estimates of negative genetic correlations between maternal and direct effects may be biased in the presence of environmental correlations between direct and maternal effects or genotype by environment interactions. The authors indicated these potential biasing factors for field datasets such as those used herein. Contradicting data to the negative correlations reported in other studies was published by Kaufman et al. (2000); in that study estimates of genetic correlation were positive, 0.10, but low. The moderate to strong and negative genetic correlations consistently estimated herein do coincide with the majority of other published estimates; however, antagonistic genetic effects might be the underlying cause, estimates are population dependent and could be overestimated.

Conclusion

In agreement with other studies, individual birth weight is heritable; however, lowly and therefore potential for genetic selection is likely nominal. Based on the higher maternal heritability compared to direct heritability, it appears the genetic aspects of the uterine environment (nutrition, space, etc.) contribute a larger portion of the phenotypic variation than the fetus' or individual pig's contribution. Consequently, potential for genetic selection for an individual's increased birth weight due their genetic merit is minimal. Even so, there is still potential, if desired, to impact individual birth weight through direct selection.

Impacting birth weight through indirect selection is also possible. Based on estimated genetic correlations, selection for increased BW measured later in life should lead to heavier birth weights. In addition, selection for reduced backfat would also result in increased birth weight. Backfat and BW or some measures of growth are common selection criteria, particularly in terminal lines.

Even with the potential for direct or indirect genetic selection to reduce or eliminate the incidence of low birth weight pigs, it appears the issue cannot be solved by selection alone, at least in a short time period. Potential for an increased incidence of light birth weight pigs with continued emphasis on litter size needs to be considered within selection programs. Furthermore, post farrowing management decisions must be considered and further examined to assist in reducing the economic impact of these light birth weight pigs on a production system.

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Table 5.1. Number of observations for each trait within the respective breed.

Traits	Large White	Landrace
Birth Weight	127,188	93,273
Weaning Weight	105,760	78,131
Off-test		
Weight	45,278	42,407
Backfat depth	26,842	25,858
Loin depth	26,789	25,840
ADFI	2,959	1,914

Table 5.2. Random, fixed and regression effects included in the model for each trait within the Large White.

	Traits					
Effects	BWT	WWT	OTWT	OTBF	OTLD	ADFI
Random						
Animal	X	X	X	X	X	X
Maternal-birth dam	X	X	X	X	X	X
Litter-birth	X					
Litter-nurse		X	X	X	X	X
Fixed						
Sex	X	X	X	X	X	
Farm	X	X	X	X	X	
Parity-birth dam	X	X	X			
Parity-nurse dam		X				
Cross foster status		X				
Farrowing group-month	X	X				
Off-test group			X	X	X	
ADFI contemporary group						X
Covariates						
Linear						
Number fully formed pigs	X	X	X			
Age at weaning		X				
Age at off-test			X			
BW at off-test				X	X	
Age at ADFI Off-test						X
Quadratic						
Number fully formed pigs	X	X				
Age at weaning		X				

BWT = individual BW at birth; WWT = individual BW at weaning; OTW = BW at off-test (172.8 ± 4.5 d); OTBF = real-time ultrasonic backfat depth at off-test; OTLD = real-time ultrasonic loin depth at off-test; ADFI = average daily feed intake.

Table 5.3. Random, fixed and regression effects included in the model for each trait within the Landrace.

	Traits					
Effects	BWT	WWT	OTWT	OTBF	OTLD	ADFI
Random						
Animal	X	X	X	X	X	X
Maternal-birth dam	X	X	X	X	X	X
Litter-birth	X					
Litter-nurse		X	X	X	X	X
Fixed						
Sex	X	X	X	X	X	
Farm	X	X	X	X	X	
Parity-birth dam	X	X	X		X	
Parity-nurse dam						
Cross foster status		X	X	X		
Farrowing group-month	X	X				
Off-test group			X	X	X	
ADFI contemporary group						X
Covariates						
Linear						
Number fully formed pigs	X	X	X			
Age at weaning		X	X		X	
Age at off-test			X			
BW at off-test				X	X	
Age at ADFI Off-test						X
Quadratic						
Number fully formed pigs	X	X				
Age at weaning		X				

BWT = individual BW at birth; WWT = individual BW at weaning; OTW = BW at off-test (171.5 ± 4.6 d); OTBF = real-time ultrasonic backfat depth at off-test; OTLD = real-time ultrasonic loin depth at off-test; ADFI = average daily feed intake.

Table 5.4. Estimates of fixed effects for Large White from GIBBS2F90.

	Traits					
Effects	BWT	WWT	OTWT	OTBF	OTLD	ADFI
Fixed						
Sex						
Male	2.02	7.95	38.69	-0.48	0.83	-
Female	1.96	7.71	34.13	-0.38	0.97	-
Cross foster status						
Fostered	-	-0.24	-	-	-	-
Non-fostered	-	0.24	-	-	-	-
Covariates						
Linear						
Number fully formed pigs	-0.03	-0.09	-0.42	-	-	-
Age at weaning	-	-0.10	-	-	-	-
Age at off-test	-	-	-0.34	-	-	-
BW at off-test	-	-	-	0.02	0.02	-
Age at ADFI Off-test	-	-	-	-	-	0.000
Quadratic						
Number fully formed pigs	0.000	0.0005	-	-	-	-
Age at weaning	-	0.0005	-	-	-	-

BWT (kg) = individual BW at birth; WWT (kg) = individual BW at weaning; OTW (kg) = BW at off-test (172.8 ± 4.5 d); OTBF (cm) = real-time ultrasonic backfat depth at off-test; OTLD (cm) = real-time ultrasonic loin depth at off-test; ADFI (kg/d) = average daily feed intake.

Table 5.5. Estimates of fixed effects for Landrace from GIBBS2F90.

	Traits					
Effects	BWT	WWT	OTWT	OTBF	OTLD	ADFI
Fixed						
Sex						
Male	2.06	4.76	31.37	-0.29	1.74	-
Female	2.00	4.46	25.00	-0.22	1.79	-
Cross foster status						
Fostered	-	0.23	-8.80	-0.36	-	-
Non-fostered	-	0.79	-7.11	-0.36	-	-
Covariates						
Linear						
Number fully formed pigs	-0.03	-0.08	-0.46	-	-	-
Age at weaning	-	-0.08	0.11	-	0.02	-
Age at off-test	-	-	0.60	-	-	-
BW at off-test	-	-	-	0.01	0.01	-
Age at ADFI Off-test	-	-	-	-	-	0.000
Quadratic						
Number fully formed pigs	0.000	-0.0005	-	-	-	-
Age at weaning	-	0.0036	-	-	-	-

BWT (kg) = individual BW at birth; WWT (kg) = individual BW at weaning; OTW (kg) = BW at off-test (171.5 ± 4.6 d); OTBF (cm) = real-time ultrasonic backfat depth at off-test; OTLD (cm) = real-time ultrasonic loin depth at off-test; ADFI (kg/d) = average daily feed intake.

Table 5.6. Genetic variance (diagonal) and covariance (off diagonal) estimates for Large White.

	Direct						Maternal					
	BWT	WWT	OTW	OTBF	OTLD	ADFI	BWT	WWT	OTW	OTBF	OTLD	ADFI
BWT	0.007	0.022	0.253	-0.006	-0.005	0.002	-0.003	-0.004	-0.153	0.002	0.005	0.000
WWT		0.223	1.630	-0.033	-0.051	0.063	-0.006	-0.108	-0.741	0.017	0.035	-0.039
OTW			40.035	0.076	-0.070	1.117	0.027	-0.628	-11.834	0.031	-0.043	-0.387
OTBF				0.077	-0.013	0.012	0.001	0.010	-0.016	-0.019	0.000	0.002
OTLD					0.097	-0.015	0.001	0.023	0.071	0.000	-0.026	0.012
ADFI						0.067	-0.002	-0.047	-0.524	0.001	0.005	-0.038
BWT							0.014	0.035	0.235	-0.003	-0.005	0.003
WWT								0.204	1.032	-0.014	-0.023	0.048
OTW									13.857	-0.066	-0.078	0.500
OTBF										0.013	0.000	-0.002
OTLD											0.019	-0.006
ADFI												0.038

BWT = individual BW at birth; WWT = individual BW at weaning; OTW = BW at off-test (172.8 ± 4.5 d); OTBF = real-time ultrasonic backfat depth at off-test; OTLD = real-time ultrasonic loin depth at off-test; ADFI = average daily feed intake.

Table 5.7. Genetic variance (diagonal) and covariance (off diagonal) estimates for Landrace.

	Direct						Maternal					
	BWT	WWT	OTW	OTBF	OTLD	ADFI	BWT	WWT	OTW	OTBF	OTLD	ADFI
BWT	0.031	0.085	1.381	-0.003	0.000	0.022	-0.008	-0.028	-0.733	0.001	0.000	-0.024
WWT		0.802	6.262	0.002	-0.019	-0.016	-0.014	-0.288	-3.258	-0.001	0.002	-0.052
OTW			204.380	0.242	-0.099	3.776	-0.328	-2.383	-56.665	0.036	0.012	-0.524
OTBF				0.009	-0.003	0.004	0.003	-0.003	0.091	-0.002	0.001	0.009
OTLD					0.010	-0.010	-0.006	-0.009	-0.042	0.001	-0.003	-0.004
ADFI						0.267	-0.003	0.044	-0.154	0.002	0.005	-0.101
BWT							0.058	0.157	1.289	-0.003	0.002	0.031
WWT								0.876	5.286	-0.003	0.004	0.106
OTW									66.051	-0.056	0.047	1.057
OTBF										0.002	0.000	-0.003
OTLD											0.003	-0.003
ADFI												0.140

BWT = individual BW at birth; WWT = individual BW at weaning; OTW = BW at off-test (171.5 ± 4.6 d); OTBF = real-time ultrasonic backfat depth at off-test; OTLD = real-time ultrasonic loin depth at off-test; ADFI = average daily feed intake.

Table 5.8. Standard deviations of genetic variance (diagonal) and covariance (off diagonal) estimates for Large White.

	Direct						Maternal					
	BWT	WWT	OTW	OTBF	OTLD	ADFI	BWT	WWT	OTW	OTBF	OTLD	ADFI
BWT	0.001	0.003	0.031	0.001	0.002	0.003	0.001	0.003	0.024	0.001	0.001	0.003
WWT		0.024	0.175	0.009	0.012	0.013	0.004	0.020	0.131	0.006	0.007	0.012
OTW			2.745	0.085	0.118	0.195	0.046	0.155	1.463	0.059	0.082	0.143
OTBF				0.006	0.006	0.005	0.002	0.007	0.063	0.000	0.000	0.005
OTLD					0.006	0.012	0.002	0.010	0.097	0.006	0.006	0.007
ADFI						0.017	0.003	0.012	0.095	0.002	0.007	0.010
BWT							0.001	0.003	0.028	0.001	0.001	0.002
WWT								0.016	0.107	0.003	0.006	0.009
OTW									1.356	0.039	0.050	0.076
OTBF										0.000	0.000	0.002
OTLD											0.006	0.005
ADFI												0.006

BWT = individual BW at birth; WWT = individual BW at weaning; OTW = BW at off-test (172.8 ± 4.5 d); OTBF = real-time ultrasonic backfat depth at off-test; OTLD = real-time ultrasonic loin depth at off-test; ADFI = average daily feed intake.

Table 5.9. Standard deviations of genetic variance (diagonal) and covariance (off diagonal) estimates for Landrace.

	Direct						Maternal					
	BWT	WWT	OTW	OTBF	OTLD	ADFI	BWT	WWT	OTW	OTBF	OTLD	ADFI
BWT	0.001	0.004	0.043	0.001	0.002	0.002	0.001	0.003	0.028	0.001	0.001	0.002
WWT		0.021	0.179	0.008	0.008	0.018	0.004	0.015	0.157	0.005	0.008	0.017
OTW			2.997	0.079	0.120	0.282	0.043	0.173	1.690	0.055	0.094	0.179
OTBF				0.006	0.006	0.006	0.002	0.006	0.048	0.000	0.000	0.006
OTLD					0.006	0.007	0.002	0.008	0.082	0.000	0.006	0.006
ADFI						0.014	0.003	0.017	0.189	0.003	0.006	0.009
BWT							0.001	0.003	0.027	0.001	0.001	0.002
WWT								0.015	0.126	0.003	0.006	0.011
OTW									1.322	0.028	0.055	0.094
OTBF										0.006	0.000	0.002
OTLD											0.006	0.003
ADFI												0.006

BWT = individual BW at birth; WWT = individual BW at weaning; OTW = BW at off-test (171.5 ± 4.6 d); OTBF = real-time ultrasonic backfat depth at off-test; OTLD = real-time ultrasonic loin depth at off-test; ADFI = average daily feed intake.

Table 5.10. Heritability (diagonal) and genetic correlations (off diagonal) for Large White.

	Direct						Maternal					
	BWT	WWT	OTW	OTBF	OTLD	ADFI	BWT	WWT	OTW	OTBF	OTLD	ADFI
BWT	0.064	0.544	0.477	-0.235	-0.188	0.107	-0.296	-0.098	-0.491	0.280	0.328	-0.024
WWT		0.105	0.545	-0.259	-0.342	0.516	-0.104	-0.504	-0.421	0.346	0.500	-0.427
OTW			0.248	0.044	-0.036	0.681	0.036	-0.219	-0.502	0.045	-0.047	-0.315
OTBF				0.524	-0.156	0.166	0.031	0.084	-0.016	-0.587	-0.013	0.038
OTLD					0.329	-0.190	0.036	0.160	0.061	-0.015	-0.597	0.196
ADFI						0.296	-0.063	-0.402	-0.544	0.028	0.133	-0.752
BWT							0.124	0.663	0.543	-0.247	-0.251	0.139
WWT								0.096	0.613	-0.275	-0.340	0.542
OTW									0.086	-0.162	-0.144	0.692
OTBF										0.081	0.116	-0.124
OTLD											0.072	-0.201
ADFI												0.166

BWT = individual BW at birth; WWT = individual BW at weaning; OTW = BW at off-test (172.8 ± 4.5 d); OTBF = real-time ultrasonic backfat depth at off-test; OTLD = real-time ultrasonic loin depth at off-test; ADFI = average daily feed intake.

Table 5.11. Heritability (diagonal) and genetic correlations (off diagonal) for Landrace.

	Direct						Maternal					
	BWT	WWT	OTW	OTBF	OTLD	ADFI	BWT	WWT	OTW	OTBF	OTLD	ADFI
BWT	0.061	0.539	0.546	-0.162	-0.012	0.236	-0.186	-0.170	-0.509	0.135	0.015	-0.369
WWT		0.075	0.489	0.028	-0.204	-0.035	-0.063	-0.344	-0.448	-0.019	0.035	-0.154
OTW			0.292	0.182	-0.068	0.511	-0.096	-0.178	-0.488	0.064	0.016	-0.098
OTBF				0.445	-0.263	0.085	0.127	-0.029	0.120	-0.637	0.106	0.269
OTLD					0.250	-0.187	-0.258	-0.099	-0.050	0.164	-0.486	-0.097
ADFI						0.310	-0.022	0.090	-0.037	0.088	0.188	-0.522
BWT							0.112	0.695	0.660	-0.278	0.142	0.340
WWT								0.082	0.695	-0.089	0.081	0.302
OTW									0.094	-0.176	0.105	0.347
OTBF										0.077	-0.206	-0.225
OTLD											0.075	-0.129
ADFI												0.162

BWT = individual BW at birth; WWT = individual BW at weaning; OTW = BW at off-test (171.5 ± 4.6 d); OTBF = real-time ultrasonic backfat depth at off-test; OTLD = real-time ultrasonic loin depth at off-test; ADFI = average daily feed intake.

Chapter 6: Determining the Economic Impact of Piglet Birth Weight on a U. S. Commercial Swine Production System.

Introduction

For swine producers to regain and maintain profitability into the future, a continued emphasis must be placed on the improved efficiency of their entire production system. Consequently, all aspects of production need to be evaluated for potential improvements to augment efficiency. One potential area to focus on in terms of its economic impact on production is piglet birth weight. A number of studies have reported associations between birth weight and economically important traits such as growth (Quiniou et al., 2002; Fix et al., 2010a; Schinckel et al., 2010), efficiency (Fix et al., 2010c; Schinckel et al., 2010), and survival (Quiniou et al., 2002; Fix et al., 2010b). While it is evident from the results published therein on associations between birth weight and production traits, economic impacts were not discussed; however, based on the roles those traits play in profitability, economic impact is likely considerable. The objective of this work was to create a spreadsheet which takes into account the effects of birth weight previously discussed to determine potential culling levels based on birth weight, and to improve profitability of swine production companies. The methodology and parameters behind the creation of the spreadsheet will be described herein.

Materials and Methods

Prior to any design of the spreadsheet, data must be collected to determine associations between birth weight and traits of interest, mainly growth and mortality.

Data Used

Data used for the foundation of the growth and survival information used in our spreadsheet were published in Fix et al. (2010a and 2010b). More details are provided therein; however, a brief summary of the data collection follows. Data were collected on all live born pigs (n = 5,727) during a 4 week period at a commercial sow farm. Pigs were farrowed from Large White x Landrace sows bred to Duroc boars. Pigs were weaned weekly (n = 4) and transferred to a separate site nursery for 7 weeks and then to a third site for finishing. Pigs were kept in discrete groups after weaning. All 4 groups were tracked through finishing placement. Only weaned groups 2 and 3 were followed during finishing. Individual morality was recorded throughout and individual BW was measured 2 days prior to weaning (n = 4,108; 18.7 ± 2.1 days of age), within 5 days of finishing placement (n = 3,435; 74.8 ± 1.9 days of age), and 16 weeks into finishing (n = 1,586; 172.8 ± 1.8 days of age). To estimate any associations between birth weight and efficiency, a similar protocol was followed prior to weaning for a second study, Fix et al. (2010c). However, fewer pigs were used and at weaning 440 pigs were transferred to the North Carolina Swine Evaluation Station (Clayton, NC) where pen feed intake could be collected. In that trial, pigs were penned by birth weight for a nursery (10 pigs/pen) and finishing (5 pigs/pen).

In Fix et al. (2010a and 2010b) nonlinear associations between birth weight and BW (weaning, finishing placement, and 16 weeks into finishing) and mortality (pre-weaning and nursery) were estimated. Strictly based on those 2 relationships the potential economic value of a pig greatly differs due to birth weight. In Fix et al. (2010c), when pigs are harvested at a constant age, any efficiency differences are due to differences in the location of pigs on the growth curve. Lighter birth weight pigs were more efficient due to being lighter BW at the conclusion of finishing. Therefore, an assumption made for the creation of our spreadsheet, was efficiency did not differ between pigs of varying birth weights.

Objectives of the Spreadsheet

The basis for the creation of a spreadsheet was to determine if a culling level exists for birth weight, which would increase the profitability of the production system through the immediate removal of light birth weight pigs. To determine such a threshold does exist three main factors must be considered: differences in expected revenue due to birth weight, differences in variable costs incurred due to birth weight, and effect of removing pigs on performance of the remaining cohorts.

Curves developed in Fix et al. (2010ab) with respect to growth and mortality may be used to estimate expected revenue for a pig with a given birth weight. Similarly, these curves can be used to predict the costs incurred. Finally, removing light birth weight pigs from the system reduces pig density and Gonyou and Stricklin (1998) discussed the association between reduced pen density and increased growth performance. The combination of these three factors forms the basis for a spreadsheet estimating the impact of removing light birth weight pigs on profit.

Economic Inputs

When implementing economic values, careful consideration should be paid not only to which factors to include, but also their respective values. Production systems vary considerably but there are three common time points for ownership of the pigs to change, weaning, after a nursery phase (feeder pigs), or conclusion of finishing (top hogs). Most commonly pigs are either sold as weaned pigs or kept and sold as market hogs; however, all three will be considered herein. Similarly, costs incurred and impact on production should be separated into pre-weaning, nursery, and finishing phases.

Revenues. Calculating the expected revenues for a given birth weight for each potential change of ownership point is a straightforward formula. Weaned pig prices and feeder pig prices are often quoted on a per head basis; therefore, calculation of differences in potential revenue at those two time points is the probability of survival till the specified time point multiplied by the price per pig. Per head prices are often adjusted for the average weight or quality of the pigs; however, for ease of depiction, revenue was estimated using an "average" pig. To calculate the potential revenue for a finished hog, survival, likelihood of being a cull, and BW are used to determine a weighted average of the revenue expected for each birth weight.

Costs. Costs associated with a production system during each phase are likely more firm specific than the revenues. However, due to the increase in mortality, increased likelihood of being a cull pig, and reduced end BW associated with light birth weight pigs, previously described, a greater portion of light birth weight pigs receive no revenue or greatly reduced revenue while incurring a portion or all of the costs. Removing, light birth weight pigs would lead to a reduction in the number of pigs fitting that description. Costs, in the spreadsheet include: vaccines/medical, labor, feed, transportation, etc. Again, costs are separated into phases of pre-weaning, nursery, and finishing.

Production Parameters

Estimates for the impact of a reduction in number of pigs nursed are not available, such as those provided in Gonyou and Stricklin (1998) for the grow-finish period. Still the spreadsheet allows for increased growth due to reduced pen density during all three phases but as suggested in Gonyou and Stricklin (1998) there is a level where more space does not result in any further increase in growth; therefore, a maximum level of response is an input allowed into the spreadsheet. Specifics for this maximum are likely system dependent. All of these considerations should be taken into account for spreadsheet design.

Results and Discussion

Inputs for the spreadsheet with respect to costs and impact of removing light birth weight pigs on the performance of remaining cohorts are tremendously specific to a production setting. Therefore, actual outcomes for culling decisions will not be discussed herein; however, for the revenue portion predictions are more robust and consequently potential outcomes will be summarized.

Outcomes

As previously described and discussed in detail in Fix et al. (2010b), birth weight is associated with pre-weaning and nursery survival. Tables 6.1, 6.2, and 6.3 provide comparisons of the expected revenue for pigs of various birth weights to a pig with a birth weight in close proximity to the mean (1.4 kg) at weaning, end of the nursery, and conclusion of finishing, respectively. In each instance, as the birth weight separates from the mean, the difference in revenue becomes greater. More specifically the lightest and heaviest birth weight pigs are expected to have the greatest deficit and surplus in expected revenue compared to a pig with an average birth weight. As market price increased differences in predicted value of pigs became greater. Based strictly on predicted growth and survival curves with respect to birth weight, there is considerable differences in the future value of pigs with different birth weights.

Spreadsheet Considerations

Removal of the lightest birth weight pigs on average is eliminating pigs from the system that create less value at each time point in consideration. Also, removing lower birth weight pigs would reduce future variable costs associated with leaving the pigs in production. Finally, improvement in the performance of remaining cohorts due to increased space; once again, this is dependent on management and not necessarily applicable in all situations. All of these are considered in the spreadsheet. As more pigs are culled, there are fewer pigs available to create revenue and each increase in birth weight for the thresholds is culling pigs which on average are of greater value. This must be combined with the reduction in future variable costs and improved gain of the remaining cohorts. The relationship between the decrease in revenue and the decrease in costs is what determines the culling level to be implemented. Again, this outcome is highly dependent on firm specific input.

Conclusion

Estimated future value is greatly reduced for pigs of lower birth weight. Outcomes for culling decisions will be highly specific for firms with respect to their inputs for survival and growth curves, costs, and effects of reduced density on performance. However, regardless of the situation there is potential for profits to be increased due to culling pigs with lower birth weights immediately. Rather than allowing them to continue into to production when their likelihood of being a full value at harvest is greatly reduced compared to their heavier cohorts.

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Table 6.1. Differences in predicted revenue ($) for weaned pigs of various birth weights, compared to an average birth weight pig (1.4 kg)[1].

	Price per Weaned Pig						
Birth weight, kg	$34.00	$36.00	$38.00	$40.00	$42.00	$44.00	$46.00
0.8	-$11.91	-$12.61	-$13.31	-$14.01	-$14.71	-$15.41	-$16.11
1.0	-$7.53	-$7.97	-$8.41	-$8.86	-$9.30	-$9.74	-$10.19
1.2	-$3.42	-$3.62	-$3.82	-$4.02	-$4.22	-$4.42	-$4.62
1.4	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
1.6	$2.56	$2.71	$2.86	$3.01	$3.16	$3.31	$3.46
1.8	$4.33	$4.59	$4.84	$5.10	$5.35	$5.61	$5.86
2.0	$5.50	$5.82	$6.14	$6.47	$6.79	$7.11	$7.44
2.2	$6.23	$6.60	$6.97	$7.33	$7.70	$8.07	$8.43
2.4	$6.69	$7.08	$7.47	$7.87	$8.26	$8.65	$9.05

[1] Formula used to calculate differences in predicted revenue = (Expected pre-weaning survival rate$_{(\text{Birth weight = i kg})}$ x Price per weaned pig) – (Expected pre-weaning survival rate$_{(\text{Birth weight = 1.4 kg})}$ x Price per weaned pig). See Table 3.1 for visual depiction of association between birth weight and pre-weaning survival rate.

Table 6.2. Differences in predicted revenue ($) for feeder pigs of various birth weights, compared to an average birth weight pig (1.4 kg)[1].

	Price per Feeder Pig						
Birth weight, kg	$64.00	$66.00	$68.00	$70.00	$72.00	$74.00	$76.00
0.8	-$22.17	-$22.86	-$23.55	-$24.24	-$24.94	-$25.63	-$26.32
1.0	-$14.42	-$14.87	-$15.32	-$15.77	-$16.22	-$16.67	-$17.12
1.2	-$6.75	-$6.96	-$7.17	-$7.38	-$7.59	-$7.80	-$8.01
1.4	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
1.6	$5.40	$5.56	$5.73	$5.90	$6.07	$6.24	$6.41
1.8	$9.43	$9.73	$10.02	$10.31	$10.61	$10.90	$11.20
2.0	$12.33	$12.71	$13.10	$13.48	$13.87	$14.25	$14.64
2.2	$14.37	$14.82	$15.26	$15.71	$16.16	$16.61	$17.06
2.4	$15.80	$16.29	$16.79	$17.28	$17.77	$18.27	$18.76

[1] Formula used to calculate differences in predicted revenue = [(Expected pre-weaning survival rate$_{(\text{Birth weight = i kg})}$ x Expected nursery survival rate$_{(\text{Birth weight = i kg})}$) x Price per feeder pig] – [(Expected pre-weaning survival rate$_{(\text{Birth weight = 1.4 kg})}$ x Expected nursery survival rate$_{(\text{Birth weight = 1.4 kg})}$) x Price per feeder pig]. See Figure 3.1 for visual depictions of associations between birth weight and pre-weaning and nursery survival rate.

Table 6.3. Differences in predicted revenue ($) at harvest for pigs of various birth weights, compared to an average birth weight pig (1.4 kg)[1].

	Live Market Hog Price						
Birth weight, kg	$43.00	$45.00	$47.00	$49.00	$51.00	$53.00	$55.00
0.8	-$39.42	-$41.25	-$43.09	-$44.92	-$46.75	-$48.59	-$50.42
1.0	-$26.76	-$28.00	-$29.25	-$30.49	-$31.74	-$32.98	-$34.22
1.2	-$13.09	-$13.70	-$14.31	-$14.92	-$15.52	-$16.13	-$16.74
1.4	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
1.6	$11.38	$11.91	$12.44	$12.97	$13.50	$14.03	$14.56
1.8	$20.60	$21.56	$22.52	$23.48	$24.44	$25.39	$26.35
2.0	$27.72	$29.01	$30.30	$31.59	$32.88	$34.17	$35.46
2.2	$33.03	$34.56	$36.10	$37.63	$39.17	$40.71	$42.24
2.4	$36.84	$38.56	$40.27	$41.99	$43.70	$45.41	$47.13

[1] Formula used to calculate differences in predicted revenue = [(Expected pre-weaning survival rate$_{(\text{Birth weight = i kg})}$ x Expected nursery survival rate$_{(\text{Birth weight = i kg})}$ x Expected full value rate$_{(\text{Birth weight = i kg})}$) x (Expected harvest weight$_{(\text{Birth weight = i kg})}$ x Live weight price)] + [(Expected pre-weaning survival rate$_{(\text{Birth weight = i kg})}$ x Expected nursery survival rate$_{(\text{Birth weight = i kg})}$ x Expected cull pig rate$_{(\text{Birth weight = i kg})}$) x (Expected cull pig weight$_{(\text{Birth weight = i kg})}$ x Cull pig live weight price)] – [(Expected pre-weaning survival rate$_{(\text{Birth weight = 1.4 kg})}$ x Expected nursery survival rate$_{(\text{Birth weight = 1.4 kg})}$) x Expected full value rate $_{(\text{Birth weight = 1.4 kg})}$) x (Expected harvest weight$_{(\text{Birth weight = 1.4 kg})}$ x Live weight price)] + [(Expected pre-weaning survival rate$_{(\text{Birth weight = 1.4 kg})}$ x Expected nursery survival rate$_{(\text{Birth weight = 1.4 kg})}$) x Expected cull pig rate $_{(\text{Birth weight = 1.4 kg})}$) x (Expected cull pig weight$_{(\text{Birth weight = 1.4 kg})}$ x Cull pig live weight price)]. See Figures 2.3 and 3.1 for visual depictions of associations between birth weight and survival rate (pre-weaning and nursery) and BW prior to harvest.