ABSTRACT

BRYAN, MIRANDA RAYE. Associations Among Body Condition, Reproductive Performance and Body Lesions in Group Housed Sows. (Under the direction of Dr. Mark Knauer and Dr. Joe Cassady).

There were two objectives for this study: first, to quantify relationships between sow body condition and reproductive performance and second, to estimate the associations among body lesions with body condition and reproductive performance. Whiteline sows were measured at breeding (n = 1571) and before farrowing (n = 887) on a commercial farm in Eastern North Carolina. Following breeding, sows were housed in gestation stalls for 40 d, and then allocated to pens of 4 to 5 sows (1.49 or 1.86 m^2 per sow, respectively). Body condition measures included: a Knauer sow body condition caliper, weight, 10th rib backfat, 10th rib longissimus muscle area and visual body condition score (scored on a 1 to 5 scale by a technician). Weight and 10th rib backfat were used to estimate lipid content, lipid percentage, protein content, protein percentage and lipid to protein ratio. Sow reproductive traits were: number born alive, litter birth weight, number weaned (NW), piglet survival (NW ÷ (total born + pigs transferred)), litter weaning weight, wean-to-conception interval, farrowing rate and average daily feed intake. Well-being traits included locomotion (1-7 with 1 being most favorable), cracked hooves (0 = no crack, 1 = crack < 12.7 mm, 2 = crack > 12.7 mm), toe length difference (0 = < 12.7 mm, 1 = 12.7 to 19.1 mm, 2 = > 19.1 mm), overgrown hooves (0 = < 63.5 mm, 1 = 63.5 to 82.6 mm, > 82.6 mm), vulva lesions (0 = no lesion, 1 = lesion present) and shoulder lesions (0 = no lesion, 1 = abrasion, 2 = open wound). Data were analyzed in SAS using PROC GLM for continuous traits and PROC GLIMMIX for categorical traits.

Results identified an ideal breeding caliper score, longissimus muscle area, and body condition score in relation to piglet survivability. An ideal farrowing caliper score, weight, body condition and lipid content were found relative to piglet survivability. An ideal breeding or farrowing backfat in relation to subsequent reproduction could not be determined; however, leaner sows at breeding had a greater subsequent number born alive, birth weight, weaning weight, and piglet survivability, and a shorter wean-to-conception interval in comparison to fatter sows. Leaner sows were less likely to farrow. An ideal breeding lipid content, lipid percent, protein content, protein percent and lipid to protein ratio could not be found in relation to any reproductive trait. An optimal protein content was found in relation to litter weaning weight and average daily feed intake.

For this study, there were no significant associations between body condition and foot and leg abnormalities. Thinner sows had a greater probability of developing vulva lesions during gestation. Vulva lesions reduced piglet survivability by 4.3%. Thinner sows in general had a greater probability of developing shoulder abrasions and open wounds. Thin sows may be favorable for reproductive performance and feed costs, but well-being is compromised.

Associations Among Body Condition, Reproductive Performance and Body Lesions in Group Housed Sows

by
Miranda Raye Bryan

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APPROVED BY:

Dr. Mark Knauer Committee Co-Chair	Dr. Joseph Cassady Committee Co-Chair
Dr. William Flowers	Dr. David Dickey

BIOGRAPHY

Miranda R. Bryan was born on February 2, 1989 and raised in Osage City, Kansas. She developed a love for livestock at a young age while showing pigs and calves for 4-H and spending time at her Grandparents' Angus farm. Miranda attended Kansas State University where she received her B.S. in Animal Science and Industry. While at Kansas State, she volunteered and worked at Sunset Zoo, and later worked for Dr. Lily Edwards studying animal behavior. Miranda's research experience helped her land a job after graduation as a research technician at Innovative Swine Solutions, LLC in Carthage, Illinois. Working at Innovative Swine Solutions allowed her to pinpoint her passion for swine breeding and genetics and led to her Masters of Science Degree at North Carolina State University.

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Chapter 1: Literature Review

Introduction

Properly managing sow body condition to optimize reproductive output enables pig farmers to maximize profits and animal well-being. Feeding sows to a specific body condition can be a challenge for producers, especially when there are multiple methods of subjective and objective measurement techniques. Using an objective method to evaluate sow body condition helps to ensure sows are not over or underfed during gestation. Overfeeding sows during gestation is expensive and wasteful, while underfeeding in some situations has been linked to a decrease in subsequent reproductive performance. The association between sow body condition with subsequent reproduction is not well defined in terms of what level is optimal for both reproduction and well-being. This information would be invaluable to the swine industry.

The five topics covered in this literature review are: first, the physiological impact of sow body reserves on reproduction; second, methodologies for quantifying sow body condition; third, the genetics of sow body condition; fourth, managing sow body condition for optimal reproduction; and lastly, managing sow body condition for optimal sow well-being.

The physiological impact of sow body reserves on reproduction

Hormones

There are few studies investigating the impact of sow body condition on hormone function and production in swine, but there are a few in other species that explore body condition and endocrine response. Considine et al. (1996) compared leptin concentrations in humans that were normal, obese and obese that lost 10% of their body weight. The authors reported a strong relationship between body fat percentage and serum leptin concentrations (r = 0.89). Obese participants that lost 10% of their body weight realized a 53% decrease in serum leptin concentrations. In mares, Gentry et al. (2002) considered two body condition groups (high or low) and their impact on hormone concentrations during the seasonal anovulatory period. Results showed no differences for plasma concentrations of luteinizing hormone (LH), follicle-stimulating hormone (FSH), thyroid-stimulating hormone (TSH), growth hormone (GH), glucose or insulin. However, leptin, progesterone and plasma prolactin concentrations were greater and plasma insulin-like growth factor-1 (IGF-1) concentrations tended to be greater in mares with high body condition compared with those with low body condition.

The relationship between body condition and leptin has been well documented in swine. This is important because leptin has been shown to regulate gonadotropin-releasing hormone (GnRH), GH and LH production (Barb et al., 2001). Estienne et al., (2000) explored the effect of body condition on LH and leptin concentrations in milk and serum. Sows were categorized at farrowing based on backfat thickness as thin (less than 20 mm), medium (20 to 25 mm) or fat (over 25 mm). Serum levels of leptin at farrowing were correlated with backfat thickness ($r^2 = 0.67$). At weaning, serum leptin levels were greater for fat sows (3.1 ± 0.2 ng/ml), than medium (2.6 ± 0.2 ng/ml) or thin sows (2.7 ± 0.2 ng/ml). Mao et al. (1999) investigated the impact of feed restriction during final week of lactation on hormone levels in primiparous sows. Sows that were restricted lost more weight during lactation and had lower plasma leptin concentrations and LH pulse frequency compared with sows that maintained their body weight.

The impact of body condition loss on hormone production in swine has been well established in controlled studies. Armstrong et al. (1986) evaluated impact of body condition loss in first parity sows by providing either ad libitum access to feed or restricting intake during lactation. The authors suggested preprandial levels of urea nitrogen and free fatty acids were moderately correlated for restricted sows ($r^2 = 0.68$), but not for sows provided access to ad libitum feed. The authors suggested restricted sows catabolized fat and protein, but the ad libitum sows catabolized either fat or protein. The authors further reported no differences in LH or estradiol between backfat groups. Zak et al. (1997) conducted a similar study, but sows were provided access to ad libitum feed (AA), provided access to ad libitum feed from day 0 to 21 then restricted (AR) or restricted from day 0 to 21 then fed ad libitum (RA). Sows that were restricted lost more body weight and backfat than those provided access to ad libitum feed. The mean plasma LH concentration for the AR group was significantly lower than the RA and AA group.

Body condition loss also has an impact on ovarian function. A study by Clowes et al., (2003a) fed sows to target body protein loss levels of high (>15%), moderate (~10%) and low (~5%) during lactation. The mean protein loss was 16, 9 and 7% for the high, moderate and low levels, respectively. Sows that lost approximately 16% of their body protein had fewer follicles of less than 4 mm, a smaller volume of follicular fluid in the largest follicles and lower follicular fluid estradiol concentrations than the other two groups. Follicular fluid estradiol concentrations for the group that lost 9% of body protein were lower than the sows that lost approximately 7%, but there was no difference in follicular fluid volume or number. A subsequent study by Clowes et al. (2003b) confirmed previous findings (Clowes et al., 2003a). Gilts were fed during gestation to reach a high or moderate body mass at farrowing, and then fed during lactation to achieve a high or moderate protein loss. At weaning, first parity sows with a greater body mass had a greater number of large follicles, greater follicular fluid estradiol concentration and a heavier uterine weight. Sows with moderate protein loss had more large follicles and greater follicular fluid estradiol concentration than sows that lost a high amount of protein. Sows with a high body mass at parturition and moderate protein loss during lactation showed the greatest follicular development. A body protein percentage loss of greater than 12% can decrease ovarian function and reproductive performance (Clowes et al., 2003a). Hence, sows should be managed to minimize protein losses during lactation.

Methodologies for quantifying sow body condition

Visual appraisal

Visual body condition in sows is generally based on a 1 to 5 scoring system with 1 being too thin, a score of 3 considered ideal and 5 being over conditioned. Sows are then commonly fed based on assessed body condition score (BCS) throughout gestation. Neary and Yager (2002) developed written guidelines for visually assessing sow body condition scores (Table 1.1). Images of sows with differing subjective body condition scores are shown in Figure 1.1.

The “ideal” visual BCS of a sow can vary between production systems. Fitzgerald et al. 2009 studied the repeatability and reproducibility of visual BCS using scorers with no experience, some experience or extensive experience. Repeatability referred to the accuracy for each individual while reproducibility accounted for variation between individuals. All individuals scored the sows twice after attending two, one hour training sessions. The authors reported a nine point scoring system had a numerically greater correlation with last rib backfat (r = 0.58) when compared with the traditional five point system (r = 0.54). Repeatability of body condition scores ranged from 0.43 to 0.82 with an average of 0.69. The repeatability of the nine point scoring system (0.71) was numerically greater compared to the five point system (0.68). Overall, repeatability and reproducibility accounted for 70.6 and 29.4% of the total variation, respectively. The study further reported that some participants consistently over-estimated sow condition while others tended to under-estimate BCS. Collectively, results suggested that participants had their own version of ideal sow body condition.

It is important that production systems standardize sow body condition scoring across farms. Yet some farms experience high employee turnover meaning many employees may never become proficient at livestock evaluation. Proper farm training programs, like that outlined by Fitzgerald et al. (2009), could help improve stockmanship skills, but would also decrease work productivity for time spent training new hires. Therefore, objective body condition tools should be considered when assessing sow body condition or training workers to reduce variation between scores assigned by farm staff.

Weight

Weight can be a valuable, objective means to quantify sow body condition. The most accurate method to measure weight is with a scale. However, weighing gilts and sows may require extra labor for farm staff. Sows may have to be moved to a scale or staff may have to move heavy scales between barns. Currently, most U.S. commercial sow farms do not have scales. However, sow farms should consider including a sow scale to help monitor sow condition when a farm is built new or remodeled.

An alternative method to estimate weight is to use a sow weigh tape to capture heart girth circumference or length from flank-to-flank. Measuring sow heart girth is possible but can be a challenge for farm staff in most current facilities. The flank-to-flank measurement is easier to obtain in current production systems and flank-to-flank and heart girth measurements are moderately correlated (r = 0.69, Fitzgerald et. al, 2009). The correlation between weight with heart girth and flank-to-flank measurements has been reported as 0.9 (O'Connell et al., 2007) for gestating sows and 0.98 (Sulabo et al., 2007), for growing pigs and gestating sows. Sulabo et al. (2007) used the following regression equation to estimate weight of growing pigs and gestating sows when given flank-to-flank measurement: body $weight^{0.33}$, kg = 0.0511 x flank-to-flank (cm) + 2.161. (r^2 = 0.96). Similar to gestation, flank-to-flank measurements for lactating sows have been evaluated by Sulabo et al. (2007). The following equation describes the relationship between the flank-to-flank measurement and weight for lactating sows: body $weight^{0.33}$, kg = 0.0371 x flank-to-flank (cm) + 2.161. However, only 61% of variation in sow weight can be explained by this model. The authors further suggested that different regression equations be used to estimate weight during gestation and lactation. While a flank-to-flank measurement is easier to obtain than weight for most production systems, using the various regression equations may be a difficult concept for some farm staff to grasp and could lead to errors in calculations. Having the weight estimate printed on the tape makes the product practical for current production systems.

Backfat

Backfat is another useful, objective method for measuring body condition in sows. When combined with weight, it has been shown to be an accurate predictor of body fat percentage (r^2 = 0.90, Mullan and Williams, 1990). Backfat can be measured in real-time with B-mode or A-mode ultrasound. However, B-mode appears to be a more accurate measure. See (1998) evaluated five different ultrasound machines across three technicians to evaluate machine and technician accuracy. Correlations between the A-mode and B-mode ultrasound ranged from 0.11 to 0.78. Three of the A-mode machines consistently overestimated backfat. Machine inaccuracies make it difficult to feed according to backfat and keep sows at an ideal body condition. In comparison to A-mode ultrasound, B-mode ultrasound is very accurate, but is relatively expensive and requires additional training. Many farms use B-mode ultrasound for checking sows for pregnancy. Developing software to automatically estimate backfat depth with B-mode pregnancy detection devices would reduce machine costs and training relative to B-mode machines typically used to capture backfat (i.e. Aloka 500).While progress has been made for A-mode ultrasounds, the accuracy is still rather low in comparison with their B-mode counterparts.

Variable associations between backfat and body condition score have been reported ((Esbenshade and Britt, 1986; Young et al., 2001; Maes et al., 2004; Knauer et al., 2007; Fitzgerald et al. 2009; and Schenkel et al., 2010). A study by Knauer et al. (2007) evaluated the body condition of sows at harvest. Backfat depth at the tenth rib and BCS were assessed. Backfat depth ranged from 4.6 to 62.4 mm and BCS ranged from 1 to 5. The correlation between backfat and BCS was 0.74, greater than those reported by Fitzgerald et al. (2009)

(0.48, 0.51, 0.52, and 0.58). Nevertheless, there is great variation reported in the literature for the correlation between last rib backfat and BCS. Esbenshade et al. (1986), Young et al. (2001), Maes et al. (2004), Fitzgerald et al. (2009) and Schenkel et al., (2010) reported correlations of 0.30, 0.44, 0.45 to 0.53, 0.54 to 0.65 and 0.66 to 0.70, respectively, between backfat and BCS. Perhaps variation in estimates is due to the experience and accuracy of scorers.

Muscling

Ultrasound can be used to measure muscling in sows, but requires purchasing expensive ultrasound equipment and providing worker training to increase reliability. See (1998) suggests that A-mode ultrasounds overestimate loin depth and the type of machine has a significant effect on the final estimate. The author further reported that a machine x technician interaction was present when measuring loin depth. This shows that proper training of technicians is necessary to reduce variation. While B-mode ultrasound is more accurate, training and price make it impractical for most producers currently. The creation of software that could measure loin depth or loin area by adapting pregnancy checking ultrasound equipment could make these measurements easier for commercial production systems. Perhaps future production systems will be able to more readily implement ultrasound measures as precision technology advances on sow farms.

Caliper

Researchers at North Carolina State University have developed a new tool to quantify sow body condition, the Knauer sow body condition caliper. The caliper is used to measure the angularity of the top line of a sow when viewed from the rear. This measurement is based on findings by Edmonson et al. (1989) that showed as animals lose body condition in the form of muscle and fat, their backs become more angular. Conversely, as they gain muscle and fat their backs appear wider and flatter. A comparison of angularity of the back of an over-conditioned and under-conditioned sow is shown in Figure 1.2. To use the caliper, a person stands behind the sow and palpates for the last rib. The two arms of the caliper line up with the last rib and rest softly on the edge of the loin. The arm will swivel to a score that corresponds to the angle of the back. Modified versions of the caliper have been portioned in to three categories: feed more, feed the same and feed less to increase the ease of use for employees.

The genetics of sow body condition

Genetic differences

Few studies have been performed that investigate the difference in sow body condition between genetic lines. Moeller et al. (2004) explored differences in sow production in the following 6 lines: American Diamond Swine Genetics (ADSG), Danbred (DB), DeKelb-Monsanto Dk44 (DK), DeKalb-Monsanto GPK347 (GPK347), National Swine Registry (NSR), and Newsham Hybrids (NW). These lines were crosses of maternal pure-lines from each company and consisted mainly of Yorkshire/Large White and Landrace breeds. Measurements were recorded across four parities. All lines differed significantly for farrowing backfat depth (16.7 - 23.1 mm) except DK and NSR (20.8 and 20.6 mm, respectively). Backfat loss during lactation was greatest for GPK347 (1.89 mm) and least for DB, DK and NH (1.02, 1.04 and 1.27 mm, respectively). Danbred, NH and NSR had similar farrowing weights, but were significantly different from the other lines. Weight loss was similar for all lines (19.7-21.9 kg) except GPK347 (24.7 kg). The absence of literature regarding body condition of different breeds is discouraging, but not unexpected due to the success of crossbreeding in the swine industry. Moeller et al. (2004) suggested that lines from genetic companies were significantly different, even though each line consisted of the Yorkshire, Large White and Landrace breeds. Breeding companies have used their own selection indices and criteria which have led to variation from the original herd book and other companies that may produce the same breed. The lines from each breeding company should be treated as a new and unique population for this reason (Kyriazakis and Whittemore, 2006).

Variance component estimates for sow body condition traits

Heritabilities. Backfat depth has been shown to be moderately to highly heritable in the Landrace, Yorkshire, Duroc, Hampshire and Large White breeds. For the landrace breed, the heritability of backfat depth has been reported as 0.28 for gilts (Merks, 1988), 0.46 for gilts and boars (Johnson and Nugent, 2003), 0.53, 0.54 and 0.61 for gilts and barrows (Kennedy et al., 1985; Lo et al., 1992; Li and Kennedy, 1994, respectively), 0.33 and 0.54 for sows (Ferraz and Johnson, 1993) and 0.59 for boars (Mrode and Kennedy, 2010). For the Yorkshire breed, the heritability of backfat depth has been reported as 0.42 for gilts (Bereskin, 1986), 0.23, 0.41 and 0.47 for gilts and boars ((Merks, 1988; McKay, 1990; Johnson and Nugent, 2003, respectively), 0.44 and 0.55 for gilts and barrows (Kennedy et al., 1985 and Li and Kennedy, 1994, respectively), and 0.59 for boars (Mrode and Kennedy, 1993). Studies on the Duroc breed have reported backfat depth heritabilities of 0.423 for gilts (Bereskin, 1986), 0.37 for gilts and boars (Johnson and Nugent, 2003), 0.44, 0.51 and 0.54

for gilts and barrows (Kennedy et al, 1985, Li and Kennedy, 1994, and Lo et al., 1992, respectively) and 0.59 for boars (Mrode and Kennedy, 1993). Heritabilities of 0.32 and 0.34 for gilt and boars (Johnson and Nugent, 2003 and McKay, 1990, respectively), and 0.40 and 0.50 for gilts and barrows (Kennedy et al., 1985, and Li and Kennedy, 1994, respectively) have been reported for the Hampshire breed. The Large White breed has reported heritabilities of 0.36 and 0.41 by Ferraz and Johnson (1993) and 0.49 by ten Napel and Johnson (1997) for sows. Lewis and Bunter (2013) reported heritabilities of backfat for landrace and large white sows from parity 1 through 5 of 0.44, 0.37, 0.30, 0.32 and 0.26, respectively. The correlation for backfat depth between gilts and parity 2, 3, 4 and 5 were reported as 1.00, 0.63, 0.63 and 0.70, respectively. While backfat depth has been shown to be moderately to highly heritable in all of these breeds, there is great variation in the reported heritabilities for individual breeds.

Longissimus muscle area has been shown to be moderately to highly heritable in many swine breeds. A heritability of 0.45 has been reported by NSIF (2002) for swine in general. A study by Johnson and Nugent (2003) collected gilt and boar data from Landrace, Yorkshire, Duroc and Hampshire breeds from 1992 to 1999. Pig weights, body length, backfat depth, and longissimus muscle area at 100 and 177 days of age were recorded and heritabilities were calculated. Heritabilities for longissimus muscle area of 0.34, 0.29, 0.22 and 0.26 were calculated for Landrace, Yorkshire, Duroc and Hampshire breeds. These are similar to the heritabilities calculated for gilts and barrows by Chen et al. (2002) of 0.31, 0.33, 0.32, and 0.35 for Landrace, Yorkshire, Duroc and Hampshire, respectively. Lo et al., 1992 analyzed data from purebred Duroc, purebred Landrace and each reciprocal cross and calculated heritability for longissimus muscle area of 0.46 for gilts and barrows.

The heritability of body weight has been studied to a lesser degree in sows. Lewis and Bunter (2013) measured sow backfat and body weight at 20, 21, 26 and 29 weeks of age, at mating, at day 110 of gestation and at weaning through 5 parities. Through the first parity, the heritability of body weight was reported as 0.31, 0.35, 0.30, 0.30, 0.25 and 0.34 for 20, 21, 26, and 29 weeks of age, mating, day 110 of gestation and weaning, respectively. Heritability decreased as parity increased. The heritability of body weight during parity 2 was 0.27, 0.16 and 0.28 at mating, day 110 of gestation and weaning, respectively. For parity 3, heritabilities for body weight were reported as 0.36, 0.16 and 0.28 for mating, day 110 of gestation and weaning, respectively. Parity 4 suggested heritabilities of 0.20, 0.12, 0.17 for mating, day 110 of gestation and weaning, respectively. For parity 5 sows, heritabilities of 0.22, 0.08 and 0.22 were reported for mating, day 110 of gestation and weaning, respectively. Heritabilities were greatest before the first farrowing because residual variation increased with age.

Genetic correlations. The majority of genetic correlations between body condition traits and reproductive traits are generally low, regardless of breed (ten Napel and Johnson, 1997). A study by Chen et al. (2003) explored growth and reproductive traits in Yorkshire, Duroc, Hampshire and Landrace pigs. Genetic correlations between backfat at 113.5 kg and reproductive traits are shown in Table 1.2. The greatest correlation reported was the negative correlation between litter weight at 21 d and backfat depth for all breeds. Grandinson et al. (2007) measured last rib backfat depth at farrowing on Yorkshire sows and reported similar results with regard to body weight with a genetic correlation of -0.31, -0.09, 0.19 and -0.22

for piglet birth weight, piglet daily gain from birth to weaning, piglet daily gain from weaning to 9 weeks and piglet mortality, respectively. Although correlations were relatively low, an increase in gilt backfat depth could be negatively associated with piglet weight. The correlation between gilt and sow backfat is moderately high, which suggests that a sow with greater backfat could also negatively impact piglet weight.

Managing sow body condition for optimal reproduction

Feeding management

Gestation. General nutritional requirements for a sow vary depending on weight, parity, and stage of gestation. From breeding to day 90 of gestation, the NRC (2012) advises sows be fed a ME intake of 6,500 – 7,000 kcal/day, 6.3 – 10.6 g/day of lysine, 4.5 – 10.8 g/day of methionine + cysteine, 1.3 – 1.9 g/day of tryptophan, 8.89 – 12.42 g/day of calcium and 3.87 – 5.4 g/day of phosphorous. After day 90 of gestation until farrowing, sows need a ME intake of about 7,700 – 8,200 kcal/day, 11.1 – 16.7 g/day of lysine, 7.8 – 10.8 g/day of methionine + cysteine, 2.4 – 3.2 g/day of tryptophan, 16.4 – 19.94 g/day of calcium and 7.13 – 8.67 g/day of phosphorus. Recommendations for sow feed intake during gestation were created by van Heugten (2001) and are summarized in Table 1.3.

From weaning to breeding, sows are often flushed or fed ad libitum, but the research on the benefits of flushing in sows has been contradictory. King and Williams (1984) fed 4 or 1.5 kg/d to a group of sows between weaning and breeding and reported that sows fed 4 kg/d had a greater ovulation rate in comparison to sows fed 1.5 kg/d. A study by Baidoo et al. (1992) found no effect of feed intake on ovulation rate; however, they did find that sows that were restricted during lactation but fed ad libitum after weaning had an increase in embryo survival compared to sows that continued on a restricted diet (70.4 and 64.0%, respectively). Similar results were found by Kirkwood et al. (1990) showing restriction of feed intake during lactation and the first 25 days after weaning led to a decrease in the number of embryos. In contrast, Tribble and Orr (1982) found that feed intake from breeding to mating had no effect on litter size. In agreement, Cox et al. (1987) reported flushing did not increase the number of fetuses 60 days after mating in sows. However, the same authors reported flushing improved litter size in gilts. Collectively, these results suggest flushing may not be necessary for sows fed adequately during lactation.

Overfeeding gilts in early gestation has been shown to have detrimental effects on reproduction, but this has not been found in sows. Dyck and Strain (1983) fed groups of gilts either 29.4 MJ ME per day or 17.6 MJ ME per day. The authors reported gilts on the high energy diet had a greater embryonic morality rate when compared to the low energy diet, 82.6 vs 75.8%, respectively. A study by Toplis et al. (1983) fed parity 6 and 7 sows either 2 kg per day or 4 kg per day from three days after ovulation for 30 days. Results showed that intake did not affect ovulation rate, ovarian weight, embryonic survival, or embryo body weight and length. In agreement, Kirkwood et al. (1990) reported gestation feeding level from breeding to day 25 of gestation did not affect the number of embryos or embryo survival. Collectively, these results suggest overfeeding may impair reproduction in females with ample body reserves but not those recovering from lactation.

Feeding level during mid and late gestation has been shown to have little effect on sow reproduction. However, excess gestation feed intake is well known to decrease feed intake during lactation, which is generally detrimental to future reproductive performance.

Weldon et al. (1994) fed a restricted diet and an ad lib diet to two groups of sows from day 60 of pregnancy to farrowing then after farrowing all sows were fed ad libitum. Sows in the restricted feed group during gestation had a greater intake during lactation than sows fed ad libitum during gestation. Feeding high energy during late gestation has also been shown to reduce secretory cells and therefore reduce milk production (Weldon et al. 1994), which could affect weaning number and weight. During mid and late gestation, sows should be fed a moderate diet of 1.8 kg per day to 2.3 and 2.7 kg per day, respectively (van Heugten, 2001) to increase intake and milk production during lactation and optimize feed costs.

Overfeeding and underfeeding throughout gestation has shown to have an effect on sow productivity and longevity. A study by Frobish et al. (1973) compared 4 feeding levels that varied in ME over 3 parities. Sows fed less during gestation had a greater number of piglets born, but a lower average litter birth weight with sows fed 3.0, 4.5, 6.0 and 7.5 Mcal per sow per day having an average litter size of 10.58, 10.68, 10.39 and 8.7, respectively, and average litter birth weight of 1175, 1267, 1267, 1476 g, respectively. There was no statistical difference in number of piglets born alive, number weaned or weaning weight. Sows in the lowest feeding group had 46% of sows remaining in the herd at the end of the trial. The highest feeding group had 31.5% of sows remaining, while the low-moderate and high-moderate had 52.5 and 58% remaining, respectively. Sows in the low group were culled mainly due to failure to conceive, while sows in the high feeding group were culled predominately due to leg abnormalities. This shows that while feeding during gestation can be limited in order to decrease feed costs, moderate feeding will increase longevity and save in replacement gilt costs. Overfeeding during gestation should be avoided because of the decrease in longevity and high feed costs.

Lactation. Feed intake during lactation has an important impact on sow body condition and reproductive performance. Sows overfed during gestation ate fewer meals during lactation than sows on a restricted diet and therefore had a lower total lactation feed intake (Weldon, et al. 1994). Gilts that are restricted during lactation also have a greater protein loss than gilts fed ad libitum (Clowes et al., 2003a; 2003b). This loss during lactation is known to negatively impact subsequent reproductive performance (King and Williams, 1984b; Zak et al., 1997; Kirkwood et al., 1987a,b; Baidoo et al., 1992; Schenkel et al., 2010). It is advised to feed sows ad libitum during lactation to minimize body condition loss and maximize subsequent reproductive performance.

Housing

Different housing and feeding methods during gestation each have advantages and disadvantages, but it is important to ensure adequate feed intake is achieved for each sow. Individual stall housing allows for sows to be individually fed a specific amount, which makes it much easier to observe the sow for body condition issues and assure that she is eating her full amount and avoiding illness. Without automatic feeders, this is a labor intensive feeding method compared to other alternatives. Pen gestation has many different feeding management systems. Sows can be fed individually in a feeding trough or on solid flooring; however it is difficult to be certain each sow eats only her allocated feed. This can lead to agnostic behaviors and bullying. For these reasons, sows should be grouped in pens based on size, parity and aggressiveness (Chiba, 2009). Low ranking sows are especially susceptible in group housing and these sows have been shown to eat less and therefore gain less than high ranking sows (Brouns and Edwards, 1994). Pens may contain automatic feeders that allow sows to eat their predetermined amount of food relatively safely separated from other sows. This allows less labor for staff, but body condition and overall health may be more difficult to assess. Electronic identification tags can also be lost leaving sows with no way to obtain feed (Chiba, 2009).

The type of housing system used has been shown to affect reproductive performance, but the results are inconclusive. In a study by den Hartog et al. (1993) sows housed in pens had less live pigs born per year and a lower piglet birth weight than sows housed in individual stalls. The sows in stalls also weaned one more pig per year than those grouped in pens. McGlone et al. (1994) found farrowing rate was greater for sows housed in individual stalls compared to pens (83.1 and 80.0%, respectively). In contrast, Bates et al., 2003 showed sows housed in pens had a greater farrowing rate than those housed in stalls, (94.3 vs. 89.4%, respectively). Group housed sows also had a higher litter birth weight (17.7 vs. 16.7 kg, respectively) and litter weaning weight (57.1 vs. 56.2, respectively) than sows housed in stalls. Yet, the same study found no effect of housing on number of piglets born alive or number weaned. Inconsistency in space allocation and management strategies makes it difficult to determine a standard housing design in terms of reproductive performance.

Defining optimal body condition

Gilt/sow BCS in relation to reproductive performance. In a five point body condition scoring system, a score of 3 is considered to be ideal. Producers are encouraged to keep sows and gilts at the ideal body condition score of 3 throughout gestation and lactation (van

Heugten, 2001). Sows of a high body condition have a lower lactation feed intake and therefore lose more condition (Weldon et al., 1994). Sows will generally lose body condition during lactation, but the goal is to minimize this loss. It is important that sows do not lose more than one body condition score or drop below a score of 2 during lactation to maximize second litter size (Schenkel et al., 2010). While it is generally accepted that a body condition score of 3 is ideal, the relationship between body condition and subsequent reproductive performance is not well defined.

Gilt/sow weight in relation to reproductive performance. The effect of weight, especially weight loss during lactation, on reproductive performance has been well documented. A study by (Thaker and Bilkei, 2005) explored the effect of weight loss on reproductive performance. It was found that a weight loss of greater than 5% of sow body weight during lactation led to a greater wean-to-estrus interval. Losing more than 10% led to a reduced farrowing rate and as the percent of weight lost increased the subsequent total born decreased. Primiparous sows were more affected by weight loss than multiparous sows, but followed the same trend. This is in agreement with other studies that suggest excessive weight loss during lactation decreases ovulation rate (Zak et al., 1997), conception rate (Kirkwood et al., 1987a,b) and second litter size (Schenkel et al., 2010) and increases the wean to estrus interval (King and Williams, 1984b; Kirkwood et al., 1987a,b; Baidoo et al., 1992) and embryonic mortality (et al., 1992)). Collectively, these studies stress the importance of maintaining body condition during lactation.

Gilt/sow backfat in relation to reproductive performance. Backfat depth is an objective method of measurement that has been associated with subsequent reproductive performance. Yang et al., 1989 found that feeding sows to a last rib backfat depth of 18 to 20 mm at farrowing and feeding ad libitum during lactation increased piglet growth rate in comparison to sows with a backfat of less than 12 mm at farrowing that were restricted during lactation. In agreement, Young and Aherne (2005) recommend a target backfat thickness of 19 mm at farrowing, as this allows backfat thickness to decrease slightly (3 to 4 mm) during lactation with minimal detrimental effects such as difficulties rebreeding. A backfat of over 21 mm has been shown to decrease feed intake during lactation and reduce subsequent total number born and number born alive (Young et al., 2004). It has also been suggested that a depth of less than 16 mm is associated with a higher incidence of stillborns compared to sows with a depth of 16 to 23 mm (Vanderhaeghe et al., 2010). To maximize performance based on backfat, it is suggested that sows be fed to a last rib depth of 18-20 mm during gestation then fed ad libitum during lactation to minimize backfat loss and maximize current and subsequent reproductive performance.

Managing sow body condition for optimal sow well-being

Housing

Stall housing is a common practice in the United States, but concerns have arisen over the impact of stalls on sow well-being. Advantages of stall housing include: reduced aggression between sows, individual feeding, and reduced labor for inspection and moving sows (Anil et al., 2003). The main disadvantages are the decrease in space and social contact (Kirkden and Pajor, 2006). Increasing sow height and weight could have a detrimental impact on sow well-being for sows housed in stalls. Anil et al. (2002) used injury level as a quantitative measure of sow well-being. Sows were examined for injuries at various body regions including: head, forelimb, hind limb, top of back, tail base and vulva. Each region was given a 0 for no injury, 1 for a slight injury (less than 5 superficial wounds), 2 for obvious injury (5 to 10 superficial wounds, ≤ 3 deeps wounds, or both) and 3 for severe injury (> 10 superficial wounds, > 3 deep wounds or both). A deep wound was any injury where the depth was greater than 0.5 cm. Their results suggested sows with a higher stall length to animal length ratio (SLAL) or stall width to animal height ratio (SWAH) had a lower total injury score. They were able to predict the total injury score with the following equation: total injury score = 8.7885 – 2.054(SLAL) x 5.14683(SWAH) ($r^2 = 0.24$). This suggests that larger sows, relative to stall size, had higher injury scores.

The focus on animal well-being in Europe has caused a shift from stalls to group housing making a comparison of housing systems necessary. Literature reviews comparing gestation housing systems have been reported by Barnett et al. (2001) and McGlone et al. (2004). A study by Anil et al., (2003) used a scoring system to compare injuries for sows housed in pens and fed with an electronic feeding system to sows housed in individual stalls. The results of this study suggested that sows housed in pens had a greater injury score than sows housed in stalls, which is in agreement with (Karlen et al., 2007). A later study by Anil et al. (2005) once again compared injuries for sows housed in pens with an electronic feeding system and individual stalls. Injury scores were again higher for sows housed in pens during all stages of gestation. For sows housed in stalls injury scores were higher at day 108 of gestation than any other time. Injury score was negatively correlated with body weight (r = -0.07) and backfat thickness (r = -0.09) for sows housed in pens, but the opposite was true for sows housed in stalls with injury score being positively correlated with body weight (r = 0.20) and backfat thickness (r = 0.09).

Space allowance must be considered when studying well-being, whether sows are housed in stalls or pens. A study by Séguin et al. (2006) compared different space allowances for sows during gestation and the impact on body condition, lesions and reproductive performance. Sows were housed with 11 to 31 sows per pen in a large pen (72.5 to 74.5 m^2), small pen (34.0 to 49.5 m^2), or housed individually in a stall. Stocking densities were 2.3, 2.8, or 3.2 m^2 per sow in both large and small pens while sows housed in stalls were provided 2.0 m^2 per sow. Treatment group did not impact body condition or lesion scores. However, for sows housed in groups, the incidence of lesions decreased over time suggesting that most aggression occurred shortly after mixing. Salak-Johnson et al. (2007) investigated the impact of space allowance during gestation on body condition and lesions. Sows were assigned to pens with space allowances of 1.4, 2.3 or 3.3 m^2 per sow, or to a stall (1.3 m^2). The authors reported a quadratic relationship between body condition and space allowance with sows kept at 2.3 m^2 having the highest body condition score and backfat depth. For sows housed in pens, a decrease in space allowance led to an increase in shoulder, rear and hind leg lesions during the first 14 d after mixing. Yet, a space allowance of 2.3 m^2 minimized neck, rear and hind leg lesions. From day 14 of gestation until farrowing there was a linear relationship between space allowance and lesions with a decrease in space allowance increasing lesions on the ears, neck, shoulder, back and rear.

Flooring type may not affect body condition but it has been shown to impact sow well-being. Bonde et al. (2004) investigated 10 herds with different flooring materials for farrowing stalls. Floors were either fully or partially slatted with a solid concrete front. Slats were made from metals, plastic, concrete, cast iron, cast iron covered with epoxy, triangular slats or different slats within the herd. Triangular slats increased the chance of the sow slipping (odds ratio = 2.1). Sows that were housed on plastic slats were more likely to have carpal and hock lesions odds ratio = 4.9 and 4.0, respectively), while the use of cast-iron slats covered with epoxy greatly decreased the occurrence of hind feet lesions (odds ratio = 0.05). Sows housed on fully slatted floors were 2.4 times more likely to have shoulder lesions. Zurbrigg (2006) also concluded that sows on metal slatted flooring have a higher risk of lesions than sows on solid concrete. This could be because solid floors provide more surface area which reduces pressure on tissue.

Lesions

The relationship between shoulder lesions and sow body condition has been well documented. A study by Bonde et al. (2004) explored lesions in relation to body condition in 10 commercial swine herds. Shoulder lesions were scored on a 0-2 scale with 0 being no lesions, 1 being scratches and 2 being wounds. For these herds, 7% of sows had a shoulder scratch and 12% of the sows had a shoulder wound present. Thin sows had a greater probability of developing shoulder lesions (odds ratio = 4.7) compared to normal and fat sows with odds ratios of 1.0 and 0.41, respectively. In agreement, Zurbrigg (2006) reported sows having a body condition score of less than 3 at weaning were 3.7 times more likely to develop a shoulder lesion than sows with a score of 3 or greater. They also found sows with a flank-to-flank measurement of less than 104 cm were 2.8 times more likely to develop a shoulder lesion than sows with a flank-to-flank measurement of 104.5 cm or greater. In a study investigating lesions of cull sows (Knauer et al., 2007), shoulder lesions were categorized as none, abrasion (nodules or fibrous tissue evident) or open lesion (open, draining sores/healing sores). Shoulder abrasions were most prevalent and found in 12.5% of sows, with open wounds found in 5% of the population. As body condition decreased, the incidence of abrasions and open lesions increased.

Little has been reported on the impact of body condition on vulva lesions; however, the impact of housing and management on sow aggression and vulva lesions has been well established. Sows that are located lower on the social hierarchy may be weaker and more prone to attacks by stronger sows and therefore develop lesions from being bitten (Jensen et al., 2012). This is especially true for sows housed in pens with an electronic feeding system. Sows housed in this system have a greater occurrence of vulva lesions (Leeb et al., 2001; Scott et al., 2009) than any other housing system. The incidence of vulva bites increases in the last three weeks of gestation (Gjein and Larssen, 1995; Anil et al., 2005) because as pregnancy progresses the vulva becomes engorged and is easily targeted and injured (Anil et al., 2005). There has also been indication that sows with vulva bites have a higher mortality rate which is believed to be due to dystocia (Birk et al., 2012).

Feet and leg lesions have been linked to sow body condition and reproductive performance. In cull sows, Knauer et al. (2007) determined that sows with a body condition score of 1 had a lower incidence of rear and front heel lesions than those with a body condition score of 2 to 5. The same authors reported rear and front hoof cracks increased as body condition score decreased. Rear digital overgrown hooves were observed in 21.1% of sows and were more common in sows with a body condition score of 1, 2 and 3 (26.5, 22.2

and 21.3%, respectively) than sows with a body condition score of 4 (12.6%). In contrast, Díaz et al. (2013) found that sows with a lower body condition score had a lower occurrence of white line damage in the hoof and cracks in the wall of the toe. Bonde et al. (2004) determined sows of a higher body condition tended to have an increased risk of lameness. Fitzgerald et al. (2012) suggested foot and leg abnormalities reduced reproductive performance. As severity score increased for sows with hoof cracks and toe length differences, piglet mortality increased compared to control sows. Increases in severity score for sows with overgrown hooves decreased litter weaning weight by 2.16 kg. Collectively these studies suggest that foot and leg lesions are related to sow body condition.

Conclusion

There are many ways to measure body condition in sows, although some methods are much more effective than others. Visual appraisal is quick and does not require expensive equipment, but it could lead to sows being inadequately fed because scorers have their own versions of an ideal sow. Measuring weight, backfat depth and longissimus muscle area are more precise methods of managing body condition but currently require expensive equipment and an increase in labor. An objective method of measurement should be used to manage body condition in sows to ensure adequate feed intake is met to maximize reproductive performance.

The relationship between body condition and reproductive performance is inconclusive. Ideal visual body condition score and weight have not been established, although the importance of minimizing body condition and weight loss during lactation has been emphasized. An ideal last rib backfat range of 18-20 mm during gestation has been reported to compensate for backfat lost during lactation. There is a definite link between body condition and reproductive performance, but ideal recommendations for all measurements to maximize reproductive performance have not been established.

The shift of focus on sow well-being in recent years has led to increased interest in the relationship between lesions and body condition. Thinner sows have been associated with a higher occurrence of shoulder lesions and foot and leg abnormalities. These abnormalities may reduce reproductive performance. Sows lower on the social hierarchy have an increase incidence of vulva lesions, but there has been an insufficient amount of research exploring the relationship between body condition and vulva lesions.

There are a few aspects of the relationships between body condition, subsequent reproductive performance and body lesions that need to be addressed. While a body condition score of 3 is known to be ideal visually, there should be more research investigating if this score of 3 also maximizes reproductive performance. If possible, ideal recommendations for visual body condition score, backfat depth, longissimus muscle area, weight and caliper score should be established that maximize reproductive performance. This will allow producers to aim for a specific target and will make it easier for them to improve sow body condition. More research is also necessary to determine the relationship between sow body condition and well-being for sows housed in pens. It would be interesting to measure the change in body condition during gestation to determine the impact of social dynamics on body condition and body lesions. It is unclear whether sows lower in the social hierarchy have poorer body condition when they enter pens, or if the body condition worsens as gestation progresses. Further research on the impact of injury on reproductive performance is also suggested.

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Table 1.1 Guidelines for visual body condition scoring in sows (Neary and Yager, 2002).

1: Very Thin	2: Thin	3: Normal	4: Fat	5: Very Fat
The backbone is very prominent and can be felt with little pressure. There are visible spaces between the vertebra. The loin muscle is very shallow. The ribs and bone structure are visible with no fat cover; the tail head is very prominent; and there is severe muscle loss in the shoulder, loin, and hind regions. There is no fat over muscle, or under skin. The bone structure is very apparent.	The spinous processes are still extended, but less sharp, and can be felt with pressure. There is less space between the vertebra, and more fat cover along the entire backbone. The loin muscle has more depth and fullness, but there is no apparent fat cover. The ribs and tail head are still discernible, with more cover, and there is still slight muscle loss	There is just the right amount of fat cover over the shoulders, ribs, loin, and tail head. The spinous processes and hips can be palpated with pressure; they are not visible, and they feel smooth to the touch. The loin muscle is filled with a cover of fat.	The entire animal appears smooth and has an enlarged, rounded appearance. The spine can be felt with great pressure. There is fat filling in the flanks, tail head, and over the sternum. There is more fat cover over the shoulder, loins, and ribs.	There is no visible bone structure or definition in the muscles. The spine cannot be felt. The neck appears shorter due to fat deposits around the shoulder. The loin, hip, and tail head have a flat look due to being engulfed in heavy fat cover.

Table 1.2. Genetic correlations between backfat depth at 113.5 kg and subsequent reproductive performance (Chen et al. 2003).

	Number born alive	Litter weight at 21 d, kg	Number weaned
Yorkshire	0.193	-0.271	0.005
Duroc	0.176	-0.285	0.006
Hampshire	0.183	-0.301	0.004
Landrace	0.201	-0.292	0.007

Table 1.3. Feeding recommendations for sows during gestation (van Heugten, 2001).

Gestation Phase	Feeding Level (kg)
Wean-Breed	Ad Lib
Breed-d 21	1.8 – 2.0
d 21 – d 75	1.8–3.6 (To condition)
d 75 – d 90	1.8–2.3
d 90 – d 115	1.8 – 2.7

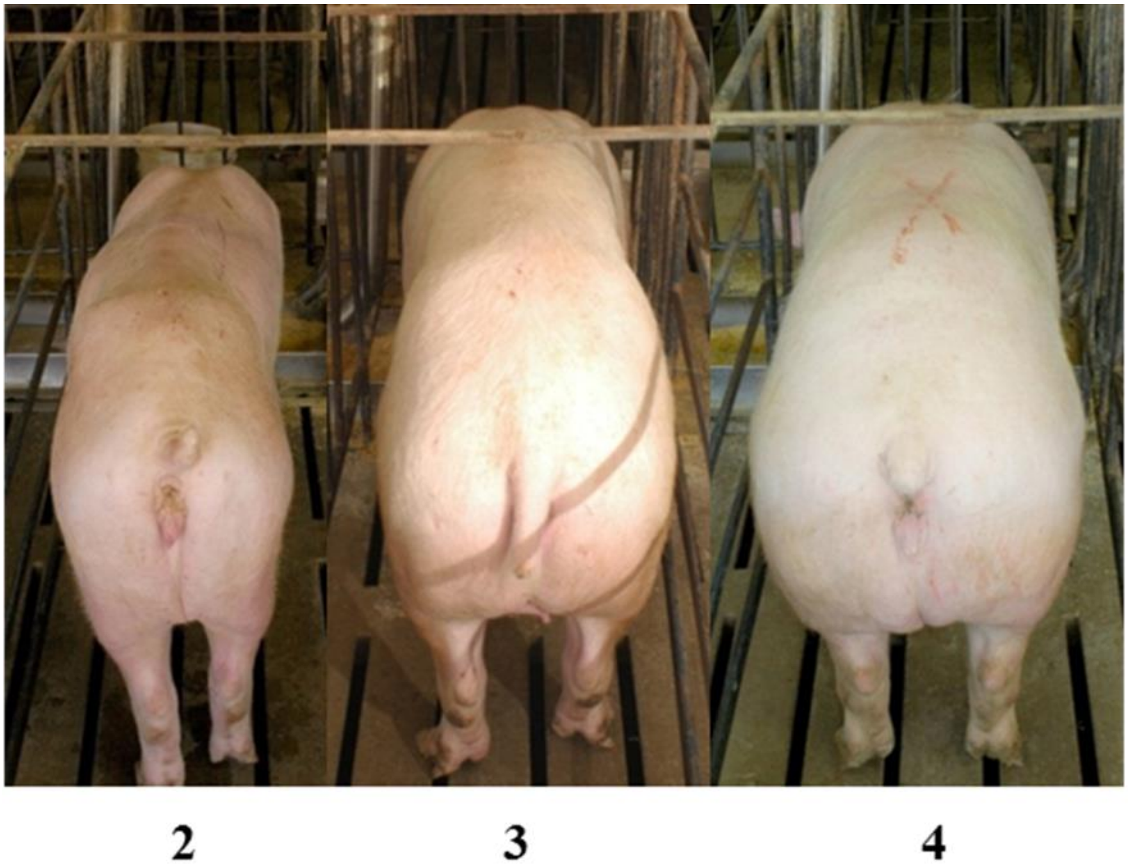

Figure 1.1. Visual guidelines for sow body condition.

Figure 1.2. The angularity of the back of an under-conditioned (left) and over-conditioned sow (right).

Chapter 2: The association between sow body condition with subsequent reproductive performance

M.R. Bryan and M.T. Knauer

ABSTRACT: The objective was to quantify relationships between sow body condition with subsequent reproduction. Sows were measured at breeding (n=1571) and before farrowing (n=887) at a commercial farm. Body condition measures included: a Knauer sow caliper (CS), weight (WT), 10th rib backfat (BF), 10th rib longissimus muscle area (LMA) and visual body condition score (BCS) scored on a 1 to 5 scale by a technician. Lipid content (LC), lipid percentage (LP), protein content (PC), protein percentage (PP) and lipid to protein ratio (L:P) were estimated from weight and backfat. Sow production traits were: number born alive (NBA), litter birth weight (BW), number weaned (NW), piglet survival (PS) which was NW divided by total born, litter weaning weight (WW), wean-to-conception interval (WCI), farrowing rate (FR) and average daily feed intake (ADFI). Data were analyzed in SAS using PROC GLM for continuous traits and PROC GLIMMIX for categorical traits. Fixed effects in all models included: farrowing group, barn, parity and the interaction between farrowing group and barn. Breeding CS had a curvilinear relationship ($P < 0.05$) with NBA, BW, NW, PS and WCI with a CS of 15 being optimal for NBA, NW and PS and 14 ideal for BW and WCI. Breeding LMA had a curvilinear relationship with PS with 51.5 cm^2 maximizing performance. Breeding BCS had a curvilinear relationship ($P < 0.05$) with NBA, BW, NW, PS and WCI with 3.2 being optimal for NBA, NW and WCI and 3.0 ideal for BW and PS. There was not a curvilinear relationship present between breeding BF, WT, LC, LP, PC, PP and L:P with reproductive traits. Farrowing CS had a curvilinear relationship ($P < 0.05$) with NW and PS with 15 being optimal. Farrowing BCS had a curvilinear relationship ($P < 0.05$) with NW and PS with 3.6 being ideal. Farrowing WT had a curvilinear relationship (P <

0.05) with WW and PS with a WT of 220 and 210 kg, respectively, being ideal. Farrowing LMA had a curvilinear relationship ($P < 0.05$) with WCI with 51.6cm^2 being ideal. Farrowing LC had a quadratic association with PS with a LC of 52 kg maximizing PS. Protein content had a curvilinear relationship with WW with a PC of 34 kg maximizing WW. There was not a curvilinear relationship present between farrowing BF, LP, PP and L:P with reproductive performance. Based on results of the current study it was concluded that sow body condition explains variation in reproductive performance. Producers should use CS or WT instead of a subjective BCS to manage gestating sows and maximize subsequent reproduction.

Key words: body condition, reproduction, sows

Introduction

Farms in the United States commonly feed gestating sows according to a 5 point body condition scoring system. Fitzgerald et al. (2009) found that participants consistently over or under-estimate body condition, forming their own "ideal" body condition. This could lead to sows being fed improperly and a reduction in reproductive performance. A quantitative method of scoring body condition should be used to ensure adequate intake is met to optimize reproductive performance.

Weight, backfat depth and longissimus muscle area are commercially methods commonly used to measure body condition in commercial herd. Weight is an accurate measure of body condition, but many farms do not have scales and weighing sows takes extra time and labor. An alternative method to measure weight is using heart girth or flank-to-flank measurements (Sulabo et al., 2007). While more labor intensive than body condition scoring, heart girth and flank-to-flank measurements take much less time and money than weighing sows on a scale, but may prove complicated for some farm staff. Backfat depth can be measured with an A or B-mode ultrasound. The A-mode ultrasound has a lower accuracy than the B-mode ultrasound (See, 1998), but it is much cheaper and does not require extensive training. B-mode ultrasound can also be used to measure longissimus muscle area, but the expense, training and labor required make it impractical for commercial production. A relatively inexpensive, quantitative method of measuring body condition could have a positive impact on the swine industry.

The Knauer Sow Body Condition Caliper was developed at North Carolina State University to inexpensively and accurately quantify sow body condition. The caliper measures the angularity of the top line of the sow when viewed from the rear. This measurement is based on findings by Edmonson et al.(1989) that showed as animals lose body condition in the form of muscle and fat, their backs becomes more angular, conversely as they gain muscle and fat their backs appear wider and flatter. An affordable, objective measurement would allow production systems to accurately evaluate sows to ensure adequate feed intake is met and performance is maximized.

The relationship between body condition and subsequent reproductive performance has surprisingly, not been well defined. On the five-point scale, a 3 is known to be visually ideal; however, there is no evidence that a 3 optimizes reproductive performance. Body condition loss is known to impact reproductive performance. Schenkel et al. (2010) suggested that gilts losing more than one point on the body condition scale or going below a 2 during lactation have a smaller second litter size.

There is a lack of research relating weight to reproductive performance; however there is evidence that weight lost during lactation is detrimental to reproductive performance. Excessive weight loss during lactation has been shown to decrease ovulation rate (Zak et al., 1997), conception rate (Kirkwood et al., 1987a,b) and second litter size (Schenkel et al., 2010) and increase the wean to estrus interval (King and Williams, 1984; Kirkwood et al., 1987; Baidoo et al., 1992) and embryonic mortality (King and Williams, 1984; Kirkwood et al., 1987a,b; Baidoo et al., 1992)

Weight can also be broken down to determine the lipid and protein composition of sows using equations from Whittemore and Yang (1989). Schenkel et al. (2010) used these equations to establish the effect of protein and lipid loss on reproductive performance. It was determined that sows that lost a protein mass of over 9% had a smaller second litter size. Sows with a high body weight at farrowing (207-245 kg) that lost over 22% of lipid mass during lactation also had a smaller second litter size.

The relationship between backfat depth and reproductive performance has been studied extensively. A target last rib backfat thickness of 19 mm at farrowing may maximize litter growth rate (Yang et al., 1989) and reduce detrimental effects such as difficulties rebreeding (Young and Aherne, 2005). A backfat of greater than 21 mm has been shown to reduce total number born and number born alive (Young et al., 2004).

Body condition impacts reproductive performance in sows, but the relationships are not adequately defined for many body condition measurements. The objective of this study was to quantify relationships between sow body condition and subsequent reproduction.

Materials and Methods

Animals and Facilities

Crossbred sows were measured at breeding (n=1571) and farrowing (n=887) at a commercial farm in eastern North Carolina from August to December, 2012. The genetic makeup of the sows was Landrace boars mated to Large White × Chester White females. The farm consisted of two curtain sided breeding and gestation barns with cool cell pads and two farrowing barns with cool cell pads. All barns had mechanical ventilation and flush gutters. Sows were housed in individual stalls until day 30 of gestation, then grouped by size and moved to pens measuring 3.02 x 2.44 m with four to five sows per pen until immediately before farrowing. The front half of the pens were solid concrete and the rear had slatted flooring.

Sows were fed diets balanced to meet or exceed NRC (2012) requirements and provided ad libitum access to water. During gestation, sows were hand fed individually according to body condition score. During lactation, sows were hand fed twice a day on a step up program starting with 1.81 kg of feed and increasing feed allowance by 0.9 kg each day after farrowing until approximately day 8 of lactation when sows were fed to appetite.

Measurements

Body condition measures included a sow body condition caliper, weight (WT), backfat (BF), longissimus muscle area (LMA) and visual body condition score (BCS). Caliper Score (CS) was measured with a Knauer Sow Body Condition Caliper at the last rib. Weight at farrowing was adjusted to account for piglet and placental weight using the following equation WT (kg) = -19.75 + 0.973 x pre-farrow WT – 1.09 x number of pigs born

(Rosero et al., 2013). Backfat and LMA were measured at the 10th rib with an Aloka 500 B-mode ultrasound (Aloka Co.,Wallingford, CT) by a trained ultrasound technician. Visual BCS was assessed by one individual using a five point scale with 1 being too thin, 3 representing ideal, and 5 being too fat. Sow lipid content (LC), protein content (PC), lipid percent (LP), protein percent (PP), and the lipid to protein ratio (L:P) were calculated using equations by Whittemore and Yang (1989). For these calculations, 10th rib backfat was converted to last rib backfat using an equation from Fitzgerald et al. (2009).

Reproductive traits included number born alive (NBA), litter birth weight (BW), number weaned (NW), litter weaning weight (WW), piglet survival (PS),wean-to-conception interval (WCI), average daily feed intake during lactation (ADFI) and farrowing rate (FR). Litter birth weight was captured within 24 hours of farrowing and consisted of all piglets born alive. Piglet survival was calculated by dividing NW by total number born + number transferred.

Statistical Analysis

Data were analyzed using general linear models (PROC GLM) for continuous traits and generalized linear mixed models (PROC GLIMMIX) for categorical traits in SAS 9.3 (SAS Institute, Cary, NC). The PROC GLM procedure is an analysis of variance that computes means using an F test. The PROC GLIMMIX procedure was used to analyze a response variable from a non-normal distribution and obtain probabilities for a binary trait. Like linear mixed models, generalized mixed linear models assume normal (Gaussian) random effects and conditional on the normally distributed random effects, data can have any distribution in the exponential family. A value of $P < 0.05$ was considered statistically significant in all tests. Fixed effects in all models included: farrowing group, barn, parity and the interaction between farrowing group and barn. The following is an example of the statistical model that was used: reproductive trait = farrowing group + barn + farrowing group*barn + parity + body condition trait.

Results

Sow body condition at breeding and subsequent reproductive performance

Partial regression estimates between sow body condition at breeding and subsequent reproductive performance are reported in Table 2.1. Sows with a greater CS at breeding were more likely to farrow (P < 0.05, Figure 2.1). The relationship between breeding CS with BW and WCI was curvilinear (P < 0.05), a CS of 14 maximized BW and minimized WCI. There was a curvilinear relationship (P < 0.05) between CS with NBA, NW and PS, a CS of 15 maximized performance for these traits (Figure 2.2). A 10 kg increase in breeding WT decreased (P < 0.05) WW and PS by 0.7 kg and 0.8%, respectively and increased (P < 0.05) WCI by 0.23 days. A one mm increase in breeding BF decreased (P < 0.05) NBA, BW, WW and subsequent lactation ADFI by 0.04, 0.06 kg, 0.17 kg and 0.013 kg, respectively. Sows with a greater BF at breeding were more likely to farrow (P < 0.05, Figure 2.3). There was a quadratic relationship (P < 0.05) between breeding LMA and PS, a LMA of 51.5 cm^2 maximized PS. The relationship between BCS with PS and BW was curvilinear, a BCS of 3.0 maximized performance for both. The relationship between BCS with NBA, NW and WCI (Figure 2.4) was curvilinear (P < 0.05), a BCS of 3.2 maximized these traits. Increasing sow BCS by 1 point decreased (P < 0.05) WW by 1.98 kg.

Sow body composition at breeding and subsequent reproductive performance

Partial regression estimates between sow body composition measurements at breeding and subsequent reproductive performance are reported in Table 2.2. The relationship between LC and reproductive performance was not significant ($P > 0.05$) for any production traits. A 1% increase in LP decreased ($P < 0.05$) NBA by 0.106. A 10 kg increase ($P < 0.05$) in breeding PC decreased WW by 6.1 kg. A 1% increase in PP increased ($P < 0.05$) NBA by 1.032. Sows with a greater PP were less ($P < 0.05$) likely to farrow. As breeding L:P increased, NBA decreased ($P < 0.05$).

Sow body condition at farrowing and reproductive performance

Partial regression estimates between sow body condition at farrowing and reproductive performance are reported in Table 2.3. Caliper score had a curvilinear relationship ($P < 0.05$) with NW and PS, a CS of 15 maximized reproductive performance. The relationship between CS and PS is shown in Figure 2.5. A one score increase in farrowing CS decreased ($P < 0.05$) NBA, BW and ADFI by 0.15, 0.31 kg and 0.04 kg, respectively. There was a curvilinear ($P < 0.05$) relationship between WT with WW and PS, a WT of 220 kg and 210 kg maximized WW and PS, respectively. A 10 kg increase in farrowing WT decreased ($P < 0.05$) NBA, WW and ADFI by 0.11, 0.09 kg and 0.03 kg, respectively. A 1 mm increase in farrowing BF decreased ($P < 0.05$) NBA by 0.03 and ADFI by 0.01 kg. A 1 cm^2 decrease in LMA decreased ($P < 0.05$) NBA by 0.04. There was a curvilinear ($P < 0.05$) relationship between LMA with WCI and ADFI, a LMA of 52 and 47 cm^2 minimized the WCI and maximized ADFI, respectively. A quadratic ($P < 0.05$) relationship was present between BCS with NW and PS, a BCS of 3.6 maximized reproductive performance. The relationship between CS and PS is shown in Figure 2.6. A one score increase in BCS decreased ($P < 0.05$) BW and ADFI by 0.96 and 0.12 kg, respectively.

Sow body composition at farrowing and reproductive performance

Partial regression estimates between sow body composition at farrowing and reproductive performance are shown in Table 2.4. Lipid content at farrowing was correlated ($P < 0.05$) with NBA, NW and ADFI. A 10 kg increase in farrowing LC decreased ($P < 0.05$) NBA and NW by 0.22, 0.15, and 0.08 kg respectively. There was a curvilinear ($P < 0.05$) between LC and PS, a LC of 52 kg maximized PS. A 1% increase in farrowing LP decreased ($P < 0.05$) NBA and ADFI by 0.06 and 0.02 kg, respectively. There was a curvilinear ($P < 0.05$) relationship between PC at farrowing with WW, a PC of 34 kg maximized WW. Additionally, there was a curvilinear ($P < 0.05$) relationship between PC and ADFI, a PC of 32 kg maximized ADFI. A 10 kg increase in PC decreased ($P < 0.05$) both NBA and NW by 0.56 and 0.48 pigs, respectively. A 1% increase in farrowing PP increased ($P < 0.05$) in BW and ADFI by 1.09 and 0.13 kg, respectively. As farrowing L:P increased, NBA and ADFI decreased ($P < 0.05$).

Average daily feed intake and reproductive performance

The relationship between ADFI and reproductive performance is shown in Table 2.5. A 1 kg increase in ADFI increased subsequent NBA by 0.69 and subsequent BW by 1.0 kg. There was a curvilinear relationship ($P < 0.05$) between ADFI with NW, PS and WCI in the same lactation. Wean-to-conception interval was minimized ($P < 0.05$) when ADFI was 6.6 kg. NW and PS increased exponentially ($P < 0.05$) as ADFI increased. Average daily feed intake alone accounted for 41.5, 37.6 and 21.6% of the variation in NW, PS and WCI in the same lactation, respectively. A one kg increase in ADFI increased ($P < 0.05$) WW in the same lactation by 8.64 kg. ADFI alone accounted for 13.4% of the variation in WW.

Discussion

Ideal body condition score

Visual body condition scoring is known to be highly subjective (Fitzgerald et al., 2009). Fitzgerald et al. (2009) explored the repeatability of body condition scoring. The repeatability, reported as the accuracy for each individual, ranged from 0.43 to 0.82. Results suggested that participants had their own ideal body condition. Repeatability was greater for the group that trained participants (0.75) in comparison to those with only some experience in beef cattle (0.64). In the present study, an experienced scorer was used, which may not be available on a commercial swine farm where a high employee turnover rate could result in insufficient visual appraisal training. Inconsistency in scoring could lead to inadequate feed consumption and variation within the herd, especially if multiple staff members are responsible for scoring.

The current study reported a breeding BCS of 3 maximized PS and BW and a 3.2 optimized NBA, NW and WCI. Based on the 5 point scale explained by Neary and Yager (2002), a score of 3 is ideal in terms of appearance. This ideal appearance correlated with improved reproduction and maximized most of the subsequent reproductive traits. An ideal BCS could not be calculated to maximize WW because of the linear nature of the relationship. The 5 point scale can be used throughout all stages of production, but this study showed that sows that may be considered fat, with a farrowing BCS of 3.6, actually maximized NW and PS. For sows at farrowing an ideal appearance, or BCS of 3, may not reflect the optimal reproductive performance. In this instance a quantitative method of measurement such as caliper score or the adjusted weight may be a more effective measurement of body condition to maximize reproductive performance.

The body condition loss during lactation was not measured in the present study, but has been shown to have a negative impact on reproductive performance. Esbenshade et al. (1986) showed a negative correlation (-0.31) between body condition loss in gilts and sows and number weaned. Schenkel et al. (2010) suggested a loss of greater than one point on the body condition scale or a score of less than 2 in gilts reduced second litter size.

Backfat

In the current study an ideal 10th rib backfat depth was not identified at farrowing or weaning due to the linear relationship between BF and reproductive traits. In contrast, an ideal farrowing last rib backfat of 18 to 20 mm has been suggested by Yang et al. (1989) and Young and Ahearn (2005). Young et al. (2004) found sows with a greater BF at farrowing have a lower ADFI during lactation, which is in agreement with the current results. The current study also suggests that a high BF at weaning is detrimental to subsequent NBA, BW, WW, WCI and ADFI but has a positive relationship with FR. In agreement, Young et al. (2004) found sows with a backfat of greater than 21 mm had a smaller number born alive than sows with a backfat of 17 – 21 mm. Studies among gilts have been contradictory to the present findings. Young et al. (1991) found no relationship between gilt backfat and number born alive, but fatter gilts had a shorter WCI. The decrease in farrowing rate for sows with low BF may be due to the decrease in serum leptin levels found in sows with a lower BF.

Sows with a lower BF have been shown to have lower levels of serum leptin and therefore, LH and GNRH (Mao et al., 1999), which may negatively impact conception and farrowing rate.

Ideal caliper score

The caliper is a new, quantitative method of measuring body condition and therefore there are no previous studies investigating this relationship between caliper and reproductive performance. The current study established an ideal score of 15 at breeding to maximize NW and PS. An ideal farrowing CS of 14 was suggested to maximize BW and minimize WCI and a score of 15 to maximize NBA, NW and PS. Collectively, these results suggest that the caliper is an effective method of objectively measuring sow body condition and can be utilized to maximize reproduction. Perhaps the caliper is a more valuable quantitative measure than BF due to the inability of this study to establish ideal recommendations for BF.

Body composition characteristics

For the current study, an increase in L:P decreased subsequent NBA. Farrowing LP was also negatively associated with NBA. Conversely, Schenkel et al. (2012) suggested an increase in breeding L:P increased subsequent NBA in gilts. The study by Schenkel et al. (2012) also suggested an increase in LP and PP increased NBA, which was not in agreement with the current study. Further research is needed to validate the association between body composition characteristics and reproductive performance.

Average daily feed intake

Average daily feed intake improved subsequent NBA and BW, while ADFI in the current lactation was a better predictor of NW, WW, PS and WCI. In agreement, Koketsu et al. (1996) found an association between ADFI and subsequent NBA, with a 1 kg increase in ADFI increasing subsequent NBA by 0.11 pigs. Koketsu et al. (1996) also suggested that increasing ADFI from 4 to 7 kg increased WW by 3 kg. The current study suggests a quadratic relationship between ADFI and WCI with an ADFI of 6.6 kg minimizing the WCI. A lower lactation ADFI has been shown to increase WCI (King and Williams, 1984; Kirkwood et al., 1987; Baidoo et al., 1992).

Implications

The current study identified both objective and subjective sow body condition methods were associated with subsequent reproductive performance. While BCS can be used by skilled scorers to manage sow body condition, a quantitative measure would be beneficial to farm staff with little to no training. Measuring caliper score and weight are effective methods to achieve desired sow body condition to maximize reproductive performance.

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Table 2.1. Partial regression estimates for the relationship between sow body condition at breeding and subsequent reproductive performance from 1,571 crossbred sows.

	CS	CS ɫ	WT,kg	BF,mm	LMA,mm^2	LMA,mm^2 ɫ	BCS	BCS ɫ
NBA	1.37*	-.0464*	-.00447	-.0435*	.0320		2.93*	-.457*
BW	1.46*	-.0522*	-.00491	-.0611*	.0187		3.68*	-.599*
NW	1.25*	-.0416*	-.00805	-.0249	.0221		3.53*	-.563*
WW	-.417		-.0665*	-.173*	-.144		-1.98*	
PS	9.26*	-.313*	-.0828*	-.151	3.66*	-.0355*	23.7*	-3.88*
WCI	-3.17*	.112*	.0226*	.0739*	.0229		-6.04*	.968*
ADFI	.0113		-.0008	-.0126*	.00681		-.0032	
FR	.09*		.00367	.0277*	.0271		.230	

* $P < 0.05$

[a] Fixed effects in all models included: farrowing group, barn, parity and the interaction between farrowing group and barn.

ɫ = quadratic estimate for respective trait

CS = caliper score; WT = sow body weight; BF = backfat depth; LMA = longissimus muscle; BCS = body condition score (1 to 5 where 1 is underconditioned, 3 is ideal and 5 is overconditioned); NBA = number born alive; BW = litter birth weight; NW = number weaned; WW = weaning weight; PS = piglet suvivability; WCI = wean to conception interval; ADFI = average daily feed intake; FR = farrowing rate, expressed as a log odds estimate

Table 2.2. Partial regression estimates for the relationship between body composition at breeding and subsequent reproductive performance for 1,571 crossbred sows.

	LC,kg	LP,%	PC,kg	PP,%	L:P
NBA	-.0218	-.106*	.0395	1.032*	-1.51*
BW	-.0164	-.0814	.0219	.764	-1.14
NW	-.0185	-.0439	-.0527	.215	-.562
WW	-.0677	.0455	-.605*	-2.35	1.01
PS	-0.132	.313	-.444	1.22	-3.87
WCI	-.0162	-.0454	.0488	.111	-.529
ADFI	-.00123	-.00817	.00646	.0873	-.119
FR	.00662	.0463	-.0254	-.504*	.681

* $P < 0.05$

[a] Fixed effects in all models included: farrowing group, barn, parity and the interaction between farrowing group and barn.

LC = Lipid content, kg = -20.4 + 0.21 x (Weight) + 1.5 x (Last rib backfat depth) (Whittemore and Yang, 1989); LP = Lipid percent; PC = Protein content, kg = -2.3 + 0.19 x (Weight) – 0.22 x (Last rib backfat depth); PP = Protein percent; L:P = Lipid to protein ratio; NBA = Number born alive; BW = Litter birth weight; NW = Number weaned; WW = Weaning weight; PS = Piglet suvivability; WCI = Wean to conception interval; ADFI = Average daily feed intake; FR = Farrowing rate expressed as a log odds estimate

Table 2.3. Partial regression estimates for the relationship between sow measurements at farrowing and subsequent reproductive performance from 887 crossbred sows.

	CS	CS[ɪ]	WT,kg	WT,kg[ɪ]	BF,mm	LMA,mm^2	LMA, mm^2[ɪ]	BCS	BCS[ɪ]
NBA	-.154*		-.0111*		-.0305*	-.0418*		-.220	
BW,kg	-.306*		-.00362		-.0593	-.0415		-.962*	
NW	1.06*	-.0359*	-.00867*		-.0181	-.0147		3.05*	-.435*
WW,kg	-.0187		.920*	-.00207*	-.0275	.263		2.25	
PS,%	.0977*	-.00319*	.00838*	-2E-05*	-.00065	-.000343		.273*	-.0386*
WCI	.0205		.00404		.0166	-.405*	.00390*	.0482	
ADFI,kg	-.0353*		-.00290*		-.0107*	.110*	-.00116*	-.121*	

* $P < 0.05$

ɪ = quadratic estimate for respective trait

[a] Fixed effects in all models included: farrowing group, barn, parity and the interaction between farrowing group and barn.

CS = caliper score; WT = sow body weight; BF = backfat depth; LMA = longissimus muscle; BCS = body condition score (1 to 5 where 1 is underconditioned, 3 is ideal and 5 is overconditioned); NBA = number born alive; BW = litter birth weight; NW = number weaned; WW = weaning weight; PS = piglet suvivability; WCI = wean to conception interval; ADFI = average daily feed intake; FR = farrowing rate, expressed as a log odds estimate

Table 2.4. Partial regression estimates for the relationship between body composition at farrowing and subsequent reproductive performance.

	LC	LC,kg[ɨ]	LP,%	PC	PC[ɨ]	PP,%	L:P
NBA	-.0223*		-.0566*	-.0556*		.244	-.648*
BW,kg	-.0300		-.116	.0208		1.09*	-1.52
NW	-.0148*		-.0289	-.0481*		.0750	-.340
WW,kg	-.0125		-.0305	6.93*	-.100*	.644	-.664
PS,%	.00843*	-7.60E-05*	-.000384	-.00342		-.006	-.00291
WCI	.0108		.0328	.0142		-.211	.393
ADFI,kg	-.00797*		-.0217*	0.195*	-0.00303*	0.125*	-.271*

* $P < 0.05$

ɨ = quadratic estimate for respective trait

[a] Fixed effects in all models included: farrowing group, barn, parity and the interaction between farrowing group and barn.

LC = Lipid content, kg = -20.4 + 0.21 x (Weight) + 1.5 x (Last rib backfat depth) (Whittemore and Yang, 1989); LP = Lipid percent; PC = Protein content, kg = -2.3 + 0.19 x (Weight) – 0.22 x (Last rib backfat depth); PP = Protein percent; L:P = Lipid to protein ratio; NBA = Number born alive; BW = Litter birth weight; NW = Number weaned; WW = Weaning weight; PS = Piglet suvivability; WCI = Wean to conception interval; ADFI = Average daily feed intake; FR = Farrowing rate expressed as a log odds estimate

Table 2.5. Relationship between ADFI and reproductive performance.

	Previous ADFI,kg	ADFI,kg	ADFI,kgᵻ
NBA	.691*		
BW,kg	.996*		
NW	.339	2.98*	-.162*
WW,kg	.611	8.64*	
PS,%	2.21	25.2*	-1.51*
WCI	.696	-7.63*	0.578*
FR	.00894		

* $p < 0.05$

ᵻ = quadratic estimate for respective trait

[a] Fixed effects in all models included: farrowing group, barn, parity and the interaction between farrowing group and barn.

ADFI = Average daily feed intake ; NBA = Number born alive; BW = Litter birth weight; NW = Number weaned; WW = Weaning weight; PS = Piglet suvivability; WCI = Wean to conception interval; FR = Farrowing rate expressed as a log odds estimate

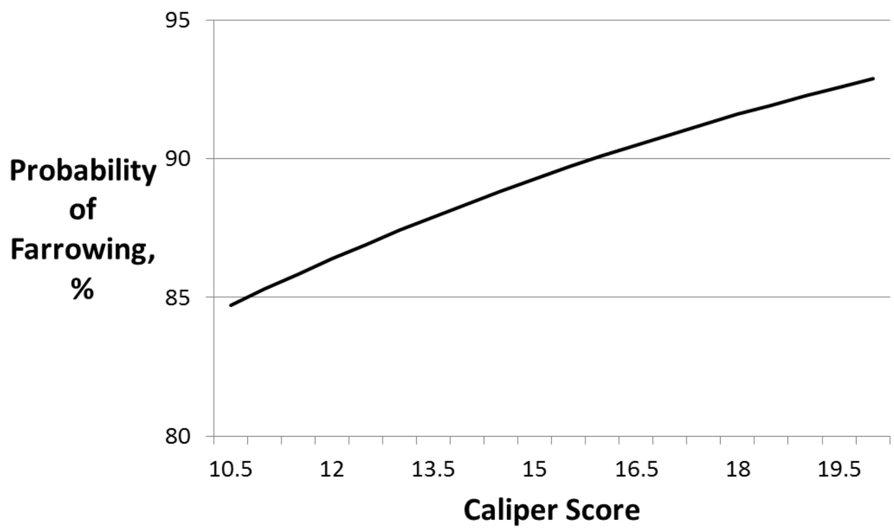

Figure 2.1. Relationship between breeding caliper score and farrowing rate for 1,571 crossbred sows.

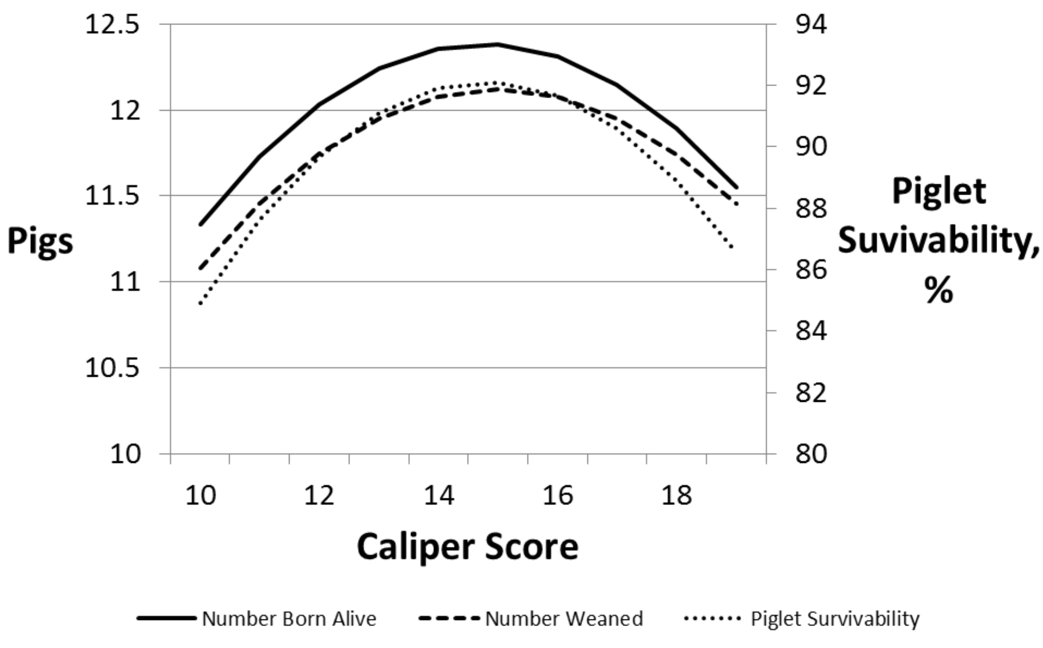

Figure 2.2. Relationship between breeding caliper score with number born alive, number weaned and piglet survibility.

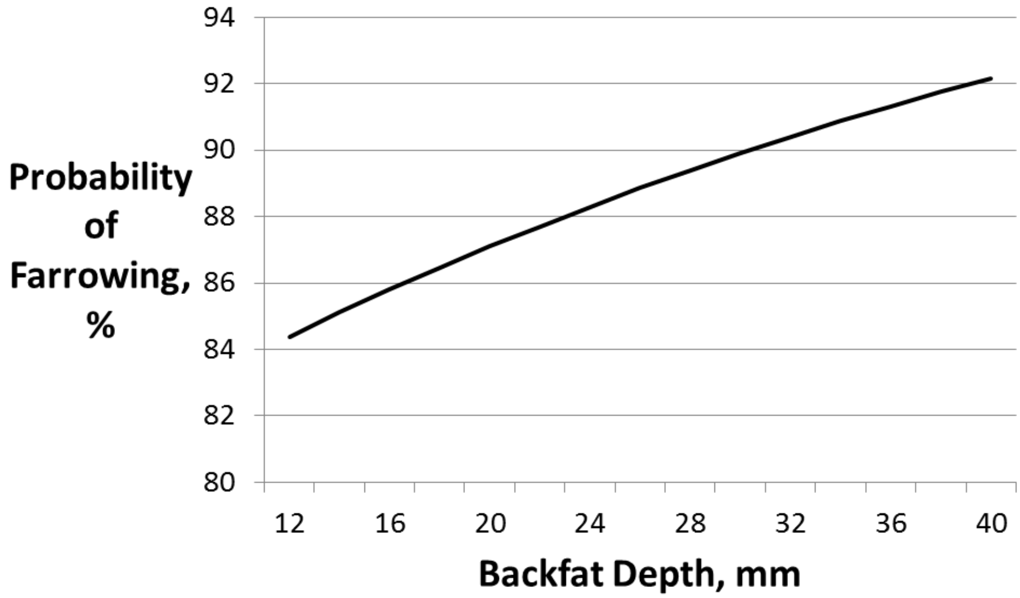

Figure 2.3. Relationship between breeding backfat depth and farrowing rate.

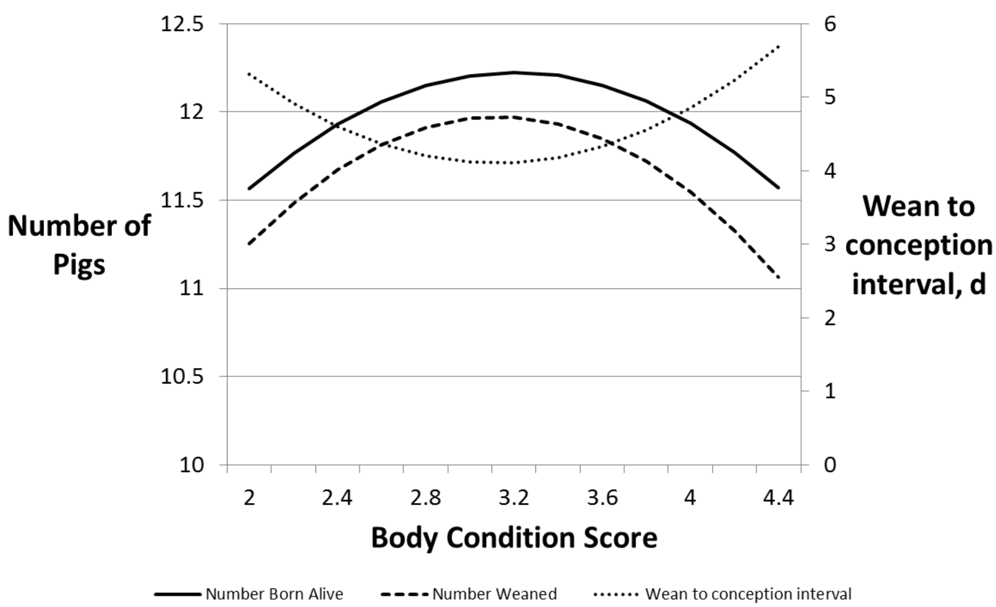

Figure 2.4. Relationship between breeding body condition score with number born alive, number weaned and wean-to-conception interval.

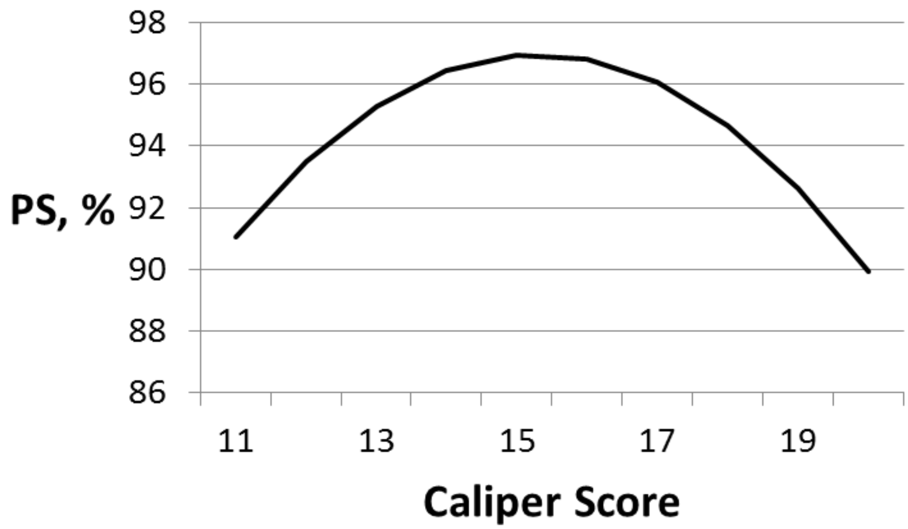

Figure 2.5. Relationship between farrowing caliper score with piglet survivability.

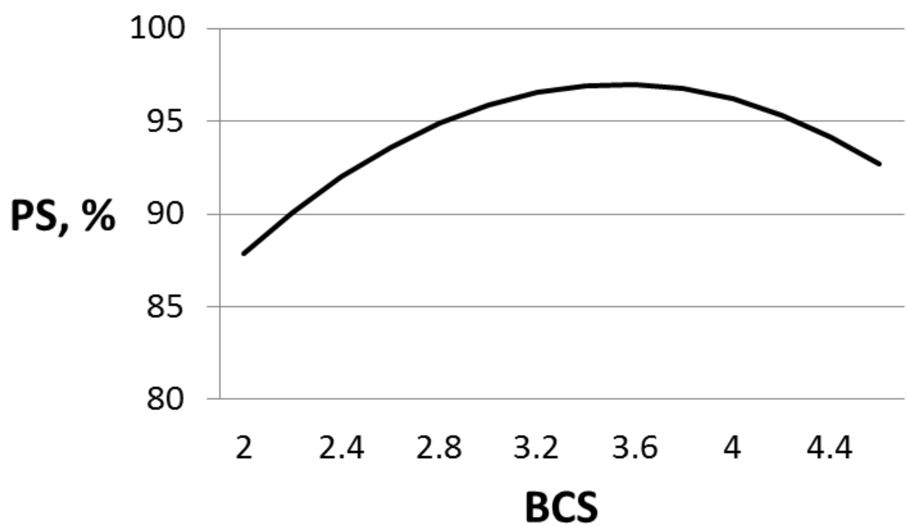

Figure 2.6. Relationship between farrowing body condition score with piglet survivability.

Chapter 3: Associations between sow body lesions with body condition and reproductive performance.

M. R. Bryan and M.T. Knauer

ABSTRACT

The objective of this study was to determine the association between foot and leg, vulva and shoulder lesions with body condition and reproductive performance for sows housed in gestation pens. Whiteline sows (n=887) were measured before farrowing and at weaning for the next reproductive cycle in a commercial farm in eastern North Carolina. Foot and leg abnormalities included: cracked hooves, toe length difference, overgrown hooves and poor locomotion. Vulva lesions were scored 0 (no lesion) or 1 (lesion present). Shoulder lesions were scored 0 (no lesion), 1 (abrasion) or 2 (open). Sow body condition measures included: a Knauer sow caliper (CS), weight (WT), visual body condition score (BCS), backfat (BF) and longissimus muscle area (LMA). Lipid content (LC), lipid percentage (LP), protein content (PC), protein percentage (PP) and lipid: protein ratio (L:P) were estimated using backfat and body weight. Sow production traits included: number born alive, litter birth weight, number weaned, litter weight, piglet survival (number weaned ÷ (total number born + net transfer)), wean-to-conception interval and average daily feed intake. Data were analyzed in SAS using PROC GLM for continuous traits and PROC GLIMMIX for categorical traits. Fixed effects in all models included: farrowing group, barn, parity and the interaction between farrowing group and barn. Vulva lesions were recorded on 17.6% of sows at farrowing and 0% of sows at weaning. There were no shoulder lesions, abrasions and open wounds recorded on 100, 0 and 0%, respectively, of sows at farrowing and 73, 21 and 6% of sows at weaning, respectively. Foot and leg abnormalities were not significantly associated with body condition. The incidence of vulva lesions at farrowing was associated ($P < 0.05$) with a lower CS, WT, BCS, BF, LC, LP and PC at farrowing, reduced ($P < 0.05$) piglet survival (4.3%). Sows with a lower CS at farrowing had a greater ($P < 0.001$) incidence of shoulder abrasions and open lesions at weaning. Backfat and BCS at farrowing had a curvilinear association ($P < 0.05$) with shoulder lesions at weaning with a BF of 39 mm and a BCS of 4.2 minimizing lesions. As LC and LP at farrowing increased, the probability of lesions occurring at weaning decreased ($P < 0.001$). An increase in farrowing PP increased ($P < 0.001$) the probability of shoulder lesions occurring at weaning. Farrowing L:P had a quadratic relationship with shoulder lesions with a ratio of 2.4:1 minimizing the occurrence of lesions. As CS, WT and BCS at weaning decreased the occurrence of shoulder lesions increased ($P < 0.01$). Backfat at weaning and shoulder lesions had a curvilinear association ($P < 0.05$) with the probability of shoulder lesions at weaning decreasing exponentially as BF increased. Results showed vulva and shoulder lesions were generally associated with thinner sows but had little impact on reproductive performance. As weaning LC and LP increased, the probability of lesions occurring at weaning decreased ($P < 0.001$). A greater weaning PC was positively associated ($P < 0.001$) with the occurrence of shoulder lesions. Although statistically significant, body condition measures explained little variation in lesion scores ($r^2 \leq 0.05$).

Key Words: lesion, reproduction, sow

Introduction

Monitoring injuries is one method of assessing well-being in sows (Anil et al., 2003). For sows housed in stalls, an increase in body weight has been shown to increase injuries, but for sows group housed in pens, an increase in body weight may decrease injuries (Anil et al., 2003). Injuries to the feet, vulva and shoulders have been reported (Anil et al., 2003; Bonde et al., 2004; Zurbrigg, 2006; Knauer et al., 2007; Fitzgerald et al., 2012; Lundgren et al., 2012), thus reducing injuries is an important aspect of increasing sow well-being.

There have been multiple studies relating body condition and reproductive performance to foot and leg abnormalities. Díaz et al. (2013) suggested that sows with a greater body condition had a greater occurrence of white line damage and cracks in the wall of the toe. Conversely, Knauer et al. (2007) suggested cull sows with a lower body condition are more likely to develop rear and front hoof cracks. Cull sows with a lower body condition were also more likely to develop overgrown hooves (Knauer et al., 2007). Fitzgerald et al. (2012) linked foot and leg abnormalities to a reduction in reproductive performance. As severity score increased for sows with hoof cracks and toe length differences, piglet mortality increased. Increases in severity score for sows with overgrown hooves decreased litter weaning weight adjusted for piglet additions, removals and mortality by 2.16 kg.

There have been no known studies relating vulva lesions to body condition and reproductive performance; however, body weight has been shown to be positively correlated with social rank (Arey, 1999). Sows with a lower social rank have been shown to be weaker and more likely to be attacked (Jensen et al., 2012).

The relationship between shoulder lesions and body condition has been studied extensively; however, there is no evidence of a reduction in reproductive performance due to shoulder lesions. There is a general consensus that sows with poorer body condition have an increased risk of shoulder lesions (Bonde et al., 2004; Zurbrigg, 2006; Knauer et al., 2007; Lundgren et al., 2012)

While lesions have been linked to poor body condition, there has been little evidence of the effect of lesions on reproductive performance. The objective of this study was to determine the association between foot, vulva and shoulder lesions with body condition and reproductive performance for sows housed in gestation pens.

Materials and Methods

Data

Whiteline sows (n=887) were measured for body condition and scored for lesions at farrowing and at weaning in a commercial sow farm in eastern North Carolina from August to December, 2012. Sow gestation consisted of curtain-sided breeding and gestation barns fitted with cool cell pads, mechanical ventilation and flush gutters. Sows were housed in individual stalls until day 30 of gestation, then grouped by size and moved to pens measuring 3.02 x 2.44 m with four to five sows per pen until immediately before farrowing. This resulted in a pen space allowance of 1.49 or 1.86 m^2 per sow, respectively. Pens were 50% solid concrete and 50% slatted with one nipple drinker per pen. Sows lactated in individual farrowing stalls with woven wire flooring. Sows were fed during gestation and lactation according to diets balanced to meet or exceed NRC (NRC, 2012) requirements and offered water ad libitum. During gestation, sows were hand fed individually according to body condition score. During lactation, sows were hand fed twice a day for the first 8 days of lactation on a step up program starting with 1.81 kg of feed and increasing by 0.9 kg per day. After day 8 of lactation sows were fed three times per day to appetite.

Body condition measures included a sow body condition caliper, weight (WT), backfat (BF), longissimus muscle area (LMA) and visual body condition score (BCS). Caliper score (CS) was measured with a Knauer Sow Body Condition Caliper at the last rib.

Weight at farrowing was captured approximately one week prior to parturition. Therefore farrowing WT was adjusted to account for piglet and placental weight using the following equation WT (kg) = -19.75 + 0.973 x pre-farrow WT – 1.09 x number of pigs born (Rosero et al., 2013). Backfat and LMA were measured from a 10th rib cross-sectional image using an Aloka 500 B-mode ultrasound (Aloka Co., Wallingford, CT) by a trained ultrasound technician. Visual BCS was assessed by the first author using a five point scale with 1 being too thin, 3 representing ideal, and 5 being too fat. Sow lipid content (LC), protein content (PC), lipid percent (LP), protein percent (PP), and the lipid to protein ratio (L:P) were calculated using equations by Whittemore and Yang (1989). Backfat depth at the last rib was converted to 10th rib backfat for use in the body composition calculations by using the following equation developed from the results of Fitzgerald et al. (2009): last rib BF, mm = -0.051 + 0.7842*(10th BF, mm).

Well-being traits recorded at farrowing and weaning included foot lesions, locomotion, shoulder lesions and vulva lesions. Foot lesions were assessed by an experienced staff member and included: cracked hooves (0 = no crack, 1 = crack less than 12.7 mm, 2 = crack > 12.7 mm), toe length difference (0 = < 12.7 mm, 1 = 12.7 mm to 19.05 mm, 2 = > 19.05 mm) and overgrown hooves (0 = < 63.5 mm, 63.5 mm to 82.6 mm, > 82.6 mm). Locomotion was assessed on a 7 point scale (Knauer et al., 2011) and sows considered lame were scored a 7 for the locomotion score if they were not bearing full weight on one or more limbs. Vulva lesions were scored on a binary scale where 0 was no lesion and 1 indicated a lesion was present. Similar to Knauer et al. (2007), shoulder lesions were recorded on a 3 point scale with 0 being no lesion, 1 being an abrasion and 2 an open wound.

Reproductive traits included number born alive (NBA), litter birth weight (BW), number weaned (NW), litter weaning weight (WW), piglet survival (PS),wean-to-conception interval (WCI) and average daily feed intake during lactation (ADFI). Piglet survival was calculated by dividing NW by total number born + number transferred.

Statistical Analysis

Data were analyzed using general linear models (PROC GLM) for continuous traits and generalized linear mixed models (PROC GLIMMIX) for categorical traits in SAS 9.3 (SAS Institute, Cary, NC). The PROC GLM procedure is an analysis of variance that computes means using an F test. The PROC GLIMMIX procedure was used to analyze a response variable from a non-normal distribution and obtain probabilities for a binary or multinomial trait. Like linear mixed models, generalized mixed linear models assume normal (Gaussian) random effects and conditional on the normally distributed random effects, data can have any distribution in the exponential family. A value of $P < 0.05$ was considered statistically significant in all tests. Fixed effects in all models included: farrowing group, barn, parity and the interaction between farrowing group and barn. Fixed effects that were not significant were removed from the model.

For the multinomial trait, shoulder lesion, two intercepts and one regression estimate were given in the output. The first intercept compares sows with a shoulder lesion score of 0 vs the scores of 1 and 2. The second intercept is shoulder scores 0 and 1 vs a score of 2. The probability of each event was calculated by converting the log odds ratio given in the output to a probability using the following equation: (exp(intercept + (trait level*regression estimate)))/ (1+ exp(intercept + (trait level*regression estimate))). For example, the regression estimate of 0.179, intercept of -1.559 for 0 vs the scores of 1 and 2 and intercept of 0.337 for 0 and 1 vs 2 were reported for the relationship between CS and shoulder lesions. A sow with a CS of 14 would have a 72.16% probability ((exp(-1.559 + (14*0.179)))/ (1+ exp(-1.559 + (14*0.179))) = 0.7216) of developing no shoulder lesions and a 94.52% chance of having no shoulder lesions or an abrasion. The probability of having open wounds was calculated by subtracting 94.52% from 100% which gives a sow with a CS of 14 a 5.48% chance of having an open shoulder lesion. To calculate the probability of abrasions, the probability of no shoulder lesion and the probability of open wounds were subtracted from 100%, which resulted in a probability of 22.36%.

Results

Feet and leg conformation

Frequencies of locomotion scores and foot, shoulder and vulva lesion scores at farrowing and weaning are summarized in Table 3.1. Ideal locomotion scores were recorded on ≥ 96% of sows. Similarly, no foot lesions were noted on more than 99% of sows. Neither locomotion score nor foot lesions were associated ($P > 0.05$) with body condition measures or reproductive performance.

Vulva lesions

Vulva lesions were recorded on 17.6% of sows at farrowing and 0% of sows at weaning. A greater probability of vulva lesions was associated with thinner sows. Regression estimates for the relationship between lesions and body condition measurements are shown in Table 3.2. As farrowing CS, WT, BF and BCS increased, the probability of vulva lesions decreased ($P < 0.001$). Associations between lesions and body composition characteristics are shown in Table 3.3. As farrowing LC, LP and PC increased, the probability of vulva lesions decreased ($P < 0.001$). The presence of vulva lesions at farrowing decreased PS by 4.3% ($P < 0.001$), but did not affect any other reproductive traits, as shown in Table 3.4. The occurrence of vulva lesions was associated with increased fetal loss, in terms of stillborns and mummies, by 2.4% ($P < 0.05$).

Shoulder lesions

No shoulder lesions, abrasions, and open lesions occurred in 100, 0 and 0%, respectively, of sows at farrowing and 73, 21, and 6%, respectively, at weaning. The absence of shoulder lesions was associated ($P < 0.05$) with a greater CS, BF and BCS at farrowing and CS, WT, BF and BCS at weaning. As farrowing CS increased, the probability of abrasions and open lesions at weaning decreased ($P < 0.05$). The association between lesion score with farrowing BF ($P < 0.05$) and BCS ($P < 0.01$) was quadratic in nature with a BF of 39 mm and a BCS of 4.2 minimizing abrasions and open wounds at weaning. As weaning CS (Figure 3.1), WT and BCS increased, the probability of shoulder lesions decreased ($P < 0.001$). The relationship between weaning BF and shoulder lesions was curvilinear (Figure 3.2) with a greater backfat associated with a lower probability of shoulder lesions ($P < 0.05$).

The relationship between body composition characteristics and lesions are shown in Table 3.3. Shoulder lesions were associated with a lesser LC, LP and L:P and a greater PP at farrowing and weaning. As LC and LP at farrowing increased, the probability of abrasions and open wounds decreased ($P < 0.001$). An increase in PP at farrowing increased the probability of lesions occurring at weaning ($P < 0.001$, Figure 3.3). The association between shoulder lesions and farrowing L:P was curvilinear with a ratio of 2.4:1 minimizing the occurrence of shoulder lesions at weaning (P < 0.05). As weaning LC and LP increased, the probability of the occurrence of shoulder lesions decreased (P < 0.001). As weaning PP increased, the probability of shoulder lesions occurring also increased (P < 0.001).The relationship between shoulder lesion and weaning L:P was curvilinear with sows having the greatest ratios having the lowest probability of shoulder lesions (P < 0.05).

Discussion

Foot and leg lesions

The current study could not assess the relationship between body condition and foot abnormalities because of the lack of abnormalities in the herd. In contrast, Díaz et al. (2014) reported sows with greater body condition had a greater occurrence of white line damage and cracks in in the wall of the toe. Knauer et al. (2007) suggested cull sows with a lower body condition had a greater incidence of overgrown hooves and rear and front hoof cracks. Perhaps the absence of foot and leg lesions is because sows had excellent structural conformation. Sows were structurally sound and this may have reduced the number of hoof cracks, over grown hooves, toe length differences and poor locomotion scores in the population.

Vulva lesions

This is the first known study to relate body condition to vulva lesions in sows. Thinner sows were associated with a greater frequency of vulva lesions. Sows were fed individually in separate piles on the concrete portion of the pen and this feeding practice may have increased competition for food and agnostic behaviors. Attacks on the vulva become prevalent in the last three weeks of gestation (Gjein and Larssen, 1995; Anil et al., 2005) because as pregnancy progresses the vulva becomes swollen and easily targeted (Anil et al., 2005). Jensen et al. (2012) suggested that sows lower in the social hierarchy may be weaker and more prone to this type of attack. Future studies would need to be performed to determine the changes in body condition from pen mixing to farrowing. In the current study it is unclear whether sows with vulva lesions were thinner when penned in gestation or if sows lower in the social hierarchy could not compete for adequate feed consumption and therefore became thin.

Based on results from the current study, it is concluded that sows inflicted with vulva lesions had a lower piglet survivability and further analysis suggests a greater number of neonatal deaths in sows with vulva lesions, perhaps due to stress during gestation. The effect of stress on fetal development has received little attention, but it is believed that stress can influence reproductive performance. A study by von Borell and Hurnik (1990) recorded behavior of individually housed sows during gestation because stereotypical behaviors can indicate chronic stress in sows (Stolba et al., 1983). Sows that showed stereotypical behavior during gestation, defined as repetitive behavior (> 1 per min) with no apparent function, had a smaller number born alive. Under-nutrition during gestation could be a metabolic stress (von Borell et al., 2007), but little research has shown a reduction in reproductive performance in sows due to under-nutrition possibly because most gestational nutrition studies do not nutritionally challenge the animals. The stress of suffering from agnostic behaviors and potentially under-nutrition due to competition at feeding may decrease piglet survival and increase neonatal mortality for sows housed in pens.

Shoulder lesions

The results of this study coincide with findings by Bonde et al. (2004), Knauer et al. (2007), Zurbrigg (2006) and Lundgren et al. (2012) stating that thinner sows have a greater occurrence of shoulder lesions. Lundgren et al. (2012) suggested that sows weaning heavier litters had a greater frequency of shoulder lesions, in contrast to the current study. Based on the results from the current study it is concluded that a greater farrowing and weaning PP increased the odds of shoulder lesions being present, while a greater farrowing and weaning LP decreased these odds. Most genetic companies select for minimum backfat and leanness Rauw et al. (1998) but this may be detrimental to sow well-being in the form of shoulder lesions. Lewis and Bunter (2013) determined the genetic correlations between backfat at mating for the first parity with the second, third, fourth and fifth parity to be 1.00, 0.63, 0.63, and 0.70, respectively. This shows that while backfat and shoulder lesions are moderately to highly correlated, shoulder lesions can be reduced with adequate feeding levels. The relationship between LP and PP with shoulder lesions shows the necessity of the lipid covering on the shoulder to reduce lesions.

Implications

Based on results from the current study it was concluded that shoulder lesions are influenced by body condition at farrowing and weaning. It is also suggested that a negative relationship between vulva lesions and piglet survivability is present. Genetic associations between shoulder lesions and body condition can be overcome by ensuring adequate feed intake during gestation. Sows maintaining a greater body condition during gestation were less likely to develop shoulder and vulva lesions.

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Table 3.1. Frequencies of locomotion and lesion scores at farrowing and weaning for 887 crossbred sows.

		Score							
Trait	Stage of production	0	1	2	3	4	5	6	7
Locomotion	Farrowing		96.4	2.4	0.6	0	0	0	0.7
	Weaning		97.4	1	0.3	0	0	0	1.3
Cracked hooves	Farrowing	100	0	0					
	Weaning	99.8	0.07	0.13					
Toe length difference	Farrowing	99.15	0.85	0					
	Weaning	99.26	0.74	0					
Overgrown hooves	Farrowing	99.27	0.61	0.12					
	Weaning	99.19	0.61	0.2					
Vulva	Farrowing	82.4	17.6						
	Weaning	100	0						
Shoulder	Farrowing	100	0	0					
	Weaning	72.7	21.1	6.2					

Locomotion = 6 point scale according to work by Knauer et al. (2011). Sows were considered lame and given a 7 for the locomotion score if they were not bearing full weight on one or more limbs.
Cracked hooves = 0 = no crack, 1 = crack less than 12.7 mm, 2 = crack > 12.7 mm
Toe length difference = 0 = < 12.7 mm, 1 = 12.7 mm to 19.05 mm, 2 = > 19.05 mm
Overgrown hooves = 0 = < 63.5 mm, 1 = 63.5 mm to 82.6 mm, > 82.6 mm
Vulva = 0 = no lesion, 1 = lesion present
Shoulder = 0 = no lesion, 1 = abrasion, 2 = open wound (Knauer et al., 2007)

Table 3.2. Log odds estimates for the association between body condition measures and lesions at farrowing and weaning for 887 crossbred sows.

				Farrowing			
	CS	WT,kg	BF,mm	BFɫ,mm	LMA,mm^2	BCS	BCSɫ
Shoulder Lesions	.179*	.296	.288*	-.00374**	.00450	3.96*	-.478**
Vulva Lesion	-.138*	-.0100*	-.0274*		-.0258	-.612*	
				Weaning			
	CS	WT,kg	BF,mm	BFɫ,mm	LMA,mm^2	BCS	BCSɫ
Shoulder Lesions	.211*	.00932*	.190*	-.00194**	.0151	.751*	

*$p < 0.001$

**$p < 0.05$

[a] Fixed effects in all models included: farrowing group and parity

ɫ = quadratic estimate for respective trait

CS = Caliper score; WT = Weight; BF = Backfat depth at the last rib; LMA = Longissimus muscle area; BCS = Body condition score (1 to 5 where 1 is under-conditioned, 3 is ideal and 5 is over-conditioned)

Table 3.3. Log odds estimates for body composition characteristics and lesions at farrowing and weaning for 887 crossbred sows.

	Farrowing					
	LC	LP	PC	PP	L:P	L:P[ɪ]
Shoulder Lesions	.0411*	.163*	-.0372	-1.28*	8.57**	-1.89**
Vulva Lesion	-.0199*	-.0465*	-.0493*	.206	-.555	
	Weaning					
	LC	LP	PC	PP	L:P	L:P[ɪ]
Shoulder Lesions	.0432*	.184*	.0239	-1.25*	6.82**	-1.38**

*p < 0.001

**p < 0.05

[a] Fixed effects in all models included: farrowing group and parity

ɪ = quadratic estimate for respective trait

LC = Lipid content = -20.4 + 0.21 x (Weight) + 1.5 x (Last rib backfat depth) (Whittemore and Yang, 1989); LP= Lipid percent; PC = Protein Content = -2.3 + 0.19 x (Weight) – 0.22 x (Last rib backfat depth); PP = Protein percent; L:P = Lipid to protein ratio

Table 3.4. Partial regression estimates for the relationship between the presence of vulva lesions at farrowing and reproductive performance.

	Vulva	SE
NBA	-.0624	.247
BW,kg	.0538	.715
NW	-.359	.225
WW,kg	-2.709	2.33
PS,%	-4.24*	1.82*
WCI	-.258	.270
ADFI,kg	-.0946	.241

*p < 0.001

[a] Fixed effects in all models included: farrowing group and parity

NBA = Number born alive; BW = Litter birth weight; NW = Number weaned; WW = Litter wean weight; PS = Piglet Survivability; WCI= Wean-to-conception interval; ADFI = Average daily feed intake;

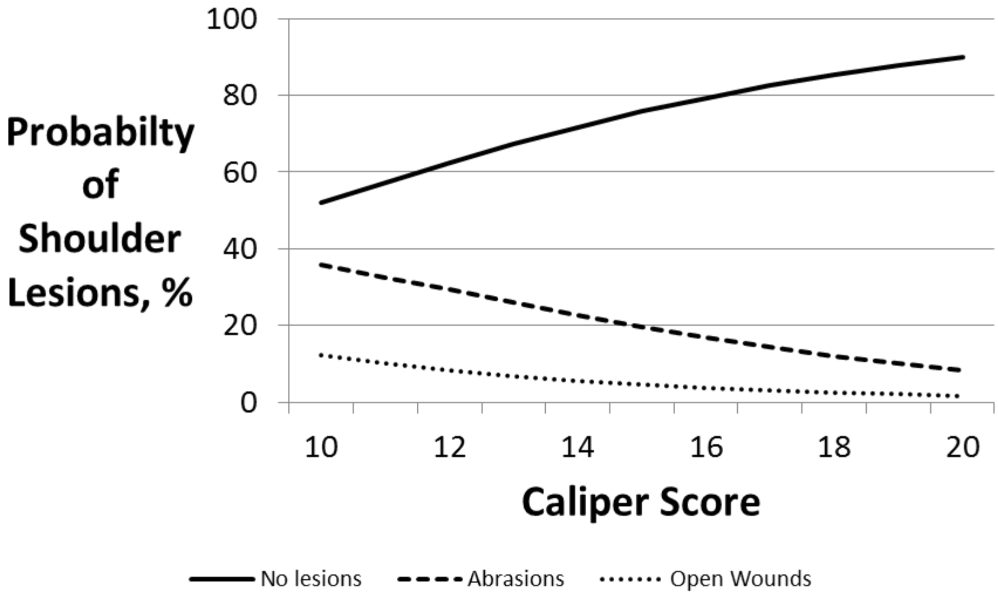

Figure 3.1. The probability of shoulder lesions occurring at weaning based on caliper score at weaning.

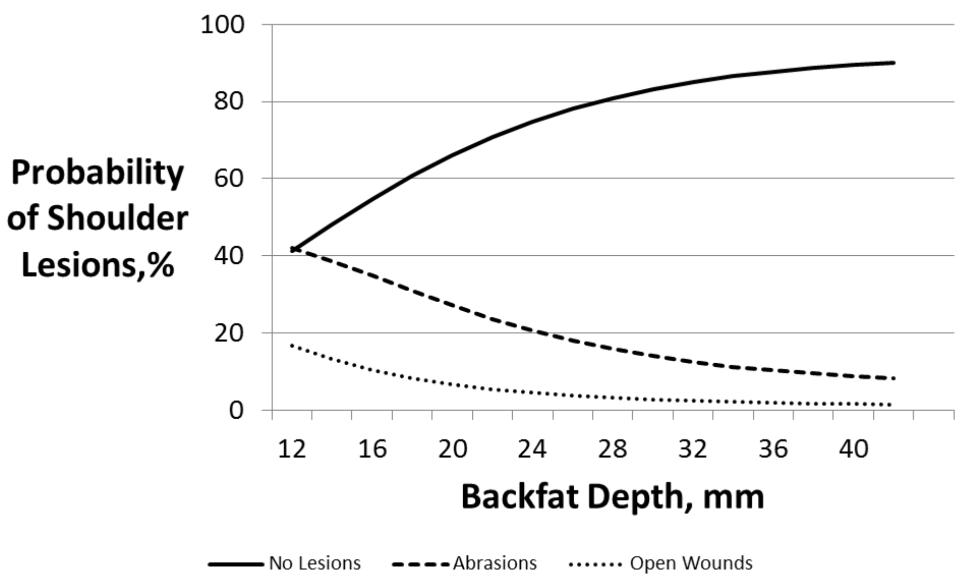

Figure 3.2. The probability of lesions occurring at weaning based on weaning backfat depth.

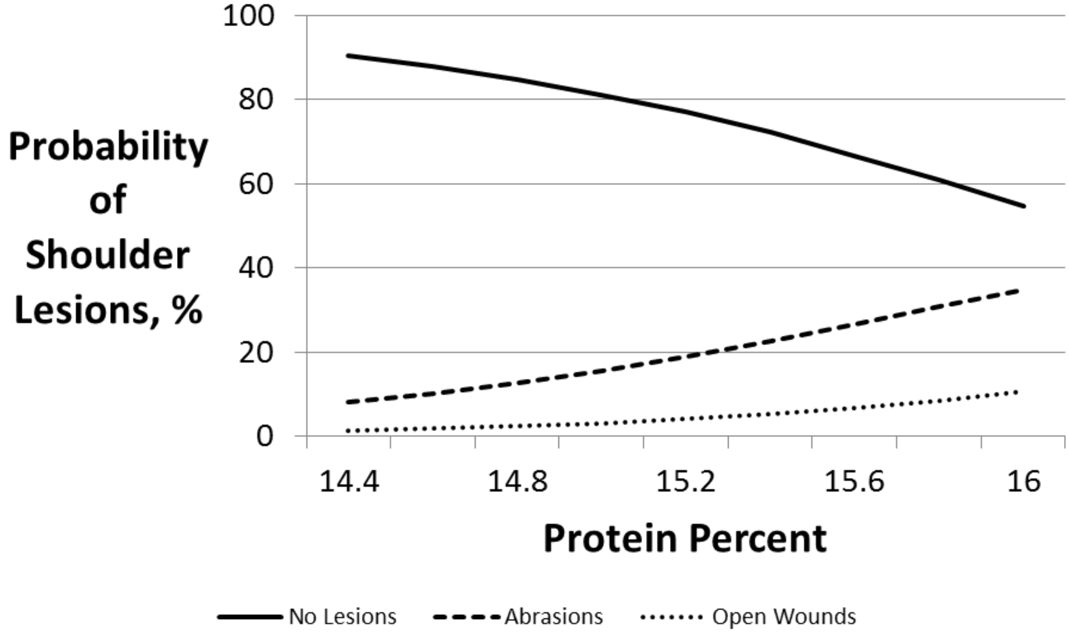

Figure 3.3. Probability of shoulder lesions at weaning associated with farrowing protein percent composition.