

Abstract

GARRISON, CHELSEA ERIN. Late Gestation Feeding Strategies to Improve Piglet Colostrum Intake and Piglet Quality. (Under the direction of Dr. Mark Knauer).

The present study examined the effect of late gestation diet (LGD) and feeding level (FL) on sow BW, sow body condition (BC), piglet colostrum intake (CI) and piglet quality. Second parity sows (n=61) at the North Carolina Tidewater Research Station were randomly allocated on d 104 of gestation, based on BC, to one of six dietary treatments in a 2 × 3 factorial design. Sows received one of two LGD, gestation (GEST) or lactation (LACT), and one of three FL (1.5, 3.0 or 4.5 kg/d). The GEST contained 2,979 Kcal/kg ME and 0.58 SID lysine and LACT contained 3,322 Kcal/kg ME, 0.99 SID lysine, and 2.5% added fat. Dietary treatments were fed until parturition. Sow BW and caliper score (CS) were documented on d 104 and 112 of gestation, and at weaning (WEAN). Piglets were weighed at birth (BWT), 24 h of age (WT24) and 21 d of age (WWT). Piglet CI was estimated as WT24 – BWT. Piglet survival was calculated as litter size at weaning (of the biological dam) ÷ total number born. During lactation, lactation feed intake (LFI) was recorded and sows were checked for estrus after WEAN and wean-to-estrus interval (WEI) was calculated. Data analysis was performed in SAS using PROC GLM. Fixed effects included diet, feeding level and a covariate of litter size for reproductive traits. Sow BW and CS traits measured after d 104 of gestation included initial measure (d 104) as a covariate. Sow was the experimental unit. Sow BW at d 104, 112 and WEAN did not differ (p<0.05) between LGD. Yet at d 112 of gestation, sows fed LACT had greater (p<0.05) CS than those fed GEST (15.25 vs. 14.73). At WEAN sows fed LACT had similar (p>0.05) CS to GEST (12.22 vs. 11.88, respectively). Sows fed LACT had similar

($p > 0.05$) LFI and WEI to those fed GEST. One kg/d increase in late gestation FL increased ($p < 0.01$) sow BW and CS on d 112 by 5.04 kg and 0.41, respectively. One kg/d increase in late gestation FL increased ($p < 0.05$) sow BW loss during lactation by 2.84 kg but not CS loss ($p > 0.05$). From d 104 to WEAN, one kg/d increase in late gestation FL tended ($p = 0.08$) to increase sow WEAN WT by 2.18 kg and improved ($p < 0.05$) WEAN CS by 0.38. Gestation FL did not impact ($p > 0.05$) LFI or WEI. Average litter size at birth, 24 h, and WEAN was 13.11, 12.49, and 11.05, respectively. Average piglet BWT, CI, and WWT were 1.16 kg, 111 g, and 5.63 kg, respectively. Total litter CI was not correlated ($p > 0.05$) with litter size. Hence on a piglet basis, an increase in litter size by one piglet reduced ($p < 0.01$) average piglet CI by 12.8 g. A one day increase in gestation length improved ($p < 0.05$) average piglet CI by 8.4 g. In relation to dietary treatments, average BWT did not differ ($p > 0.05$) between diets or feeding levels, yet average piglet CI was greater ($p < 0.01$) for sows fed LACT compared to those fed GEST (127 vs. 96 g). A kg increase in feeding level increased ($p = 0.05$) average piglet CI by 9 g. Average piglet WWT was heavier ($p < 0.01$) for sows fed LACT compared to those fed GEST (5.84 vs. 5.45 kg). Both BWT CV and WWT CV were lower ($p < 0.05$) for sows fed LACT compared to those fed GEST. Sows fed LACT had similar ($p > 0.05$) piglet survival to those fed GEST (87.3 vs. 84.2%, respectively). Results suggest, regardless of feeding level, feeding a lactation diet during the last 10 d of gestation reduced litter variation, enhanced piglet colostrum intake and improved piglet weaning weights. Increased feeding level in late gestation also increased piglet colostrum intake.

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Late Gestation Feeding Strategies to Improve Piglet Colostrum Intake and Piglet Quality

by
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Biography

Chelsea E. Garrison was born on April 19, 1989 in Pinehurst, North Carolina. She grew up in close proximity to her grandparent's crop and beef cattle farm, which led to her interest in working with large animals. Chelsea attended North Carolina State University where she received her B.S. in Animal Science. During this time she volunteered at a small animal hospital and the NCSU Dairy Unit, interned at Carolina Tiger Rescue, and worked with Dr. Mark Knauer during the summer as a swine research assistant. While gaining experience as a research assistant, she further developed her appreciation for animal agriculture and husbandry, which led to her pursuit of a Masters of Science Degree at North Carolina State University.

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Chapter 1: Literature Review

Piglet birth weight

Significance of birth weight

Low birth weight (LBW) piglets have become more common due to intense selection for sows that produce large litters (De Vos et al., 2013). Consequently, many sows are not able to support fetal growth to the full potential; a phenomenon also known as intrauterine growth restriction (IUGR) (Wollmann, 1998). Low birth weight is associated with reduced piglet quality and a decrease in the probability of survival of both the preweaning and nursery phases (Fix et al., 2010). As birth weight decreases, piglets are more likely to be poorer quality at weaning, finisher placement and at 16 weeks into finishing (Fix et al., 2010). Greater within-litter variation in birth weight can impact piglets similarly to LBW, yet individual birth weights are a more accurate predictor of survival (Fix et al., 2010). The reduced growth performance of LBW piglets results in decreased meat and carcass quality, ultimately leading to an economic loss for the farmer (De Vos et al., 2013).

Prewaning Mortality

Low birth weight piglets consume less colostrum in a highly competitive environment and, therefore, have a greater chance of preweaning mortality (Devillers et al., 2004). From 1998 to 2008, number of pigs born alive increased in the U.S. from 10.2 to 11.4 piglets per litter (PigCHAMP, 1998; PigCHAMP, 2008) perhaps indicating an increase in LBW piglets. This is because studies have shown that larger litter sizes are associated with smaller average piglet birth weights (Roehe, 1999; Quiniou et al., 2002). Based on a review of piglet survival during lactation, preweaning mortality impacts between 10 and 20% of liveborn piglets (Alonso-Spilsbury et al., 2007), with the highest proportion of deaths

occurring within the first several days of life (Fix et al., 2010). Decreasing mortality rates are of great interest to producers because of its impact on profitability, but as previously described, piglet quality also greatly influences production. This is because LBW piglets that survive but remain to be poor quality at harvest, as a result of reduced growth performance, are often sent to alternative markets at a reduced value (Fix et al., 2010).

Peripartal Feeding Strategies

Studies have examined the association of severe feed restriction of pregnant sows on birth weight and postweaning growth of piglets. Reduction of energy intake by half of the recommended (NRC, 1968) amount (6,000 kcal ME per day) during gestation has shown to decrease birth weights of piglets, with no effects on postweaning growth (Pond, 1973). Yet withholding feed during the middle or late phases of gestation for 40 days reduced both birth weight and neonatal growth (Hard & Anderson 1979). Pond et al. (1985) assigned twenty-seven sows to one of three treatment: adequate feed (1.82 kg/d) during gestation; early restricted feed intake (0.6 kg/d) during the initial 70 days of gestation, then an adequate amount until parturition; late restricted feed intake (0.6 kg/d) during the last 70 to 75 days of gestation. Litter size and number of stillborn piglets were not impacted by the treatments, however average piglet birth weight was lower for early restricted and late restricted sows compared to pigs from the adequately fed sows (1.26 and 1.10 vs. 1.44 kg, respectively). In agreement, Buitrago et al. (1974) noted a decrease in piglet birthweights when sows were fed a low energy diet of 2.2 vs. 8.0 Mcal DE per day throughout gestation. However, other studies report feeding energy levels below nutritional requirements had no

impact on piglet birth weights (Dwyer et al., 1994; Nissen et al., 2003; Rehfeldt & Kuhn, 2006), implying that sows were able to mobilize their maternal nutrients to maintain fetal growth and development (De Vos et al., 2013). Collectively these results suggest sows can mobilize body tissues to sustain fetal development when fed moderately low, but not severely low, energy levels throughout gestation.

Bump feeding during late gestation

Increasing feeding level a substantial amount during a specific period of gestation is commonly referred to as “bump feeding”. Pork producers commonly debate the value of this practice yet the science as related to piglet birth weights is quite clear. Increasing feeding level in late gestation to enhance piglet birth weights has been shown to work for gilt litters (Table 1.1), but not sows (Table 1.2, Cromwell et al., 1989; Shelton et al., 2009; Soto et al., 2011). Shelton et al. (2009) reported gilts fed an extra 0.9 kilograms of feed from day 90 of gestation to farrowing had greater average piglet birth weights than control gilts (1.50 vs. 1.41 kg). However, the same study reported multiparous sows that were bump fed had lower average piglet birth weights (1.43 vs. 1.54 kg). Similarly, Cromwell et al. (1989) showed an increase in average piglet birth weight from first litter sows that were bump fed 1.36 kilograms from day 90 of gestation to farrowing (1.40 vs. 1.36 kg) but not multiparous sows. In agreement, Soto et al. (2011) reported increased average piglet birth weights in gilt litters that were bump fed starting at day 100 of gestation (1.44 vs. 1.31 kg) but not sows. Perhaps bump feeding is successful for first parity sows because they are well short of their mature size and require nutrients for their own growth in addition to maintenance (Moehn et al., 2011).

HMB

HMB (β -hydroxy β -methyl butyrate) is a metabolite of the essential amino acid leucine that is involved in skeletal muscle protein turnover and can be used as a supplement to stimulate muscle hypertrophy and growth in meat-producing animals (Szczesniak et al., 2014). It also exhibits a role in disease prevention and enhances the immune system by increasing the metabolic activity of phagocytes and the proliferation of B and T lymphocytes (Krakowski et al., 2002).

Administration of HMB during late gestation has shown positive effects on piglet birth weight (Krakowski et al., 2002; Tatara et al., 2012), weight gained during the colostrum period (Flummer & Theil, 2012) and weight gained from birth to weaning (Nissen et al., 1994). Krakowski et al. (2002) began administration of HMB 4 to 6 weeks before parturition for 21 days at a dose of 15 mg/kg of body weight per day. The authors showed sows fed HMB had a greater mean piglet birth weight than control sows (1.24 vs 1.15 kg). In agreement, Tatara et al. (2012) reported sows fed 0.05g/kg of HMB for two weeks before farrowing had heavier piglet birth weights than controls (1.62 vs. 1.32 kg). Increases in growth hormone (GH) and insulin-like growth factor 1 (IGF-1) serum levels were shown in piglets from sows that were supplemented with HMB during gestation (Tatara et al., 2007; Tatara et al., 2012). Growth hormone and IGF-1 have a significant role in regulating growth and metabolism in both animals and humans (Tatara et al., 2007). While HMB appears to be a promising feed additive to increase average piglet birth weight, it needs to be evaluated using modern genetic lines.

Arginine

Proper amino acid intake is essential during late gestation and lactation for growth and development of fetuses and mammary glands (Everts, 1998). The ratio and total supply of required amino acids differs over the course of gestation (De Vos et al., 2013). Threonine is needed in high amounts during early gestation, while Arginine and Leucine become more vital during late gestation for mammary and fetal growth (Kim et al., 2008).

Supplementation of 1% dietary L-arginine beginning at day 30 until parturition resulted in an increase in total litter weight by 28%, and the number of pigs born alive by 23% (Mateo et al., 2007). Supplementation of arginine can also complement placental angiogenesis by means of the arginine-NO pathway (De Vos et al., 2013).

Lysine

Lysine is the first limiting amino acid in standard corn-soybean diets fed during gestation and lactation. Hence, a sow's performance relies on adequate consumption (diet composition × feed intake) of lysine (Yang et al., 2009).

Heo et al. (2008) and Yang et al. (2009) investigated the impact of dietary lysine during gestation on subsequent reproductive performance. Both studies evaluated two levels of lysine (0.6 and 0.8%) from day 80 of gestation until farrowing. Heo et al. (2008) reported no impact of lysine level on total number born, yet the increased lysine level did improve litter birth weight (15.33 vs. 13.12 kg). Similarly, Yang et al. (2009) showed no differences between treatments for total number of pigs born, but average litter birth weight was higher for sows fed 0.8 vs. 0.6% lysine (13.8 vs. 12.6 kg).

Zhang et al. (2011) used 200 multiparous sows to determine the impact of lysine intake from mid to late gestation on reproductive performance. Treatments began at day 30 of gestation, after embryos are implanted (den Hartog and van Kempen, 1980). Diets contained four different lysine levels (0.46, 0.56, 0.65 and 0.74%) and sows were fed 2.2 kg per day from day 30 to 80 of gestation and 3 kg per day from day 80 until farrowing. Results showed no impact of lysine level on total number of pigs born, yet sows fed 0.65 to 0.74% lysine had greater average piglet birth weights. Based on the study's results, the optimum level of dietary lysine for multiparous gestating sows was 0.65% as further increases in dietary lysine would add cost but not improvements in subsequent reproduction.

Kim et al. (2009) recommends the use of a phase feeding strategy during gestation to meet specific amino acid requirements as the requirements change based on fetal and mammary gland growth. When considering lysine needs for maintenance and tissue gain, sows require 5.57 grams of lysine per day from day 0 to 60 of gestation, and 8.78 grams per day from d 60 to 114 (Kim et al., 2009). Amino acid ratio demands also fluctuate during gestation. Threonine requirement increases during early gestation (d 0 to 60) while Arginine and Leucine are more imperative during late gestation (d 60 to 114) (Kim et al., 2009). Due to the differences in ideal dietary amino acid requirements, BW loss, and voluntary feed intake during lactation between primiparous and multiparous sows, Kim et al. (2009) suggests adopting a parity-split feeding system along with phase feeding. However, the complexity of these feeding practices may be too challenging for large production systems.

Colostrum

Production of colostrum begins during the final month of gestation, but primarily takes place during the last week prior to farrowing (Devillers et al., 2007). Colostrum supplies energy required for body growth and thermoregulation of neonatal piglets, provides piglets with immunological protection (Rooke and Bland, 2002) and growth factors that are essential for intestinal growth and function (Wang and Xu, 1996; Xu et al., 2000). Due to the amount of immunoglobulins present, colostrum is characterized by having a high protein concentration, which decreases by about 50% during the first 48 hours after farrowing (Klobasa et al., 1987). The metabolism of the sow changes as it progresses towards farrowing to reserve glucose for fetuses and lactation by increasing the use of energy substrates acquired from fat (Boyd and Kensinger, 1998). Lactogenesis begins at approximately day 90 of gestation and is separated into two different categories: Lactogenesis I, which prepares the mammary tissue for the production of milk components, and Lactogenesis II, the phase in which colostrum excretion takes place starting soon before parturition (Quesnel et al., 2012). From 16 to 24 hours after parturition, routine suckling of the piglets is required to trigger lactation (Quesnel et al., 2012). Colostrum intake is positively correlated with weaning, intermediate and finishing weight (Declerck et al., 2016). Hence, adequate piglet colostrum intake is necessary for preweaning survival and enhancing lifetime growth.

Piglet colostrum consumption

The most critical time for piglet survival is the first 24 hours after birth, with early death caused predominantly by inadequate colostrum consumption (Quesnel et al., 2012).

Colostrum yield is not correlated with litter size or litter weight, but is related to piglet vitality at birth (Le Dividich et al., 2005; Devillers et al., 2007; Quesnel, 2011). These results suggest as litter size has increased in the U.S. (Knauer and Hostetler, 2013), each piglet is receiving less colostrum. Devillers et al. (2011) showed piglets with a colostrum consumption of less than 200 g/d and more than 200 g/d had preweaning mortality rates of 43.4 and 7.1%, respectively. Devillers et al. (2011) explains that IgG absorption by the piglet reaches a plateau after 200 grams of ingested colostrum, as shown by plasma IgG concentrations, and uses this level as a recommended minimum amount of intake. In contrast, Le Dividich et al. (2005) suggested the minimum required amount of colostrum consumption of 160 grams per kilogram of piglet weight. Average amount of individual colostrum intake was between 250 to 300 grams in two experiments (Devillers et al., 2007; Quesnel, 2011), however there was much variation, ranging between 0 and more than 700 grams. The greatest level of intake displays the magnitude of consumption of the piglet to be very high when the supply of colostrum is unlimited (Le Dividich et al., 2005).

A study conducted by Le Dividich et al. (2005) estimated that 55% of sows do not produce the amount of colostrum needed for their litter, with two other studies estimating this percentage to be 30% (Foisnet et al., 2010; Decaluwé et al., 2013). With a recommended colostrum consumption of 180 g/kg per piglet, and an average litter size of 13 piglets, each sow would have to produce at least 3.25 kg of colostrum (Quesnel et al., 2012). Forty percent of litters are greater than 14 piglets born alive, exceeding the average number of teats on a sow (Martineau & Badouard, 2009). There has been increasing

selection for number of teats, but the heritability of teat number is 0.10 to 0.20, which is considered to be lowly heritable (Hurley, 2009).

Measuring Colostrum Yield

There are many factors that influence sow colostrum yield. Overfeeding during gestation negatively impacts mammary development as a result of excessive fat deposition (Farmer and Sorensen, 2001). There is a slight association between parity and colostrum yield, with a tendency for greater yield in second or third parity sows compared to primiparous or older sows (Devillers et al., 2007). Devillers et al. (2007) noticed a 50% drop in colostrum protein in 60% of sows within 24 hours after parturition; therefore they concluded that an appropriate time of measuring colostrum yield should be within 24 hours after the onset of farrowing (Devillers et al., 2007). An equation was formulated by Devillers et al. (2004b) to estimate colostrum intake from, birth weight and the age at estimation:

$$CI = -217.4 + 0.217 \times t + 1861019 \times BW/t + BW_B \times \left(54.80 - \frac{1861019}{t}\right) \times (0.9985 - 3.7 \times 10^{-4} \times t_{FS} + 6.1 \times 10^{-7} \times t_{FS}^2)$$

where CI = colostrum intake (g/day), BW_B =body weight at birth (kg), t_{FS} =interval between birth and first suckling (min), t =time, and BW =body weight.

Feeding Level

Peripartal feeding strategies have been shown to impact colostrum yield and nutritional composition. Decaluwé et al. (2014) showed sows fed 4.5 vs. 1.5 kg of feed per day beginning at day 108 of gestation until farrowing had greater colostrum yield per sow (3,999 vs. 3,508 g) and per kg of liveborn piglet (239 vs. 200 g). Heo et al. (2008) reported

higher fat concentration in colostrum for sows fed a high energy diet (3400 ME kg/d) versus a low energy diet (3265 ME kg/d) from d 80 to 110 of gestation.

Body condition

Decaluwé et al. (2014) reported fat sows (>23 mm of back fat) vs. sows in moderate condition (17 to 23 mm) had a lower total colostrum yield (3,163 vs. 3,991 g, respectively) and lower colostrum yield per kilogram of liveborn piglet (178 vs. 245 g). Yet the same study showed sows with moderate body condition had similar colostrum yield when compared to sows with thin condition.

HMB

Supplementation of β -hydroxy- β -methylbutyrate (HMB) during late gestation has been shown to enhance colostrum fat content (Nissen et al., 1994), colostrum yield and piglet growth (Flummer & Theil, 2012). Flummer and Theil (2012) supplemented 8 of 16 sows with 2.5 g of HMB from day 108 of gestation until 28 days after parturition. The results from this study showed an increase in colostrum yield in g/piglet (512 vs. 434 g), a lower mortality rate from 0 to 24 h postpartum (0 vs. 4.8%), and a higher weight gain of HMB piglets during the colostrum period (132 vs. 76 g/d). Nissen et al. (1994) reported a 41% increase in milk fat on day 1 of lactation for sows supplemented with 2 g of HMB beginning three to four days before farrowing and continuing through the lactation period. Perhaps the increase in milk fat is the reason for the 7% greater pig weight at weaning for pigs nursing HMB-fed sows (Nissen et al., 1994).

Lysine

Greater lysine intake during gestation has been shown to improve colostrum composition (Heo et al., 2008; Yang et al., 2009; Zhang et al., 2011). Heo et al. (2008) supplemented high lysine (0.8 vs. 0.6%) beginning on d 80 of gestation and observed an increase in colostrum protein concentration. Similarly, Yang et al. (2009) reported a positive correlation between lysine level during late gestation and colostrum protein concentration. Zhang et al. (2011) used four different lysine levels (0.46, 0.56, 0.65, and 0.74%) from d 30 to 110 of gestation. Protein concentration of colostrum increased as lysine level increased.

The NRC (NRC, 2011) recommended 0.6% lysine level for gestational diets. According to van Heugten (2000), 3.6 to 4.0 pounds of feed are needed to fulfill the average lysine requirement for sows in gestation, assuming the ration contains 0.60% of total lysine. This requirement increases during late gestation to 5.9 pounds of feed. Depending on parity, by day 115 of gestation a sow's lysine requirement is between 15.3 and 16 grams per day (Everts, 1994). Zhang et al. (2011) supports the concept that the lysine levels recommended by the NRC (1998) for multiparous sows in gestation (0.52 to 0.54%) are not sufficient to support high quality colostrum, increased piglet birth weight, and optimal body condition of the sows. To optimize these criteria, Zhang et al. (2011) proposed a dietary level of 0.65% lysine for multiparous gestating sows. While 0.75% lysine resulted in even greater productivity in this study, it would not be economically efficient for producers to use this level.

Fat

Piglets are born with only about 2% body fat, most of which is structural and cannot be used as energy (Mersmann, 1974). Piglets from sows supplemented with fat did not mobilize more fat during a 72-hour fast after birth when compared to controls (Seerley et al., 1978a; Seerley et al., 1978b), therefore it seems that fat supplementation to sows during late gestation only slightly enhances piglets' energy stores at parturition (Pettigrew, 1981). An alternative method to increase energy availability to piglets would be to increase the fat in the sow's colostrum and milk. Adding dietary fat during late gestation results in a higher fat concentration of colostrum (Pettigrew, 1979). When exposed to cold stress at 54 hours of age, piglets from sows fed added fat were more thermostable compared with control piglets (Seerley et al., 1974), but this treatment difference was not portrayed when cold stress took place at 6 hours of age (Pettigrew, 1979). These results suggest that the advantages to piglets of added fat in the sow's diet are derived from colostrum and milk (Pettigrew, 1979).

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Tables:

Table 1.1: Effect of feeding level in late gestation on piglet birth weight (kg) in gilts.

Study	Day of gestation	Control	Increased feed
Cromwell et al. (1989)	90 to 115	1.36	1.40
Shelton et al. (2009)	90 to 115	1.41	1.50*
Soto et al. (2011)	100 to 115	1.31	1.44*

*p<0.05, control vs. increased feed

Table 1.2: Effect of feeding level in late gestation on piglet birth weight (kg) in sows.

Study	Day of gestation	Control	Increased feed
Cromwell et al. (1989)	90 to 115	1.48	1.46
Shelton et al. (2009)	90 to 115	1.54	1.43
Soto et al. (2011)	100 to 115	NR	NR

NR = not reported, not significant

Chapter 2: Late gestation feeding strategies to improve piglet colostrum intake and piglet quality

Abstract

The present study examined the effect of late gestation diet (LGD) and feeding level (FL) on sow BW, sow body condition (BC), piglet colostrum intake (CI) and piglet quality. Second parity sows (n=61) at the North Carolina Tidewater Research Station were randomly allocated on d 104 of gestation, based on BC, to one of six dietary treatments in a 2 × 3 factorial design. Sows received one of two LGD, gestation (GEST) or lactation (LACT), and one of three FL (1.5, 3.0 or 4.5 kg/d). The GEST contained 2,979 Kcal/kg ME and 0.58 SID lysine and LACT contained 3,322 Kcal/kg ME, 0.99 SID lysine, and 2.5% added fat. Dietary treatments were fed until parturition. Sow BW and caliper score (CS) were documented on d 104 and 112 of gestation, and at weaning (WEAN). Piglets were weighed at birth (BWT), 24 h of age (WT24) and 21 d of age (WWT). Piglet CI was estimated as WT24 – BWT. Piglet survival was calculated as litter size at weaning (of the biological dam) ÷ total number born. During lactation, lactation feed intake (LFI) was recorded and sows were checked for estrus after WEAN and wean-to-estrus interval (WEI) was calculated. Data analysis was performed in SAS using PROC GLM. Fixed effects included diet, feeding level and a covariate of litter size for reproductive traits. Sow BW and CS traits measured after d 104 of gestation included initial measure (d 104) as a covariate. Sow was the experimental unit. Sow BW at d 104, 112 and WEAN did not differ ($p < 0.05$) between LGD. Yet at d 112 of gestation, sows fed LACT had greater ($p < 0.05$) CS than those fed GEST (15.25 vs. 14.73). At WEAN sows fed LACT had similar ($p > 0.05$) CS to GEST (12.22 vs. 11.88, respectively). Sows fed LACT had similar ($p > 0.05$) LFI and WEI to those fed GEST. One kg/d increase in late gestation FL increased ($p < 0.01$) sow BW and CS on d 112 by 5.04 kg and 0.41, respectively. One kg/d increase in

late gestation FL increased ($p < 0.05$) sow BW loss during lactation by 2.84 kg but not CS loss ($p > 0.05$). From d 104 to WEAN, one kg/d increase in late gestation FL tended ($p = 0.08$) to increase sow WEAN WT by 2.18 kg and improved ($p < 0.05$) WEAN CS by 0.38. Gestation FL did not impact ($p > 0.05$) LFI or WEI. Average litter size at birth, 24 h, and WEAN was 13.11, 12.49, and 11.05, respectively. Average piglet BWT, CI, and WWT were 1.16 kg, 111 g, and 5.63 kg, respectively. Total litter CI was not correlated ($p > 0.05$) with litter size. Hence on a piglet basis, an increase in litter size by one piglet reduced ($p < 0.01$) average piglet CI by 12.8 g. A one day increase in gestation length improved ($p < 0.05$) average piglet CI by 8.4 g. In relation to dietary treatments, average BWT did not differ ($p > 0.05$) between diets or feeding levels, yet average piglet CI was greater ($p < 0.01$) for sows fed LACT compared to those fed GEST (127 vs. 96 g). A kg increase in feeding level increased ($p = 0.05$) average piglet CI by 9 g. Average piglet WWT was heavier ($p < 0.01$) for sows fed LACT compared to those fed GEST (5.84 vs. 5.45 kg). Both BWT CV and WWT CV were lower ($p < 0.05$) for sows fed LACT compared to those fed GEST. Sows fed LACT had similar ($p > 0.05$) piglet survival to those fed GEST (87.3 vs. 84.2%, respectively). Results suggest, regardless of feeding level, feeding a lactation diet during the last 10 d of gestation reduced litter variation, enhanced piglet colostrum intake and improved piglet weaning weights. Increased feeding level in late gestation also increased piglet colostrum intake.

Introduction

Selection for hyperprolific sows has increased the percentage of low birth weight piglets (M. De Vos et al., 2013), reduced litter uniformity (Wolf et al., 2008), and intensified the metabolic demand of the sow to produce an adequate level of colostrum for her litter

(Decaluwé et al., 2014). Low birth weight piglets are physiologically compromised in the amount of stored energy available, and therefore more susceptible to hypothermia and are at a disadvantage when it comes to competing with littermates at the udder (Wolf et al., 2008). The fundamental roles of colostrum are to supply the piglet with energy for thermoregulation and growth, as well as passive immunity in the form of immunoglobulins (King'ori, 2012). Roughly 30% of sows do not produce a sufficient amount of colostrum for their litter (Foisnet et al., 2010; Decaluwé et al., 2013) and 20-30% of piglet mortality results from inadequate nutrition (Fahmy and Benard, 1971). In an effort to ameliorate these counterproductive impacts, studies are needed to evaluate the impact of peripartal feeding strategies during gestation on colostrum output and subsequent reproduction. Hence, the purpose of the present study was to investigate the influence of diet and feeding level during late gestation on sow BW, sow body condition (BC), piglet colostrum intake (CI), and piglet quality.

Materials and Methods

Sows

Second parity sows (n=61) from the North Carolina Tidewater Research Station were used. The experiment was conducted during the summer months of June and July 2016. At d 104 of gestation, sows were moved to individual farrowing stalls and randomly allocated based on body condition to one of six dietary treatments in a 2 × 3 factorial design. Sows received one of two LGD (Tables 2.1 and 2.2), gestation (GEST) or lactation (LACT), and one of three FL (1.5, 3.0 or 4.5 kg/d). The GEST contained 2,979 Kcal/kg ME and 0.58 SID lysine and LACT contained 3,322 Kcal/kg ME and 0.99 SID lysine with 2.5% added fat. Sows were

fed once per day in the morning beginning at 7:30 AM. Any remaining feed from the previous day was weighed and discarded to ensure precise data collection of feed intake. Dietary treatments were fed until parturition. Each sow had ad libitum access to water. Sow BW and caliper score (CS) were documented on d 104 and 112 of gestation, and at weaning (WEAN). Caliper score, an objective measure of sow BC (Knauer and Baitinger, 2015), was measured at the last rib. A CS of <12, 12 to 15 and >15 represented BC categories of thin, ideal and fat, respectively. During lactation, sows were fed to appetite twice daily and lactation feed intake (LFI) was recorded. Piglet survival was calculated as litter size at weaning (of the biological dam) ÷ total number born. At WEAN, sows were detected for estrus daily using mature boars and wean-to-estrus interval (WEI) calculated.

Piglets

At parturition, each piglet was dried by placing it in a plastic tote beneath a 125 watt heat lamp. Feed was used in the bottom of the tote as a drying agent. Once dry, piglets were ear notched for identification, weighed (BWT) and returned to the dam to nurse. Farrowing intervention was applied when the interval between two piglets exceeded 45 min or after the birth of a stillborn piglet. Median farrowing time was calculated for each litter and the piglets were reweighed at 24 h of age (WT24). Piglet colostrum intake (CI) was estimated as WT24 – BWT. Colostrum samples were collected within two hours of parturition.

Statistical analysis

Data analysis was performed in SAS (SAS Institute, Cary, NC) using PROC GLM for both sow BW and reproduction parameters. Trait definitions are shown in Table 3. Fixed

effects for all traits included diet fitted as a categorical variable and feeding level fitted as a quantitative variable. A covariate of litter size was included for all reproductive traits. Sow BW and CS traits measured after d 104 of gestation included initial measure (d 104) as a covariate. Sow was the experimental unit.

Results and Discussion

Sow Reproductive Performance

Total litter BWT was not influenced by diet ($p=0.09$). In contrast, studies have quantified a positive correlation between litter birth weight and dietary lysine level during gestation (Heo et al., 2008; Yang et al., 2009; Zhang et al., 2011). Perhaps differences between the current study and past studies are explained by lysine level and duration of dietary treatments. In the current study, lysine levels for the GEST and LACT diets were 0.68 and 1.1%, respectively. Heo et al. (2008) and Yang et al. (2009) used lysine levels of 0.6 and 0.8%, while Zhang et al. (2011) used four lysine levels of 0.46, 0.56, 0.65 and 0.74%. In the current study dietary treatments were fed from d 104 of gestation to parturition compared with Heo et al. (2008) and Yang et al. (2009) who administered dietary treatments from d 80 to farrowing and Zhang et al. (2011) who fed dietary treatments from d 30 to 110 of gestation.

Increased feeding level during late gestation did not improve ($p>0.05$) total BWT or average BWT. Increased feeding level during late gestation, commonly called “bump feeding”, has been shown to increase piglet birth weight in gilt litters, but not in sow litters (Cromwell et al., 1989; Shelton et al., 2009; Soto et al., 2011). Perhaps this is because first parity sows are still reaching their mature size and require additional nutrients during

gestation for maintenance (Moehn et al., 2011). Yet severe feed restriction from d 30 to 70 and d 50 to 90 of gestation has shown reduced litter birth weights (Hard and Anderson, 1979). Perhaps these results can be explained by low levels of progesterone, which is a hormone required to prepare the body for pregnancy by increasing uterine gland secretions, promoting implantation, and aiding in mammary gland development (Frandsen et al., 2009). Hard and Anderson (1979) discovered a decrease in blood serum progesterone concentrations from sows without feed during the middle of gestation (d 30-70) compared to those fed 7,028 kcal/day.

Prolificacy can be defined as the number viable piglets produced per year or per lifetime. This trait is determined by age at first successful mating, ovulation rate, embryo survival, number of pigs born alive, and the sow's capability to be successfully rebred at regular intervals (Aherne and Kirkwood, 1985). In the current study, total number born (TNB) was not influenced by diet or feeding level, which corresponds with other dietary treatments during late gestation (Pond et al., 1985; Mahan, 1998; Yang et al., 2009). Porcine embryo attachment to the uterine wall occurs at d 12 of gestation (Dziuk, 1985), thus number of piglets born should not be affected by maternal nutrition factors late in gestation. However, measures could be taken during late gestation to decrease the occurrence of mummies and stillborn piglets, such as optimal feed quality and proper management practices.

The average BWT for individual piglets did not differ between the dietary treatments, however there was less ($p=0.05$) within-litter BWT variation for sows fed LACT compared to sows fed GEST (16.9 vs. 20.1% CV). Perhaps this is explained by the higher

amino acid concentration in the lactation diet. Feeding amino acids below required levels has resulted in negative effects such as intrauterine growth restriction (Wu et al., 2004) and less litter uniformity due to suppression of placental vascularity (Redmer et al., 2004). Therefore, to avoid this increase in birth weight variation, adequate amino acid availability is vital. This is supported by results from Kim et al. (2009) who reported BWT CV was lower in gilt litters that were fed an ideal amino acid diet when compared to control fed gilts (14.4 vs. 18.5%).

Colostrum Intake

Inadequate colostrum consumption causes a decrease in body temperature in newborn pigs, and is the underlying basis for most piglet deaths occurring soon after parturition (Quesnel et al., 2012). Thus, nutritional strategies to enhance energy transfer from sow to offspring should be implemented to increase piglet survival (Theil et al., 2014). In the current study, total colostrum intake was greater ($p=0.04$) for litters from LACT sows compared to those from GEST (1423 vs. 1139g). Hence, on a piglet basis, average colostrum intake was increased ($p=0.01$) by 32% for the LACT sows.

Late gestation feeding level influenced ($p=0.05$) average piglet CI. A one kg/d increase in feeding level increased average colostrum intake by 9.3 g. Decaluwé et al. (2014) discovered an increase in colostrum yield per kg liveborn piglet (239 vs. 200 g) for sows fed 4.5 kg of feed from d 108 of gestation compared with sows fed 1.5 kg of feed. These results suggest increased feeding level in late gestation can enhance piglet colostrum intake. Yet the economics of an increased feeding level should be further evaluated.

A one day increase in gestation length enhanced ($P<0.05$) piglet colostrum intake by 8.4 g per piglet. These results are supported by Devillers et al. (2007) who reported inducing farrowing reduced colostrum production. Hence, it is suggested farrowing induction not be utilized in herds with low colostrum production.

A one unit increase in caliper score at d 104 of gestation tended ($P=0.06$) to improve piglet colostrum consumption by 5.5 g per piglet. In contrast, Decaluwé et al. (2014) reported piglets from sows over 23 mm of backfat had lower consumption when compared to leaner sows.

In the current study, sows fed the diet with greater CI (LACT), also had heavier ($P<0.05$) WWT when compared to those fed the GEST diet. Several authors have reported a positive association between colostrum intake on weaning weight (Decaluwé et al., 2014; Ferrari et al., 2014; Vallet et al., 2015 Declerck et al., 2016) due to the fact that piglets with high colostrum intake generally have more energy and are able to compete with littermates to maintain routine suckling. These observations confirm the crucial role of nutrition during late gestation on not only colostrum production, but also lifetime growth (Declerck et al., 2016).

Piglet Survival

Piglet survivability was not influenced by dietary treatments. Yet the LACT diet had numerically better piglet survival than the GEST diet. Pettigrew (1981) found that supplementation of fat during late gestation resulted in an increase in colostrum fat, leading to an increase in piglet survival, but only if the herd survival rate was less than 80%, and the sow consumed at least 1,000 grams of fat before parturition. Sows fed LACT in the current

study were supplemented with less than 1,000 grams of fat from d 104 of gestation to farrowing and piglet survival was 85.8%. Hence, this may explain the lack of difference in piglet survival between the two dietary treatments.

Piglet weaning weight

Neither diet nor feeding level impacted total WWT. Yet average WWT was greater ($p=0.01$) for piglets from LACT sows when compared to GEST sows (5.84 kg vs. 5.45 kg) and WWT CV was lower ($p=0.02$) for litters from LACT sows (14.7 vs. 17.9%). In contrast, Heo et al. (2008) noted a greater litter WWT for pigs from sows fed a higher lysine (0.8 vs. 0.6%) diet from d 80 to 110 of gestation. The same study reported litters of sows with high lysine intake grew 23% faster than those of sows with low lysine intake (2.59 vs 2.10 kg/d).

Sow Weight & Body Condition

Sow weight gain from d 104 to 112 was influenced by feeding level ($p<0.01$) but not diet ($p>0.05$). A one kg increase in daily late gestation feed intake increased sow weight at d 112 by 5 kg. In contrast, Heo et al. (2008) and Yang et al. (2009) showed a greater body weight change in sows fed 0.8 vs. 0.6% dietary lysine from d 80 to 110 of gestation. Perhaps a longer gestation feeding period in the current study would have led to a more noticeable difference in body weight change between the GEST and LACT treatments.

Sow body condition change from d 104 to 112 was impacted by both diet ($p=0.03$) and feeding level ($p<0.01$). Sows fed LACT lost less body condition when compared with GEST sows (-0.3 vs. -0.9 units). A one kg/d increase in feed intake enhanced CS at d 112 of gestation by 0.4 units. In agreement, Heo et al. (2008) and Yang et al. (2009) reported greater backfat thickness in sows fed high vs. low lysine diets during late gestation. In

contrast, Heo et al. (2008) showed no impact of energy intake on sow backfat thickness when feeding three different levels of ME (3265, 3330, or 3400 ME kg) from d 80 to 110 of gestation. Yet Cools et al. (2014) reported sows fed ad libitum vs. standard level from d 105 of gestation to farrowing had greater backfat thickness at parturition. Collectively, these results indicate increasing lysine level or feed intake in late gestation can enhance sow body condition.

Weight loss during lactation was correlated with feeding level ($p < 0.05$) but not impacted by diet ($p > 0.05$). Sows lost 2.8 kg in weight during lactation for each 1 kg increase in feed during gestation. On the contrary, Heo et al. (2008) reported an inverse relationship between body weight loss during lactation and gestational dietary lysine concentration.

Sows fed more during late gestation lost more weight during lactation, yet had greater ($p = 0.05$) body condition at weaning. Similarly, Heo et al. (2008) found sows that were fed 3400 ME kg in late gestation lost less backfat and body weight during lactation when compared to those fed 3330 or 3265 ME kg.

Sow weight at weaning did not differ ($p > 0.05$) between diets, but tended ($p = 0.08$) to increase as feeding level increased. Weight at weaning was 2.2 kg heavier for each additional kg of feed intake. Heo et al. (2008) found a significant effect of both energy and lysine level on primiparous sow body weight during lactation. Yang et al. (2009) explains that sows will mobilize body fat and protein for milk production when lysine intake is inadequate, but that primiparous sows seem to be more sensitive than multiparous sows to lysine concentration during late gestation.

Wean-to-estrus interval

There was no influence of dietary treatments on wean-to-estrus interval (WEI). In contrast, Heo et al. (2008) reported a significant shorter WEI for primiparous sows fed high lysine diet during late gestation with no effect from energy intake. Yang et al. (2009) had shorter WEI for sows fed high lysine during lactation, but WEI was not influenced by lysine level during late gestation. Lower lysine intake leads to decreased LH (luteinizing hormone) pulses during early lactation and weaning, causing a prolonged WEI, especially in first-parity sows (King & Martin, 1989; Jones & Stahly, 1999b; Yang et al., 2000b).

Feed Cost

Feed is the largest expense of swine production, averaging 75 percent of total expenses in a farrow-to-finish operation (Linneen et al., 2016). In the present experiment, the cost for gestation feed was \$0.2147 per kg and the cost for lactation feed was \$0.2756 per kg. Considering average gestation length, mortality difference between treatments, and number of pigs weaned, the return on investment was approximately 8:1. Yet feed prices fluctuate regularly.

Table 2.1: Sow reproductive performance by late gestation (d 104 to farrowing) diet (LSMEANS) and feeding level (estimates).

<i>Trait</i>	<i>Gestation diet</i>				<i>Feeding level</i>		
	Gestation	Lactation	SE	p-value	Level	SE	p-value
<i>TNB</i>	13.34	12.86	0.70	0.50	0.019	0.286	0.95
<i>Total BWT, kg</i>	15.27	14.46	0.48	0.09	0.058	0.193	0.77
<i>Average BWT, g</i>	1180	1138	35	0.24	0.727	14	0.96
<i>BWT CV, %</i>	20.1	16.9	1.6	0.05	0	0.627	0.99
<i>Total WWT, kg</i>	60.0	62.3	1.6	0.15	0.80	0.63	0.21
<i>Average WWT, kg</i>	5.45	5.84	0.14	0.01	0.07	0.06	0.26
<i>WWT CV, %</i>	17.9	14.7	1.4	0.02	0.02	0.58	0.97
<i>LS21</i>	10.99	11.12	0.55	0.84	-0.13	0.22	0.56
<i>Litter colostrum intake, g</i>	1139	1423	138	0.04	90	56	0.11
<i>Piglet colostrum intake, g</i>	95.9	126.8	11.2	0.01	9.3	4.6	0.05
<i>Piglet Survival, %</i>	84.2	87.3	2.9	0.29	-1.2	1.2	0.33

TNB = total number of piglets born

BWT = birth weight

WWT = wean weight

LS21 = Litter size at weaning

Level = Feeding level (kg/d)

Table 2.2: Sow Weight and Body Condition Change by late gestation (d 104 to farrowing) diet (LSMEANS) and feeding level (estimates).

<i>Trait</i>	<i>Gestation diet</i>				<i>Feeding level</i>		
	<i>Gestation</i>	<i>Lactation</i>	<i>SE</i>	<i>p-</i>	<i>Level</i>	<i>SE</i>	<i>p-</i>
<i>Sow wt 104</i>	230.7	231.7	5.2	0.85	-1.6	2.1	0.45
<i>Sow wt 112</i>	240.6	240.5	0.8	0.88	5.0	0.3	<.0001
<i>Sow wt gain 104 to 112</i>	9.8	9.7	0.8	0.88	5.0	0.3	<.0001
<i>Sow caliper 104</i>	15.4	15.8	0.5	0.36	-0.1	0.2	0.48
<i>Sow caliper 112</i>	14.7	15.3	0.2	0.03	0.4	0.1	<.0001
<i>Sow caliper gain 104 to</i>	-0.9	-0.3	0.2	0.03	0.4	0.1	<.0001
<i>Sow BW at wean</i>	204.9	204.8	3.0	0.96	2.2	1.2	0.08
<i>Sow BW loss</i>	35.8	36.0	3.2	0.94	2.8	1.3	0.03
<i>Sow caliper at wean</i>	11.9	12.2	0.47	0.47	0.4	0.2	0.05
<i>Sow caliper loss</i>	2.9	3.0	0.44	0.76	0.0	0.2	0.85
<i>Average LFI</i>	4.90	4.84	0.18	0.73	-0.01	0.06	0.90
<i>Wean to estrus</i>	5.11	4.96	0.29	0.59	-0.02	0.12	0.86

LFI = lactation feed intake

Table 2.3: Calculated composition of diets fed from d 104 of gestation until farrowing.

Ingredient	Diet	
	Gestation	Lactation w/fat
Corn	1444	1400.5
Soybean Meal	176	453
Soy Hulls	300	
5823 Sow Base 80	80	80
5502 GroMax 7.5 XE3		6.5
5054 Easy Lax		10
Fat		50
Total:	2000	2000
Calculated Nutrients		
ME, Kcal/kg	2979	3322
Net Energy, Kcal/kg	2273	2455
Crude Protein, %	10.98	15.97
Lysine, %	0.68	1.1
TID Lysine, %	0.58	0.99
Calcium, %	0.85	0.89
Phosphorus, %	0.61	0.68

Table 2.4: Nutrient analysis of diets fed from d 104 of gestation until farrowing.

Dry Matter Basis	Diet	
	Gestation	Lactation w/fat
Crude Protein, %	12.14	17.81
Neutral Detergent Fiber, %	15.06	8.15
Acid Detergent Fiber, %	9.00	3.59
Non-fiber Carbohydrate, %	63.98	63.30
Fat, %	3.03	5.04
Calcium, %	0.76	0.69
Phosphorus, %	0.58	0.65
Sulfur, %	0.29	0.36
Magnesium, %	0.25	0.26
Sodium, %	0.18	0.18
Potassium, %	0.72	0.92
Copper, ppm	26	36
Iron, ppm	421	378
Manganese, ppm	60	56
Zinc, ppm	125	114
Ash, %	5.79	5.69
Aflatoxin, ppb	0.00	0.00

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