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Effects of Phase Feeding During Gestation on Gilt Performance, Offspring Quality and Robustness

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EFFECTS OF PHASE FEEDING DURING GESTATION ON GILT PERFORMANCE, OFFSPRING QUALITY AND ROBUSTNESS

BY

AGATHA AMPAIRE

A dissertation submitted in partial fulfillment of the requirements for the

Doctor of Philosophy

Major in Animal Science

South Dakota State University

2017
EFFECT OF PHASE FEEDING DURING GESTATION ON GILT PERFORMANCE,
OFFSPRING QUALITY AND ROBUSTNESS

This dissertation is approved as a creditable and independent investigation by a
candidate for the Doctor of Philosophy degree and is acceptable for meeting the
dissertation requirements for this degree. Acceptance of this does not imply that the
conclusions reached by the candidate are necessarily the conclusions of the major
department.

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ABBREVIATIONS

ADFI  average daily feed intake
ADG   average daily gain
ad lib ad libitum
ANOVA analysis of variance
anti-OVA anti-ovalbumin
BW    body weight
CAA   Candida albicans
CF    correction factor
cm    centimeter
CP    crude protein
CV    coefficient of variation
d    day
g    gram
h    hour
IgG   immunoglobulin G
IGF   Insulin-like growth factor
IUGR  intra uterine growth restricted
Kcal  kilocalorie
kg    kilogram
Lys   lysine
ME    metabolizable energy
mg    milligram
min   minute
mL    milliliter
mm  millimeter

mM  millimolar

mmol  millimole

µg  microgram

µL  microliter

NRC  National Research Council

OD  optical density

OVA  ovalbumin

PBS  phosphate buffered saline

RT  room temperature

SDSU  South Dakota State University

SEM  standard error of the mean
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ABSTRACT

EFFECT OF PHASE FEEDING DURING GESTATION ON GILT PERFORMANCE, OFFSPRING QUALITY AND ROBUSTNESS

AGATHA AMPAIRE

2017

A total of 51 gilts in 6 blocks were randomly assigned to one of 3 feeding regimens: Constant (Constant-f), 2.21 kg/d of a standard diet from breeding to d 112 of gestation (1.7 g Lys/kcal ME; 3276 kcal ME/kg); Bump feeding (Bump-f), the standard diet at 2.21 kg/d from breeding to d 89 and 2.61 kg/d from d 90 - 112; Phase feeding (Phase-f), 2.21 kg/d from breeding to d 89 (1.5 g Lys/kcal ME; 3275 kcal ME/kg) and 2.61 kg/d from d 90 - 112 (2.1 g Lys/Kcal ME; 3290 Kcal ME/kg) over 2 reproductive cycles. Sows received a common lactation diet from d 113 to weaning and weaned pigs received common diets post weaning. To assess gilt performance, BW, back fat, litter size, colostrum protein content and lactation feed intake were measured. To assess piglet quality and robustness, cord blood cortisol, liver and muscle glycogen at birth, immunocrit, serum IGF-1 concentrations, piglet birth weight distribution, weekly BW, and weaned pig feed intake and immune responses were measured. Data were analyzed in SAS using the Mixed and Correlation procedures in a completely randomized block design with gilt or sow as the experimental unit. Feeding regimen had minimal effects on overall gilt and sow performance. In parity 1, piglets from Phase-f gilts tended to have greater \( P = 0.13 \) cord blood cortisol than piglets from Bump-f and Constant-f sows,
tended to have a higher proportion \((P = 0.07)\) of piglets born alive in a mid-body weight category than piglets from Bump-f sows and weaned pigs from Phase-f sows consumed more feed \((P = 0.03)\) than weaned pigs from Constant-f sows when exposed to a nutritional stressor. In Parity 2, piglets from Phase-f sows tended \((P = 0.07)\) to gain more weight in week 3 of lactation, gained more weight post wean \((P = 0.05)\), and pigs from Phase-f sows tended to consume more feed \((P = 0.07)\) when exposed to a nutritional stressor than pigs from Constant-f and Bump-f sows. Piglets and weaned pigs from Phase-f sows had better performance than those from Bump-f and Constant-f sows.

**Key words:** Phase feeding, piglet survival, weaned pig performance
1.0 LITERATURE REVIEW

1.1 Introduction

Nutrition plays an important part in all body processes by providing energy, amino acids, micro and macro minerals, vitamins and water needed for growth, development and maintenance. The level and quality of nutrition has implications for animal performance because several nutrients can act as signaling molecules and regulate specific functions of proteins (Kuruvilla et al., 2002; Li et al., 2011). For example, branched chain amino acids stimulate protein synthesis in skeletal muscle (Kimball and Jefferson, 2006) but, the signaling pathways related to protein synthesis and amino acid concentration in pig skeletal muscles depend on the dietary protein level, genotype and developmental stage (Liu et al., 2015). Therefore, the quality, quantity and timing of nutrient supply are important. To adequately feed gestating animals, the developmental stages of the dam (primiparous vs multiparous) and the fetuses (early, mid or late gestation) must be considered simultaneously. Nutritional needs of a mature sow differ from those of a gilt, and different stages of gestation require different levels of nutrients (De Vos et al., 2014). Additionally, continuous improvement in animal genetics due to changes in animal breeding goals mean that animal nutrition recommendations need to be continually assessed to match the genetic potential of the animals to meet the livestock improvement goals. Nutritional needs of highly performing animals are different from those of lower producing animals and other factors such as environment and health status also influence the nutritional needs of animals.
The *Nutrient requirements of swine* published by the National Research Council (NRC) is updated periodically (the most recent update was in 2012) and provides feeding recommendations based on the most up to date empirical data from animal nutrition trials. The NRC (2012) sow nutrient requirements models reflect input from empirical data which showed that there is an increase in nutrient requirements in late gestation (Levesque et al., 2011; Samuel et al., 2012). Sows require nutrients for maintenance of body tissues (Miller et al., 2000), continued growth in body size (McGlone et al., 2004), and growth of tissues associated with reproduction such as uterus, placenta and mammary tissue (Ji et al., 2006). Piglets grow exponentially during late gestation, thus requirements for fetal tissues increase considerably (McPherson et al., 2004; Buddington et al., 2012).

The sow nutrient requirements model uses empirical data on protein retention in key tissues [maternal body protein (energy intake dependent and time dependent), fetus, placenta and fluids, uterus and mammary glands] to model changes in protein accretion in these tissues throughout gestation and estimate amino acid requirements (Figure 1.1).
Figure 1.1 Changes in protein deposition in key tissues during gestation (NRC 2012)

Adapted from Goodband et al. (2013).

The same procedure is followed to estimate energy requirements; energy retention is modeled for maintenance, maternal growth (protein and fat deposition), fetus, uterus and placenta and mammary tissue (Figure 1.2).

Figure 1.2 Energy requirement by key tissues during gestation (NRC 2012)

Adapted from Goodband et al. (2013)

By late gestation the fetus is fully formed but functionality of the organ systems may still be limited until a few weeks or days before parturition (Herpin et al., 2002).

This period of final maturation is potentially an ideal time for piglet quality to be
influenced by nutrition. There are many studies on sow nutrition in general, with most studies evaluating the impacts of adding a nutrient source to the sow diets such as fat (Rooke et al., 2001; van der Peet-Schwering et al., 2004; Mateo et al., 2009), fiber (Loisel et al., 2013; Quesnel et al., 2009), and minerals (Peters and Mahan, 2008; Jongbloed et al., 2004). Fewer recent studies have reported on feeding different levels of protein and energy. The available studies either increase or decrease the supply of protein and/or energy in the diet above or below the nutritional requirement throughout gestation. Very few studies focus on protein and energy supply in late gestation and even fewer studies have assessed the effects of nutrient supply over successive parities.

1.2 Impacts of gestation protein and energy nutrition on sow performance

Inadequate nutrition results in loss of body condition and loss of condition is likely to be more pronounced in late gestation because at this stage of gestation, fetal growth is the priority for use of available nutrients after maintenance. In the event of inadequate nutrient supply the sow will mobilize body tissues for nutrients to maintain fetal growth (Yang et al., 2009). Mobilization of maternal tissues manifests as reduced maternal body weight (BW) and back fat. Sow back fat has been shown to impact colostrum quantity and long term offspring growth. Sows with high back fat (19 mm) in gestation had heavier and fatter pigs with low carcass yield at slaughter (Amdi et al., 2014) and sows that lost back fat during gestation decreased colostrum yield (Decaluwe et al., 2013). Over feeding sows in late gestation can lead to over conditioned sows that have farrowing problems such as prolonged farrowing (Ji et al., 2006), which is thought to be due to lower uterine muscle tone especially in older sows (Gonçalves et al., 2016). This can lead to an increase in still born piglets, reducing the number of piglets born alive
(Gonçalves, 2016). Fewer piglets born alive will impact measures of sow productivity such as number of pigs per sow per year. Over feeding gilts can exacerbate leg and feet problems because the still developing skeleton is forced to bear a heavier BW (Ytrehus et al., 2007). Farrowing problems and leg soundness problems increase the culling rate (Dourmad et al., 1994) and hence reduce the longevity and lifetime productivity of the sow. A reduction in piglets born alive, reduced growth rate of piglets during lactation due to lower milk yield and increased culling lead to lower profitability. Diets which are not adequately balanced to meet protein and energy requirements, whether they contain high protein and low energy or vice versa are both detrimental to sow performance (Rehfeldt et al., 2011; Metges et al., 2014). It is imperative that sows receive the right balance of protein and energy in the diets.

In a study where diets containing lysine (Lys) levels commonly used in industry (0.6 and 0.8%) were fed starting at d 80 of gestation, Yang et al. (2009) found that sow BW and back fat increased in the higher Lys group and there was no difference in total born but the higher Lys group had a greater litter birth weight. Gonçalves et al. (2016) fed low and high Lys (10.7 and 20 g/d SID Lys) and low and high energy (4.5 and 6.4 Mcal/d NE) diets starting at d 90 of gestation. The combination of high energy and high protein in the diet had a positive effect on sow BW, but there was no treatment effect on the number born. The high-energy diet decreased the probability of piglets born alive compared to low energy diets because of increased still born piglets. Piglet birth weight was increased in high energy but protein level did not influence piglet birth weight. High protein regardless of energy level decreased pre-weaning mortality. These recent studies
show that increased nutrition in late gestation is beneficial to the sow and piglets and it appears that higher protein increases the benefits observed.

1.3 Impacts of sow nutrition in late gestation on neonatal piglet performance

The sow is the sole source of nutrients to the developing fetus, hence the quality and quantity of nutrients supplied to the sow is expected to influence fetal growth and development which has implications for piglet performance prenatally, during parturition and postnatally.

1.3.1 Pre-natal piglet growth

The nutritional environment to which the fetus is exposed prenatally impacts postnatal performance which may be due to changes in the physiology of the dam that in turn lead to altered physiology of the offspring. For example, high protein-low carbohydrate and low protein-high carbohydrate diets fed to sows during gestation resulted in different metabolic responses; the high protein-low carbohydrate group reduced glucose turnover and oxidation while the low protein-high carbohydrate group had higher glucose utilization. Consequently, fetuses from both groups prematurely expressed hepatic gluconeogenic enzymes (Metges et al., 2014). Premature utilization of body reserves for glucose instead of glucose from the sow while still in-utero could increase their chances of postnatal mortality due to insufficient energy stores after birth.

Within a litter of piglets, there are varying birth weights. Among the theories used to explain this phenomenon is inadequate nutrient supply to the small piglets due to placental insufficiency caused by uterine crowding (De Vos et al., 2013; Oksbjerg et al., 2013). It is possible that the physiology of the small piglets is altered because of the
inadequate nutrient supply. Metges et al. (2014) postulated that altered maternal and fetal glucose metabolism could be a cause of intra uterine growth restricted (IUGR) piglets. Over nutrition also has negative impacts on fetal development. Rehfeldt et al. (2011) found that feeding very low (50% of the requirement) as well as excessive protein (250% of requirement) in the diet altered gilt fat and protein metabolism and resulted in growth retardation of the fetuses. The physiological status and maturity of the piglet at the end of gestation has implications on whether it will survive the farrowing process and challenges presented by extra-uterine existence (Tuchscherer et al., 2000; Mellor and Stafford, 2004).

1.3.2 Neonatal piglet survival

One of the biggest constraints of pig production is piglet survival (Tuchscherer et al., 2000). Pre-wean mortality of piglets is generally high; in the United States of America (USA) it was estimated to be 13.7% in 2015 (Pig CHAMP 2016). Most of the piglets die within the first week of life; therefore, pig breeding companies have recently started including piglets alive at day 5 as a selection trait (Su et al., 2007; Nielsen et al., 2013) in attempt to reduce pre-weaning piglet mortality.

The loss of the placenta at birth forces the piglet to establish alternative sources of oxygen, energy, and heat. At farrowing, piglets must start using their lungs for gaseous exchange. Piglets are born with inadequate energy reserves and must be able to obtain colostrum within a few hours; further, piglets have very low body fat, hence thermoregulation needs to start at farrowing. Piglets that are unable to thermoregulate end up being weak and unable to nurse and are at a greater risk of dying from cold and
starvation (Mellor and Stafford, 2004). During late gestation, several physiological events occur to prepare the piglets for life outside the uterus; the lungs mature structurally and functionally, glycogen accumulates in the liver, gluconeogenesis is initiated and there is increased production of tri-iodothyronine and catecholamines (Liggins, 1994). This period where body organs are maturing and becoming functional may be a window to impact piglet postnatal survival and performance (Carroll et al., 2000). Three piglet traits; birth weight, energy levels and/or stores, and thermoregulatory ability have been identified (Tuchscherer et al., 2000; Herpin et al., 2002; Kammersgaard et al., 2011; Caldara et al., 2014) as key indicators of whether piglets are likely to die or survive and these traits can be affected by maternal nutrition.

1.3.2.1 Piglet size and survival

Piglet size, usually determined as birth weight is correlated with piglet survival, but this trait is highly variable (Zindove et al., 2014). As litter sizes get bigger, an increasing number of small piglets are born (Quiniou et al., 2002) which have reduced survivability (Fix et al., 2010). Although it has been firmly established that small and IUGR piglets have reduced survivability (Mitchell, 2007), it is not clear if there is a threshold in size beyond which higher birth weight is no longer an advantage. Variability in piglet size in a litter is thought to be due to competition for uterine space and placental insufficiency (Town et al., 2005), hence piglet size is partially determined early in gestation (Town et al., 2005). During the filamentous blastocyst stage, pig embryos elongate as much as up to 100 cm in length and take up as much uterine space as possible
Embryo lengths vary due to differences in stage of development. The pig ovulates about 20 viable oocytes and the fertilization rate is 90% (Town et al., 2005). These ova are not all shed at the same time. A period of several hours’ difference in fertilized ova age can make a difference when the embryos get to the elongation phase of development. The older embryos start to elongate earlier and have a competitive advantage over the late ovulated embryos in taking up uterine space (Geisert and Schmitt, 2002). The early elongated embryos may change the uterine environment through secretions that inhibit elongation of the late embryos (Pusateri et al., 1990), 1990). Comparison between a standard western breed of pig such as the Large white and the highly prolific Meishan breed (which can have 4 -5 more piglets per litter and low piglet mortality) has shown
that the Meishan embryos do not compete against each other for uterine space. The strategy employed by the Meishan is to reduce placenta size but increase placenta efficiency (Vonnahme et al., 2002).

Several studies have examined the potential of sow nutrition during late gestation to increase piglet birth weight and improve survivability. Increasing the Lys supplied in late gestation from 0.6 to 0.8% improved birth weight (Yang et al., 2009), presumably due to more amino acids to build muscle tissue (Heo et al., 2008; Yang et al., 2009). When both energy and amino acids were increased in late gestation, piglet birth weight was increased in the high-energy diet group and not increased in the high amino acid diet group but pre-wean mortality was improved in the high amino acid group irrespective of energy level (Gonçalves et al., 2016). Supplementing sow diets with medium chain triglycerides from d 84 of gestation did not affect piglet birth weight but improved piglet survival (Jean and Chiang, 1999). Including polyunsaturated fatty acids in sow diets increased piglet vitality and this was thought to be due to docosahexaenoic acid which improved organ maturity. It may not be piglet size per se which determines piglet survival, but the physiological maturity of the piglets. The better-quality piglets at birth may not necessarily be the biggest in size at birth, as bigger piglets may be less physiologically mature with lower percentages of carcass protein and fat (Canario et al., 2007) and reduced ability to metabolize circulating triglycerides (Herpin et al., 1993).

1.3.2.2 Energy stores, thermoregulation and piglet survival

Energy stores and thermoregulation ability are inter-connected in that the major energy stores (glycogen and fat) are utilized in thermoregulation. A common reason for
neonatal piglet death is chilling (Kammersgaard et al., 2011). Piglets are born with a very limited fat layer for insulation; piglet fat composition at birth is estimated at 20 g/kg BW (Gu and Li, 2003) and most of the body fat is structural fat which is not available for metabolism (Herpin et al., 1992). In addition, piglets have little hair and lack brown fat for non-shivering thermogenesis. Piglets must rely on shivering thermogenesis using skeletal muscle glycogen as an energy substrate to maintain thermal balance (Herpin et al., 2002). In a commercial setting, piglets are provided supplemental heat but may not be able to use the supplemental heat to maintain body temperature until they can walk around the sow to the heat source (Kammersgaard et al., 2011). Attended farrowing has been shown to reduce piglet death through interventions such as placing piglets near the teats so that they consume colostrum, drying them off and placing them under the heat lamp to limit the risk of chilling (White et al., 1996). Glycogen stores in the liver and skeletal muscle of piglets are deposited in late gestation (Père, 2003) but the levels deposited are limited (Theil et al., 2011) and will be depleted with normal activity within 16 hours (Theil et al., 2014). Because of having limited fat and glycogen at birth, piglets need to nurse shortly after birth to survive.

Nutritional efforts to increase the level of glycogen stores of piglets at birth have been inconsistent, Bishop et al. (1985) and Newcomb et al. (1991) did not observe an increase in glycogen when high energy diets were fed to sows. Theil et al. (2014) postulated that because plasma glucose obtained from starch is the precursor of glycogen and starch is normally abundant in sow diets in late gestation where feed level is increased, glycogen deposition is unlikely to be limited by nutritional precursors. Additionally, glycogen deposition in fetal tissues is a priority during gestation such that it
is always maximally deposited hence it is not likely to be changed by nutrition interventions (Theil et al 2011). Père et al. (2000) observed that sows undergo decreased glucose sensitivity during late gestation, that is independent of feeding level, and plasma free fatty acids are higher in pregnant than non-pregnant sows irrespective of feeding level at d 110. The fact that maternal tissues, irrespective of feeding level rely more on fatty acids as the energy source and spare glucose for the fetus could ensure that glycogen storage in fetal tissues is maximized. However, Seerly et al. (1989) observed increased glycogen levels in livers of piglets from sows fed high fat diets, and glycogen levels in liver and muscle were increased by supplementing sow diets with medium chain triglycerides starting on d 84 of gestation (Jean and Chiang, 1999). The increase in glycogen stores was thought to be due to ketones from the medium chain triglycerides readily crossing the placenta and being utilized, hence sparing glucose for glycogen synthesis. Increasing the energy of sow diets in late gestation was shown to increase the level of fat in colostrum (Heo et al., 2008) which would be expected to improve piglet survival because colostral fat is a source of additional energy to piglets (Herpin et al., 1992). These studies show that sow nutrition can be manipulated to favor piglet survival.

### 1.3.3 The role of cortisol in piglet adaptation to post-natal life

Cortisol is a steroid hormone that is increasingly produced by the fetal adrenal glands towards full term (Randall, 1983; Carroll et al., 2000). It is responsible for final fetal maturation in preparation for survival in the outside environment. Cortisol is involved in maturation of the lungs, deposition of glycogen in muscle and liver (Fowden et al., 1985), and liver and gut maturation (Sangild et al., 2000; Sangild et al., 2002). Levels of cortisol have been found to be variable in piglet serum (Kattesh et al., 1990).
which suggests that piglets in a litter are born with different levels of physiological maturity. There is a strong positive correlation between fetal cortisol and genetic merit for piglet survival (Leenhouwers et al., 2002a; Leenhouwers et al., 2002b). Litters with high genetic merit for survival were reported to have increased relative weights of adrenals, stomach, and small intestine, increased serum cortisol levels, increased glycogen reserves in liver and muscle, and increased percentage of carcass fat. It was hypothesized that higher genetic merit for survival was due to greater fetal development or maturity before parturition (Leenhouwers et al., 2002a). Because glycogen deposition is influenced by the level of cortisol, increasing piglet cortisol levels pre-term could increase piglet tissue glycogen levels at birth, by increased utilization of nutrient substrates. Cortisol also induces the activity of gluconeogenic enzymes such as glucose-6-phosphatase (Fowden et al., 1995), hence ensuring glucose availability to the piglet immediately after birth.

1.4 Impacts of sow nutrition in late gestation on pre-wean piglet performance

Within one week following farrowing, piglets are usually adapted to the extra uterine environment and management practices such as tail docking and castration have been performed; the focus then becomes maintaining health and growth. Piglet performance during the lactation period can influence their performance for the rest of their lives. While there are piglet factors such as birth weight that influence growth during lactation, the sow’s physiological status also plays an important role in piglet performance.

1.4.1 Effects of colostrum and milk on offspring performance
Colostrum and milk impact piglet performance during lactation and throughout their lives (Bartol et al., 2013). Colostrum and milk are sources of nourishment, immune protection and other bioactive compounds such as growth factors, and hormones (Blum and Baumrucker, 2002; Melnik et al., 2013). Whereas milk composition is most likely influenced by the lactation diet, colostrum composition can be influenced by the late gestation diet because colostrum is formed before farrowing. Mammary gland tissue grows rapidly starting at d 75 of gestation which coincides with an increase in mammogenic hormones such as estradiol, relaxin and prolactin (Ji et al., 2006).

Colostrum components begin to collect in the mammary glands in late gestation and secretion starts within 24 h before parturition (Martin et al., 1978). Components of colostrum may be evolutionarily conserved (Camp et al., 2012) but levels of some of the constituents of colostrum can be altered by the sow’s physiological status including nutrition during gestation. For example, sows fed high (0.8%) Lys from d 80 of gestation had higher total solids in colostrum compared to those that received low (0.6%) Lys and sows that received high (3400 kcal/kg) energy diets had high fat content in colostrum and milk compared to the sows that received low (3265 kcal/kg) energy diets (Heo et al., 2008). However, sows fed added fat from d 100 in their diets did not have higher percent fat in colostrum compared to the control (Okai et al., 1977; Jackson et al., 1995). The difference observed in fat content could be due to timing. Colostrum secretion occurs within 24 h before parturition but colostrum components start to collect in the mammary glands about 5 weeks before farrowing. Gestation diets containing high (23.4%) and low (13.3%) total fiber starting at d 106 did not influence colostrum yield but the high fiber diet resulted in 29% more lipid in colostrum than the low fiber diet (Loisel et al., 2013).
However, in that study increasingly higher quantities of the experimental diets were fed during the adaptation period from d 92. The earlier the sows’ diets are supplemented, when mammary tissue starts developing (close to d 75 of gestation), the more likely the dietary interventions are to influence colostrum yield.

Piglet growth during lactation is influenced by colostrum and milk yield as well as composition which are highly variable traits (Devillers et al., 2007; Quesnel, 2011). Colostrum and milk are the piglet’s only source of nutrition; therefore, sows that produce higher quantity and quality of colostrum would be expected to wean heavier piglets. Piglet consumption of colostrum is also highly variable and positively correlated with BW (Quesnel, 2011). Heavier birth weight piglets are expected to have a competitive advantage when it comes to gaining teat access and hence consuming more colostrum (Quesnel, 2011) but it is not known if there is a limit to piglet size as a determinant for colostrum consumption. The small piglets that are struggling for survival will likely consume less colostrum, but it is not clear if there is a difference in colostrum consumption between the mid and heavy weight piglets.

The piglet immune system is present at birth but it is still immature or in active because of a lack of antigenic exposure; the epitheliochorial placenta in pigs shields the fetus from antibodies and antigens (Bourne, 1973; Rooke and Bland, 2002). It takes several weeks for active immunity to be fully developed (Rooke and Bland, 2002). Between birth and development of active immunity, the piglet is largely dependent on passive immunity obtained from colostrum and milk (Kielland et al., 2015) and the level of IgG obtained from colostrum is related to the level of active immunity developed later in life (Rooke and Bland, 2002; Kielland et al., 2015). The immunoglobulins in
Colostrum are primarily derived from maternal blood (Figure 1.4) (Bourne, 1973). Because colostrum is formed during gestation (Martin et al., 1978), colostrum immunoglobulins are reflective of the sow’s antigenic experience and possibly physiological status and hence could potentially be influenced by late gestation feeding. For example, non-specific immune-stimulation during late gestation increased the level of IgG, cytokines, percentage of neutrophils, macrophages and lymphocytes in colostrum (Krakowski et al., 2002). Also, piglets from sows fed ovalbumin (OVA) had anti-ovalbumin (anti-OVA) antibody in serum (Telemo et al., 1991).

Figure 1.4 Sources of immunoglobulins in sow colostrum and milk (Bourne, 1973).

Transfer of immunoglobulins from colostrum into piglet circulation is only possible before gut closure, the period when whole proteins can be transported across the intestinal wall. The rate and quantity of absorption of the immunoglobulins is not static and can be influenced by hormonal levels. Cortisol stimulates gut maturation and
increased plasma cortisol at birth was correlated with increased IgG concentrations at 48 h of age which was thought to be due to increased uptake of immunoglobulins into the enterocytes (Sangild et al., 1993; Sangild et al., 1997). However, in another study, high plasma cortisol was negatively associated with colostrum intake (Devillers et al., 2011) but this finding remained unexplained.

1.5 Impacts of sow nutrition in late gestation on weaned pig performance

Like parturition when the piglet must deal with the challenges of switching from uterine to extra-uterine life, weaning is another challenging period in a piglet’s life (Niekamp et al., 2007). The piglets are separated from the sow, moved to a new facility, must start consuming solid food and typically different litters are mixed in the pens thus they must re-establish social hierarchy which can result in fights and injuries.

1.5.1 Weaned pig growth and robustness

Weaned pigs need to be robust to adapt to the changes they are exposed to at weaning and continue to grow. Robustness is defined as maintaining high production potential under challenging conditions or external stressors (Knap, 2005).

The gut of the newly weaned pig is challenged by the abrupt change to a solid diet (Xu et al., 2000). Weaned pigs often do not consume a lot of feed in the first week after weaning because of the change in dietary supply from sow milk to solid dry feed to which they are often poorly adapted. Their digestive system is also not fully developed to handle the change in nutrient source. A shift in the predominant energy digestion enzymes from lactase to maltase and amylase must occur (Miller et al., 1986; Kelly et al., 1991) because of the diet change from lactose in milk to starch in grains. Damage to the
gut mucosa from the solid diet is manifested as reduced villous height due to a high rate of enterocyte desquamation, and reduced feed intake is a contributing factor because it results in a slow rate of crypt cell hyperplasia (Pluske et al., 1997).

Weaned pigs commonly suffer from diarrhea which is thought to be due to opportunistic bacterial colonization within the first week of weaning. Another explanation for the occurrence of post weaning diarrhea proposed in the review by Pluske et al. (1997) is villous atrophy, which results in lower absorptive surface (fewer absorptive cells) but a higher secretory surface (higher secretory cells). The net result of low absorption and high secretion being osmotic diarrhea.

In the early wean period, piglets are provided a high quality, highly palatable, complex diet to encourage consumption of feed to facilitate changes in gut function, reduce hypersensitivity to soy in the diet (Friesen et al., 1993), prevent weight loss, and prevent microbial colonization of the gut by pathogenic microbes. In a study examining the impact of weaning weight on performance until 105 kg BW, different starter diets were fed and it was concluded that there was no compensatory growth for lighter weight weaned pigs even when a better starter diet containing whey proteins was fed to this group (Mahan and Lepine, 1991). Normal and low (<1.2 kg) birth weight piglets were fed unrestricted and restricted diets after weaning (Douglas et al., 2014). It was reported that only normal birth weight restricted fed piglets demonstrated compensatory growth, the low birth weight piglets were too late to catch up. Additionally, pigs which are weaned at heavier BW outperform smaller weight piglets (de Grau et al., 2005). And, colostrum intake impacted piglet growth into the post wean period where piglets that consumed at least 290 g of colostrum were 2 kg heavier at 42 days of age than those which did not
consume adequate colostrum (Devillers et al., 2011). These studies show that the effects of the gestation period (such as birth weight) and lactation period (such as wean weight) carry over into the post wean period. Therefore, the piglets’ potential for post weaning performance is influenced during gestation and lactation. As seen in the previous sections, maternal nutrition impacts piglet performance both prenatally and in the neonatal period, which sets the stage for post wean performance.

Given the effects of sow nutrition on sow and piglet performance, it is imperative that sows are fed adequately and that the timing of nutrient supply matches the nutrient demands at different time points in gestation. There are few studies focused on sow nutrition based on the new NRC (2012) nutrient requirement model and in some of these studies it is not clear whether the improvement in performance observed with increased feed intake in late gestation is due to increased protein or increased energy. There is speculation that it might be due to the increase in protein (Goodband et al., 2013) given that the requirement for amino acids increases more than the requirement for energy in late gestation (NRC 2012).

1.6 Problem Statement

Sow nutrition in late gestation can impact sow body condition and fetal development which have implications for piglet post-natal survival, and piglet growth and robustness pre-and post-weaning. Based on the revised NRC (2012) sow nutrient requirement model, gestating sows require increased nutrient supply in late gestation. ‘Bump feeding’ which is a general increase in ration volume in the last few weeks of gestation is increasingly practiced in the swine industry to provide more nutrients to the
sow during this period (De Vos et al., 2014). The effectiveness of the bump feeding strategy is reportedly variable, for example, some research trials show that bump feeding increases piglet birth weight (Heo et al., 2008) while others reported no effect on piglet birth weight especially if the sows were already in good body condition (van der Peet-Schwering et al., 2004). In addition, there is speculation as to whether it is the increased amino acids in bump feeding that are responsible for some of the benefits observed (Goodband et al., 2013). The NRC (2012) sow nutrient requirement model also predicts that there is a greater increase in requirement for amino acids in late gestation than the increase in energy requirement. This suggests that ‘Phase feeding’, where the sows in late gestation receive a higher ration volume with a higher ratio of protein to energy, would be a more appropriate feeding strategy. There is therefore a need to determine the effects of phase feeding on sow and piglet performance.

1.7 Hypothesis

Increasing the dietary protein [as indicated by standardized ileal digestible (SID) Lys] to energy ratio during late gestation when the fetuses are rapidly growing and retaining protein in tissues, should result in sows that are in good body condition at the beginning of lactation and result in better quality piglets compared to piglets from gilts where dietary protein was inadequate.

1.8 Research objective

The objective of this study was to determine the impacts of phase feeding gilts during gestation over two reproductive cycles on gilt reproductive performance, piglet quality and robustness. The objective was achieved by using 3 feeding regimens: 1)
Constant feeding (Constant-f), where the ration volume of the gilts was not changed throughout gestation, 2) Bump feeding (Bump-f), where the ration volume fed to the gilts was increased in late gestation but the composition of the ration was not changed, and 3) Phase feeding where the ration volume fed to the gilts was increased in late gestation and the ratio of SID Lys to energy in the ration was increased.

1.9 Purpose and significance of the study

Because the common solution to increase sow nutrition in late gestation (i.e. Bump feeding) has shown mixed results, some pork producers are questioning whether bump feeding provides sufficient value relative to the increased feed cost (Goodband et al., 2013). Bump feeding is likely inadequate and a different composition of the late gestation diet is needed because the requirement for amino acids increases to a greater extent than the requirement for energy. The overall purpose of this study was to compare Constant-f, Bump-f and Phase-f to determine which feeding strategy is more beneficial to the sows and piglets. The knowledge obtained could be used to select sow feeding strategies in late gestation to better meet the needs of the sow and piglets for maximum performance. To our knowledge this is the only study where the experimental gilt feeding program was formulated based on the revised NRC (2012) nutrient requirement model and reproductive performance and piglets were s through two reproductive cycles.

1.10 Operational definitions

By convention, animals entered the study as gilts or nulliparous sows on the day of breeding, then they became primigravid sows during gestation and after farrowing they became primiparous sows. To avoid confusion, the term gilt is used throughout to refer to
the dams in the present study during first parity and sow is used to refer to the dams in the present study during second parity. ‘Piglets’ is used to refer to the offspring during the lactation period while ‘pigs and / or weaned pigs’ is used to refer to the offspring after weaning.
1.11 Assumptions

To be able to compare the effects of Bump feeding (increase of both energy and protein) and Phase feeding (increase of both protein and energy with altered protein : energy ratio) in late gestation, the feeding regimen had to have equal SID Lys over the entire gestation, therefore the Lys to energy ratio was reduced in early gestation for the Phase feeding regimen. It was assumed that during early gestation, protein was not limiting because amino acid requirements are low. The SID Lys requirement is 11-14 g/d, in early gestation and increases to 15-19 g/d in late gestation as reviewed by Goodband et al. (2013).
2.0 EFFECTS OF PHASE FEEDING DURING GESTATION ON GILT AND PIGLET PERFORMANCE AND PIGLET QUALITY

2.1 Abstract

To determine the effects of phase feeding gilts in gestation on gilt and piglet performance and piglet quality until weaning, 51 gilts were randomly assigned to one of 3 feeding regimens: Constant daily feed allowance (Constant-f), 2.21 kg/d of a standard diet (1.7 g SID Lys/ kcal ME, 3276 kcal ME/kg) from breeding to d 112 of gestation; Bump feeding (Bump-f), 2.21 kg/d of the standard diet from breeding to d 89 and 2.61 kg/d from d 90 - 112; Phase feeding (Phase-f), a reduced Lys: energy diet at 2.21 kg/d (1.5 g SID Lys/ kcal ME) from breeding to d 89 and an increased Lys: energy diet at 2.61 kg/d (2.1 g SID Lys/ kcal ME) from d 90 - 112. Total SID Lys intake over gestation was equivalent between Bump-f and Phase-f regimen. Gilt BW and back fat, litter size, piglet BW and growth, cord blood cortisol and liver and muscle glycogen at birth were measured. Piglets within a litter were assigned a weight category based on birth weight. Response variables were analyzed using the Mixed procedure in SAS, correlations between variables were assessed using the Correlation procedure; gilt was the experimental unit, feeding regimen was fixed and gilt nested within feeding regimen and block was the random variable. There was no difference in gilt BW (149 ± 5 kg) at breeding. There was a feeding regimen by gestation period interaction ($P = 0.05$) in BW. There was no feeding regimen, gestation period or feeding regimen by period interaction detected in back fat, but there was a tendency ($P = 0.06$) for a greater increase in back fat in the Constant-f group between d 0 and d 30. There was no difference in mean piglet
birth weight but there was a tendency for a greater proportion of born alive piglets \((P = 0.07)\) in the intermediate weight category \((1.21-1.4 \text{ kg})\) in the Phase-f litters than Bump-f litters. Cord blood cortisol levels approached a tendency \((P = 0.13)\) to have higher levels in Phase-f piglets compared to Constant-f piglets. Tissue glycogen levels were not different between feeding regimens. There was a positive correlation \((r = 0.49, P = 0.02)\) between cord cortisol and muscle glycogen. Phase feeding did not impact sow performance, but piglets from Phase-f gilts likely have a higher probability for post-partum survival due to a greater proportion of the litter at a desirable birth weight and higher plasma cortisol at birth which is related to glycogen levels and improved survivability.

**Key Words:** late gestation, phase-feeding, piglet survival
2.2 Introduction

Late gestation is a period of increased demand for nutrients, especially amino acids (Kim et al., 2009; Levesque et al., 2011; Samuel et al., 2012) where fetal and mammary tissue are growing rapidly (Ji et al., 2006), maternal growth continues (McGlone et al., 2004), and body reserves for lactation need to be maintained (Miller et al., 2000). Inadequate nutrition during gestation can lead to low birth weight piglets (Wu et al., 2004; Wu et al., 2006; Oksbjerg et al., 2013) which are less viable, and small and intra uterine growth restricted (IUGR) piglets that have reduced survivability (Mitchell, 2007; Cabrera et al., 2012). Excessive feed intake during gestation increases the risk of farrowing problems (Ji et al., 2006), and reduces litter size due to early embryonic death (Jindal et al., 1996). Sow body condition during gestation and lactation also impacts piglet performance (Sell-Kubiak et al., 2013). Thus, there is need to pay careful attention to maternal nutrient supply. In commercial practice, the late gestation ration allocation is increased (bump feeding) to supply more nutrients to meet increased demand. However, it has not been established whether generally increasing nutrient supply (i.e. greater feed allocation) is sufficient, or whether increasing specific nutrients for which there is increased demand is more beneficial. For example, fetal growth, has a higher requirement for amino acids than for energy (De Vos et al., 2014). According to the NRC (2012) sow nutrient requirement model, in late gestation the requirement for amino acids increases to a greater extent than for energy. This suggests that providing the sows a higher ration allocation in late gestation, containing a higher ratio of Lys to energy would be a more appropriate feeding strategy than simply bump feeding. The objective of the study was to compare gilt performance, piglet quality and growth to weaning, under different gestation
feeding regimens; constant feed allocation, increased feed allocation in late gestation and increased feed allocation in late gestation with increased Lys: energy ratio.

2.3 Materials and methods

The research protocol was approved by the South Dakota State University (SDSU) Institutional animal care and use committee (No. 13-005A). Daily animal care followed standard SDSU swine unit protocol, and the Guide for the Care and Use of Agricultural Animals in Research and Teaching (Third Ed., 2010).

2.3.1 Study design and feeding regimen

Fifty-one gilts (149 ± 5 kg), distributed among 6 groups (blocks) and housed at the SDSU Swine Research facility were randomly assigned to one of 3 gestation feeding regimens: Constant, Bump and Phase feeding, at breeding (Table 2.1). Gilts assigned to the Constant feeding (Constant-f) regimen were provided a standard corn soybean diet (1.7 g SID Lys/ kcal ME, 3276 kcal ME/kg) at a constant rate of 2.21 kg/d throughout gestation. Gilts assigned to the Bump feeding (Bump-f) regimen were provided the standard diet at 2.21kg/d in early gestation (d 0 - 89) and at 2.61 kg/d in late gestation (d 90 - 112). Gilts assigned to the Phase feeding (Phase-f) regimen were provided a reduced Lys: energy diet (1.5 g SID Lys/ kcal, 3275 kcal ME/kg) at 2.21 kg/d from d 0 - 89 and an increased Lys: energy diet (2.1 g SID Lys/ kcal, 3290 Kcal ME/kg) at 2.61 kg/d from d 90 - 112 (Table 2.1).

The standard diet was formulated to meet the mean daily nutrient requirements during gestation, based on NRC (2012) model for gilts in gestation assuming 145 kg BW
at breeding, expected litter size of 12 and 1.4 kg average piglet birth weight. The Phase-f late gestation diet was formulated to meet the SID Lys requirement from d 90 - d 114 of gestation. The Phase-f early gestation diet was formulated to contain sufficient SID Lys such that gilts in the Bump and Phase-f regimens had equivalent SID Lys intake over the entire gestation (Table 2.2). Amino acid: Lys ratios met or exceeded NRC (2012) in all diets and the diets contained similar energy density.

From d 113 until farrowing, all sows received a common lactation diet (3380 kcal ME/kg, 0.88 % SID Lys), and daily feed allocation was set at the same rate as in late gestation. From d 1 of lactation until weaning, the sows were fed twice a day using a step-up protocol, whereby the ration provided at each feeding was increased or decreased based on the sow’s appetite. Feed orts were removed every other day and recorded. Water was provided ad libitum via nipple drinkers.

2.3.2 Gilt management and measurements

Gilts were housed individually throughout the trial. Farrowing was induced by intramuscular injection of 2 mL Dinoprost tromethamine (Lutalyse, Zoetis, Pasippany, New Jersey) on d 113 to ensure that farrowing was attended by trained technicians. Gilt performance was assessed as BW and back fat measurements, litter characteristics (i.e. total born, still born, mummies) and lactation feed intake. Gilt BW and 10th rib back fat was measured (Aloka, model USI-115C, Tokyo, Japan) at breeding, d 30, 60, 90 and 110 of gestation and weekly during lactation. At d 110 of gestation, a blood sample was collected from each gilt prior to the morning feeding by jugular venipuncture into a non-heparinized blood collection tube (BD Vacutainer, Franklin Lakes, NJ) for analysis of
urea nitrogen. In blocks 5 and 6, colostrum was collected from as many teats as possible from each gilt immediately after the first piglet was farrowed and prior to suckling for a total collection volume of 10 mL to determine protein content.

2.3.3 Piglet management and measurements

Assessment of piglet quality and performance were based on individual piglet BW, litter birth weight variation, umbilical cord blood cortisol levels, muscle and liver glycogen content at birth, and growth rate during lactation. At birth, umbilical cord blood was collected from as many piglets as possible per litter into non-heparinized blood collection tubes (BD Vacutainer®, Franklin Lakes, NJ). Piglets were towel dried and identified by a number following birth order. One random piglet per litter was euthanized by cervical dislocation using a captive bolt gun. A blood sample was collected into a non-heparinized vacutainer (BD Vacutainer, Franklin Lakes, NJ) to determine birth blood cortisol and liver and longissimus muscle samples (approximately 5 g each) were collected to determine glycogen content. All piglets were weighed and ear notched within 24h of birth, received 0.5 mL Excede (Zoetis, Kalamazoo, MI) and 2 mL Iron dextran within 48 hours after birth and were processed (i.e. tail docked and castrated) on d 4 ± 1 of age. Litters were equalized to 10 piglets within 72 h of farrowing by cross fostering within the same maternal feeding regimen. Sows that had less than 9 total piglets born were removed from the study. To assess within litter weight variation, piglets were assigned to one of 6 birth weight categories (< 1.00, 1.00-1.20, 1.21-1.40, 1.41-1.60, 1.61-2.00, and >2.00 kg) based on Quinou et al. (2002) and for each litter, the percentage of born alive in each category was calculated. In blocks 5 and 6, a blood sample was collected by jugular venipuncture from piglets at d 3 of age to determine serum
concentrations of Insulin-like growth factor -1 (IGF-1) and immunoglobulin immunocrit, as indicators of growth potential and nursing ability, respectively. Piglet growth rate was assessed by weekly BW measurements.

2.3.4 Sample handling and analysis

Gilt, piglet and cord blood samples were allowed to clot at room temperature and centrifuged at 3,000 × g for 20 minutes (min) before serum was removed and stored at -20°C until analysis.

Gilt sera were analyzed in triplicate for urea nitrogen according to Fawcett and Scott (1960). Briefly, 0.21 mL of boiled demineralized water were dispensed into all tubes (Kimble Chase Life Science and Research Products, LLC, Rockwood, TN) and 20 μL of urea standards or samples and 200 μL of Urease solution added to each tube and incubated at 37°C for 15-20 min. To each tube was added 5 mL of Phenol reagent followed immediately with 5 mL of alkaline hypochlorite. The tubes were vortexted and left in a dark room at room temperature (RT) for 60 min after which the absorbency was read at 634 nm using an ultraviolet-visible spectrometer (Perkin Elmer, Shelton, CT). The concentration of urea nitrogen in the samples was determined using the standard curve.

Cord, piglet and gilt sera were analyzed for cortisol using a commercially available ELISA kit [Abnova Cortisol (Pig) Elisa, Walnut, CA] following the manufacturer’s instructions. Briefly, 25 μL of standards and sera were placed into appropriate wells of a 96 well clear flat bottom Costar® assay plate (Corning Inc, Corning, NY). Cortisol Enzyme Conjugate Solution was added to each well at 100 μL and incubated for 1 h at 37°C. The plate was washed 5 times with 200 μL wash solution
per well and tapped firmly against absorbent paper to remove residual moisture. Color reagent at 100 μL per well was added and the plate incubated for 20 min at RT. The reaction was stopped by adding 50 μL of Stopping solution to each well and gently mixing for 1-2 min. The absorbency at 450 nm was read using a Spectramax 190 plate reader (Molecular devices, Sunnyvale, CA). The concentration of cortisol in the samples was determined using the standard curve.

Day 3 piglet sera were analyzed for concentration of IGF-1 by radioimmunoassay (RIA), following the procedure reported in Echternkamp et al. (1990). Briefly, IGF-1 binding proteins were extracted from the serum with a 1:17 ratio of sample to acidified ethanol (12.5% 2 N HCl:87.5% ethanol). Extracted samples were centrifuged at 12,000 × g for 10 min at 4 °C to separate the IGF-1 binding proteins. A portion of the resulting supernatant was removed and neutralized with 0.855 M Tris, stored at 4 °C for at least 4 h, and then centrifuged at 12,000 × g at 4 °C to remove any additional IGF-1 binding proteins. Antibody (UB2-495; National Hormone and Peptide Program, National Institute of Diabetes and Digestive and Kidney Diseases, Bethesda, MD, USA) diluted to 1:62500 was added to the neutralized acid ethanol serum followed by Recombinant human IGF-I (GF-050; Austral Biological, San Ramon, CA, USA) which was used as the standard and radio iodinated antigen. The extraction efficiency was 89 ± 3%, sensitivity was 12.05 pg/tube, intra assay and inter assay CV was 9.0 and 12.6 % respectively.

Piglet liver and muscle samples were flash frozen in liquid nitrogen after collection, and stored at -80° C until analysis for glycogen content using the method described by Dreiling et al. (1987). Briefly, 300-1000 mg of tissue were homogenized in 7% perchloric acid (1μL/mg of tissue). The samples were centrifuged at 5000 x g for 15
min at 4°C, the supernatant was transferred into 2 mL micro centrifuge tubes and petroleum ether (1mL/mg tissue) added to the tubes. Samples were shaken using a vortex to form two distinct layers and the upper layer containing ether carefully removed. Liver samples were diluted 1:5 and muscle samples 1:30 using 7% perchloric acid and 10 µL of each sample and glycogen standard was placed in a 96 well, clear flat bottom Costar® assay plate (Corning Inc, Corning, NY), followed by 260 µL of color reagent. Absorbance was measured at 450 nm on a Spectramax 190 plate reader (Molecular devices, Sunnyvale, CA). The concentration of glycogen was determined from the standard curve.

Immunoglobulin immunocrit was quantified following the method by Vallet (2013). Briefly, for each sample in duplicate, 50 µL of serum were mixed with 50 µL 40% (NH₄)₂SO₄ and centrifuged (BD Clay Adams Autocrit Ultra 3 Microhematocrit Centrifuge, Model 420575, BD Diagnostics, Franklin lakes, NJ) in a hematocrit microcapillary tube (Fisher Scientific, Pittsburg, PA) at 12,000 g for 5 min. The length of the immunoglobulin precipitate in the tube was expressed as a percentage of the length of the solution in the tube.

Colostrum nitrogen content was analyzed following the Dumas method as described by Jung et al. (2003) using the Elementar system (Model: Rapid N III, Elementar Americas, Inc. Mt. Laurel, NJ). Briefly, approximately 200 mg Aspartic acid (Sigma-Aldrich, St. Louis, MO) wrapped and tightly pelleted in tin foil was used as the nitrogen calibration standard and as run-in samples during analysis. Colostrum samples in triplicate (approximately 200 mg each) were packaged and tightly sealed in tin capsules. Empty tin foil was used as blanks. Oxygen dosing for optimal combustion was based on
sample type, 80 mL of oxygen per min for 80 sec (blanks), and 120 mL of oxygen for 190 sec (samples). Protein content was calculated as percentage nitrogen multiplied by 6.25.

2.3.5 Data analysis

Data were analyzed using the Mixed and Correlation procedures in SAS (SAS version 9.3, SAS Inst. Inc., Cary, NC), where gilt was the experimental unit, feeding regimen was fixed and gilt nested within feeding regimen and block was the random variable. Gestation and lactation BW and back fat, piglet BW and ADG were analyzed by analysis of variance (ANOVA) as repeated measures. The Tukey-Kramer adjustment was used to test pairwise differences between maternal feeding regimen. Correlations between cord blood cortisol, BW and muscle and liver glycogen were analyzed using the correlation procedure in SAS. Differences were considered significant at $P \leq 0.05$ and a trend at $0.05 \leq P \leq 0.10$. Least squares mean and SEM are reported.

2.4 Results and discussion

Thirty-six sows (Constant-f, n=8, Bump-f, n=13, Phase-f, n=14) successfully completed the study. Of the sows that did not successfully complete the study, data from 3 sows (Constant-f, n=2, Bump-f, n=1) were removed from the analysis because they had less than 9 total piglets born. Two gilts (Constant- f, n=2) were removed from the study due to prolonged refusal (>3 d) to consume all the daily ration despite veterinary intervention. Sell-Kubiak et al., (2013) reported that feed refusal from d 40 - 80 of gestation had a negative effect on growth rate of offspring. Ten gilts were removed due to
pregnancy failure (i.e. return to estrus, abortion). Block 5 gilts had low back fat (69 % had \( \leq 1.3 \) cm of back fat) and their daily ration was increased by an extra 300 g of the respective diet from d 90-112 to maintain their body condition.

### 2.4.1 Gilt gestation and farrowing performance

There were no differences between feeding regimen in gilt BW at breeding (Table 2.3). There was a feeding regimen by gestation period interaction \( (P = 0.05) \) in BW but using the Tukey’s test for pairwise comparison, no difference in means was detected. However, from breeding – d 30 of gestation a lower change \( (P = 0.02) \) in BW gain in the Constant-f gilts compared to Bump-f and Phase-f (9.8 vs 16.6 vs 15.5 \( \pm 1.7 \) kg, respectively) and a tendency \( (P = 0.08) \) for lower BW gain from breeding to d 110 in Constant-f compared to Bump-f and Phase-f (53.0 vs 64.8 vs 64.9 \( \pm 4.5 \) kg, respectively) was observed.

There were no differences between feeding regimen in gilt back fat at breeding. A tendency \( (P = 0.06) \) for Bump-f gilts to lose back fat while Constant-f and Phase-f gilts gained back fat (-0.08 vs 0.35 and 0.09 \( \pm 0.18 \) cm, respectively) was observed from breeding to d 30 of gestation (Table 2.3). From breeding to d 60 of gestation there was a higher \( (P = 0.04) \) change in back fat in Constant-f gilts than Bump-f and Phase-f gilts (0.54 vs 0.11 and 0.12 \( \pm 0.14 \) cm, respectively) which was due to the change in back fat from breeding - d 30 because there was no difference in back fat change from d 30 - 60. The finding that the Constant-f group gained less weight and tended to put on more back fat than the Bump-f group in early gestation was unexpected as these two groups were provided the same diet at an equivalent daily allocation. This is most likely an unintended consequence of initial gilt allocation or unknown cause of variability.
(Howard, 2002) than an effect of feeding regimen. The similar BW gain in early gestation between the Bump-f and Phase-f gilts supports the NRC (2012) model of lower amino acid requirements in early gestation because Phase-f gilts received a lower Lys containing diet in early gestation than Bump-f gilts. The tendency for lower BW gain in the Constant-f gilts was expected because they had a lower total gestation feed intake than Bump-f and Phase-f gilts.

Serum urea nitrogen, an end-product of amino acid catabolism, was measured at d 110 to monitor protein degradation (Dunshea 2002) in late gestation when the higher Lys : energy diet was supplied. No effect of feeding regimen was observed for serum urea nitrogen levels (8.78 ± 2.75 mg/100mL). This indicates that the added protein was utilized by the gilts and not excreted which also supports a need for phase feeding during gestation.

Feeding regimen had no effect on piglets born alive (12 ± 1 piglets), and this was in line with our expected litter size used to formulate the experimental diets and daily feed allocation. A mean of 0.86 ± 0.41 and 0.34 ± 0.21 piglets were still born and mummified, respectively. There was a tendency ($P = 0.09$) for more still born piglets in the Phase-f gilts (Table 2.3). Two Phase-f gilts had multiple stillborn piglets which were found with the placenta several hours after farrowing was presumed to be completed i.e. substantial quantity of placenta had been expelled and no piglets were felt on palpation after more than 1 h had passed from the previous piglet. Therefore, the greater stillborn piglets in Phase-f gilts were likely due to prolonged farrowing in the two gilts than an effect of feeding regimen. Over nutrition (feeding above recommendations) has been cited as a cause of farrowing problems (Ji et al., 2005; Ji et al., 2006) but in the present study the Phase-f late gestation diet was formulated to meet late gestation nutrient
requirements. Tydlitá et al. (2008) fed sows increasing levels of crude protein and energy in late gestation. The high crude protein levels (18% and 21%) increased farrowing duration and stillborn piglets compared to the 12% crude protein diet, but in that study energy levels were increased from 2835 kcal/kg ME in the lowest crude protein diet to 4180 kcal/kg ME in the highest crude protein diet.

2.4.2 Gilt lactation performance

Piglets were weaned at 19.6 ± 0.6 days. There was no effect of gestation feeding regimen on gilt BW at farrowing (194 ± 4 kg) or on overall BW change (-16 ± 3 kg) during lactation (Table 2.3). The relatively high BW loss in lactation was likely due to the low average feed intake (4.09 ± 0.4 kg). Reports on the effect of gestation feed intake on lactation feed intake are contradictory; differences in lactation feed intake were not observed between sows that received high or low feed levels in late gestation (Cromwell et al., 1989; Miller et al., 2000) but sows which were allowed ad lib intake had reduced intake in lactation (Weldon et al., 1994). During week 1 of lactation, Constant-f gilts gained BW while both Bump-f and Phase-f gilts lost BW, but Bump-f gilts lost more BW \((P = 0.02)\) than Phase-f gilts when compared to Constant-f gilts (Table 2.3). No other differences in BW due to feeding regimen were observed during lactation. The observed BW response during the first week of lactation seems to suggest that the Constant-f sows were limited by energy intake during late gestation and are compensating in the first week of lactation while Bump-f sows had excess energy in late gestation. The Phase-f sows were intermediary between Constant-f and Bump-f suggesting that they had a more balanced nutrient intake.
All gilts lost back fat during lactation \((P < 0.0001)\) but there was no effect of gestation feeding regimen, lactation week or their interaction on gilt back fat loss \((0.39 \pm 0.12 \text{ cm})\). Loss of back fat in lactation was not surprising because gilts are generally not able to eat enough to meet their requirements in lactation without drawing from body reserves (Eissen et al., 2000).

The overall lactation BW loss of 8% observed in this study could potentially impact subsequent reproductive success, it was reported that in gilts, lactation BW loss of > 5% increased wean to service interval and a loss of BW >10% compromised subsequent reproduction by reducing farrowing rate (Thaker and Bilkei, 2005).

Colostrum starts to collect in the mammary glands from sow serum in the days leading to parturition, we hypothesized that gilts receiving higher protein in late gestation would deposit more protein in colostrum (Elliott et al., 1971; Heo et al., 2008; Yang et al., 2009). Because a large proportion of colostral protein is immunoglobulins (Hurley and Theil, 2011) and more than 80% of immunoglobulins in colostrum are IgG (Bourne and Curtis, 1973; Bourne, 1973), the colostral protein content can be used as an indication of IgG in colostrum and hence potential for piglet immunity. There was no difference in colostral protein concentration due to feeding regimen \((17 \pm 1.48 \%)\). The colostral protein concentration agreed with the levels reported by King et al. (1996). The lack of difference in colostrum protein concentration in the present study suggests that differences in piglet immune response would likely be due to intrinsic qualities of the piglets not direct effects of Immunoglobins from colostrum.

2.4.3 Piglet quality and performance
Gilt gestation feeding regimen had no effect on piglet birth weight (1.39 ± 0.06 kg). There was a tendency ($P = 0.07$) for a greater proportion of born alive piglets in an intermediate BW category (1.21-1.40 kg) in litters from Phase-f gilts compared to litters from Bump-f gilts (Figure 2.1). The distribution of piglets in the other weight categories was not different between feeding regimens. Piglet crown-rump length at birth was measured in blocks 5 and 6 as an additional measurement of piglet size and there was no difference due to feeding regimen (crown-rump length = 28 ± 0.9 cm). Small pigs have a reduced chance of survival (Mitchell, 2007) while big pigs may not be physiologically mature (Canario et al., 2007). Other studies have reported that big pigs are at a greater risk of hypoxia during farrowing (Trujillo-Ortega et al., 2006; Trujillo-Ortega et al., 2007; Martínez-Rodríguez et al., 2011); therefore, the intermediate size pigs might be more desirable in terms of piglet survivability demonstrating a potential benefit of phase feeding during gestation on piglet quality.

Piglets progressively gained BW during lactation ($P < 0.0001$). There was a gestation feeding regimen by lactation period interaction ($P = 0.05$) in piglet ADG, where ADG in piglets from Bump-f gilts was lower ($P = 0.02$) than ADG in piglets from Constant-f gilts in the first week of lactation, there was no difference in the ADG in piglets from Phase-f and Bump-f gilts and there were no differences in any of the other weeks of lactation. Piglet ADG in lactation is indicative of sow milk production (Devillers et al., 2004). Based on the findings that piglets from Bump-f gilts had a lower ADG than Constant-f gilts during the first week of lactation and that Bump-f gilts had a more negative BW change than Constant-f gilts during the first week of lactation, it is
likely that Bump-f gilts produced less milk than Constant-f gilts during the first week of gestation.

Cord blood cortisol levels approached a tendency ($P = 0.13$) to be higher in piglets from Phase-f gilts compared to piglets from Constant-f gilts when all litters were considered. One gilt in the Constant-f group did not farrow until 3 days after farrowing was induced and the piglets were observed to be noticeably hungrier, fighting to suckle more than other newly born piglets. Piglets from this gilt had cord cortisol levels (range 81-145, mean 107 ng / mL) close to 2 standard deviations from the mean cortisol level (74.5 ± 7 ng / mL). This artificially increased the overall Constant-f regimen mean. When this sow was removed from analysis, piglets from Phase-f gilts had higher cord cortisol ($P = 0.03$) than piglets from Constant-f gilts and was not different from that in piglets from Bump-f gilts (61, 71, and 84 ± 7 ng / mL in Constant, Bump, and Phase-f, respectively). High cord cortisol level is associated with a higher genetic merit for piglet survival (Leenhouwers et al., 2002). Based on the tendency for higher cord cortisol levels, piglets from Phase-f gilts might have a better probability of survival.

To get an indication of cortisol contribution from the gilt and piglet separately, we measured cortisol in gilt serum and saliva at d 110 and cortisol from piglets euthanized at birth for tissue collection. Gilt d 110 serum and salivary cortisol, as well as, piglet birth blood cortisol did not differ between feeding regimens ($4.15 ± 2.7$, $0.42 ± 0.1$ and $47.06 ± 13.5$ ng/mL, respectively). Sow cortisol levels increase a few days before farrowing. Because gilt cortisol levels obtained at d 110 were much lower than the cortisol levels in cord blood and there was no difference between feeding regimen at d 110, we speculate that the difference in cord blood cortisol at birth was a result of fetal cortisol production.
From the standpoint of piglet quality, we hypothesized that liver and muscle glycogen would be increased in piglets receiving greater amino acids in late gestation. However, liver and muscle glycogen concentrations (113.54 ± 13.5 and 92.37 ± 11.4 mg/100g of tissue, respectively) did not differ between gestation feeding regimen. Maximum accumulation of glycogen in the liver and muscle tissues occurs between d 100 and 107 of gestation (Randall and L’ecuyer, 1976) to prepare for the immediate postnatal period when piglets must rely on liver glycogen for gluconeogenesis and muscle glycogen for muscular activity such as movement and shivering thermogenesis (Thiel et al. 2011). Studies aimed at increasing piglet glycogen reserves at birth and hence improve piglet survival by manipulating the sow diet have shown mixed results (Bishop et al., 1985; Newcomb et al., 1991; Thiel et al., 2014), but most of the studies were focused on increasing energy in the diet not protein.

The correlation between cord cortisol and liver glycogen was not significant (r = 0.25, P = 0.24) but there was a significant positive correlation (r = 0.49, P = 0.02) between cord cortisol and muscle glycogen. Fowden et al. (1985) reported that fetal cortisol was correlated with both liver glycogen and muscle glycogen but the cortisol in that study was measured before parturition. There was no correlation between birth weight and liver glycogen (r = -0.27, P = 0.16) or muscle glycogen (r = -0.21, P = 0.51), which is in agreement with Thiel et al. (2011) where BW was associated with higher glycogen pools through the body in general but not associated with the levels of glycogen in liver and muscle tissues specifically. Birth weight was not correlated with cord cortisol (r = 0.05, P = 0.41) which was unexpected because both birth weight and cord cortisol are positively associated with piglet survivability (Leenhouwers et al., 2002).
There was no effect of gestation feeding regimen on immunocrit levels in serum of piglets at d 3 of age (13.2 ± 1.6%). This was slightly higher than the 9-11% immunocrit range reported by Peters et al. (2016). Values reported by Peters et al. (2016) were measured on d 1 while we measured immunocrit on d 3 which may explain the higher range in our study. Immunocrit is an indication of nursing ability and hence colostrum intake (Vallet et al., 2013). Cabrera et al. (2012) reported that piglets farrowed early consume more colostrum than those farrowed later, but in the present study no correlation was found between immunocrit and birth order (r = -0.10, P = 0.30). Perhaps by d 3 of lactation all the piglets had a chance to nurse and hence the immunocrit was not different. IGF-1 is one of the hormones found in colostrum and can influence growth rate of piglets (Melnik et al., 2013), but the serum concentration of IGF-1 on d 3 (44.68 ± 3.36 ng/mL) was not affected by of gestation feeding regimen, indicating that neonatal piglet growth was likely to not be impacted by gestation feeding regimen.

2.5 Conclusion

Phase feeding had minimal effects on gilt and piglet performance. However, piglets from Phase-f gilts tended to have higher cord cortisol levels and a greater percentage of piglets from Phase-f gilts were in the more desirable mid- birth weight category. These findings taken together show that Phase feeding might have an advantage over constant or bump feeding concerning piglet quality and survivability.
Table 2.1 Gestation feeding regimens

<table>
<thead>
<tr>
<th>Feeding Regimen</th>
<th>Diet</th>
<th>Days on feed</th>
<th>Feed intake, kg</th>
<th>Lys: ME, g/kcal</th>
<th>SID Lys, g/d</th>
<th>ME intake, kcal/d</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant feeding</td>
<td>Standard</td>
<td>0 – 112</td>
<td>2.21</td>
<td>1.66</td>
<td>12.0</td>
<td>7240</td>
</tr>
<tr>
<td>Bump feeding</td>
<td>Standard</td>
<td>0 – 89</td>
<td>2.21</td>
<td>1.66</td>
<td>12.0</td>
<td>7240</td>
</tr>
<tr>
<td></td>
<td>Standard</td>
<td>90 – 112</td>
<td>2.61</td>
<td>1.68</td>
<td>14.4</td>
<td>8552</td>
</tr>
<tr>
<td>Phase feeding</td>
<td>Phase-f early</td>
<td>0 – 89</td>
<td>2.21</td>
<td>1.53</td>
<td>11.1</td>
<td>7237</td>
</tr>
<tr>
<td></td>
<td>Phase-f late</td>
<td>90 – 112</td>
<td>2.61</td>
<td>2.13</td>
<td>18.3</td>
<td>8587</td>
</tr>
</tbody>
</table>

1Daily nutrient requirements were determined using the NRC 2012 gestation requirement model assuming 145 kg BW at breeding, litter size of 12 and piglet birth weight of 1.4 kg. The standard diet was formulated to meet the mean energy and standard ileal digestible Lysine (SID Lys) requirement throughout gestation. The Phase-f late gestation diet was formulated to meet the SID Lys requirements from d 90 - 114 of gestation and the Phase-f early gestation diet was formulated to contain sufficient SID Lys such that gilts in the Bump and Phase-f regimens had equivalent SID Lys intake over the entire gestation.
<table>
<thead>
<tr>
<th>Ingredients</th>
<th>Standard diet</th>
<th>Phase feeding early gestation</th>
<th>Phase feeding late gestation</th>
<th>Lactation diet</th>
<th>Grower diet</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corn (NRC; 8.3% CP)</td>
<td>81.04</td>
<td>82.94</td>
<td>75.29</td>
<td>66.15</td>
<td>67.45</td>
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<tr>
<td>Soya oil</td>
<td>0.70</td>
<td>0.70</td>
<td>0.70</td>
<td>2.40</td>
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<tr>
<td>Soybean meal</td>
<td>14.40</td>
<td>12.50</td>
<td>20.30</td>
<td>27.50</td>
<td>30.35</td>
</tr>
<tr>
<td>46.5 % (NRC)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Calcium carbonate</td>
<td>1.02</td>
<td>1.02</td>
<td>1.02</td>
<td>1.20</td>
<td>0.90</td>
</tr>
<tr>
<td>Dicalcium phosphate</td>
<td>1.76</td>
<td>1.76</td>
<td>1.76</td>
<td>1.80</td>
<td></td>
</tr>
<tr>
<td>Salt</td>
<td>0.40</td>
<td>0.40</td>
<td>0.40</td>
<td>0.50</td>
<td>0.40</td>
</tr>
<tr>
<td>Monocalcium phosphate</td>
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<td>0.45</td>
<td>0.30</td>
<td>0.60</td>
<td></td>
</tr>
<tr>
<td>Choline chloride</td>
<td>0.05</td>
<td>0.05</td>
<td>0.05</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Swine vitamin premix</td>
<td>0.12</td>
<td>0.12</td>
<td>0.12</td>
<td>0.13</td>
<td>0.05</td>
</tr>
<tr>
<td>Swine mineral premix</td>
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<td>0.06</td>
<td>0.06</td>
<td>0.12</td>
<td>0.15</td>
</tr>
<tr>
<td></td>
<td>Lys</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>--------</td>
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<td>------</td>
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<td>------</td>
</tr>
</tbody>
</table>

Calculated nutrient content

<table>
<thead>
<tr>
<th></th>
<th>ME, kcal/kg</th>
<th>3276</th>
<th>3275</th>
<th>3290</th>
<th>3380</th>
<th>3330</th>
</tr>
</thead>
<tbody>
<tr>
<td>SID Lys, %</td>
<td>0.55</td>
<td>0.50</td>
<td>0.70</td>
<td>0.88</td>
<td>1.08</td>
<td></td>
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<tr>
<td>Ca, %</td>
<td>0.92</td>
<td>0.92</td>
<td>0.92</td>
<td>0.97</td>
<td>0.56</td>
<td></td>
</tr>
<tr>
<td>P, %</td>
<td>0.74</td>
<td>0.74</td>
<td>0.74</td>
<td>0.71</td>
<td>0.52</td>
<td></td>
</tr>
</tbody>
</table>

Analyzed nutrient content

<table>
<thead>
<tr>
<th></th>
<th>Crude protein, %</th>
<th>13.21</th>
<th>12.62</th>
<th>15.28</th>
<th>18.45</th>
<th>20.17</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Lys, %</td>
<td>0.65</td>
<td>0.61</td>
<td>0.81</td>
<td>1.10</td>
<td>1.24</td>
<td></td>
</tr>
</tbody>
</table>

1Gilts assigned to the Constant feeding and Bump feeding regimen received the standard diet (1.7 g SID Lys/ kcal ME, 3276 kcal/kg feed) from breeding to d 112 of gestation. Gilts assigned to the Phase feeding regimen received the Phase feeding early diet (1.5 g SID Lys/ kcal ME, 3275 kcal ME/kg feed) from d 0 - 89 and the Phase feeding late diet (2.1 g SID Lys/ kcal ME, 3290 kcal ME/kg feed) from d 90 - 112 of gestation. All gilts received the lactation diet (3380 kcal ME/kg, 0.88 % SID Lys) from d 113 of gestation to weaning.
Table 2.3 Performance in gestation and lactation of gilts fed different gestation feeding regimens

<table>
<thead>
<tr>
<th>Item</th>
<th>Feeding regimen</th>
<th>P-values</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Constant feed</td>
<td>Feeding regimen</td>
</tr>
<tr>
<td></td>
<td>Bump feed</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Phase feed</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Pooled SEM</td>
<td></td>
</tr>
<tr>
<td>Gestation BW, kg</td>
<td></td>
<td>0.93</td>
</tr>
<tr>
<td>Breeding&lt;sup&gt;2&lt;/sup&gt;</td>
<td>153</td>
<td>147</td>
</tr>
<tr>
<td>d 110</td>
<td>206</td>
<td>212</td>
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<tr>
<td>BW gain</td>
<td>53</td>
<td>65</td>
</tr>
<tr>
<td>Lactation BW, kg</td>
<td></td>
<td>0.72</td>
</tr>
<tr>
<td>Farrowing&lt;sup&gt;3&lt;/sup&gt;</td>
<td>189</td>
<td>198</td>
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<tr>
<td>Wean</td>
<td>176</td>
<td>178</td>
</tr>
<tr>
<td>BW loss</td>
<td>-13</td>
<td>-20</td>
</tr>
<tr>
<td>Gestation back fat, cm</td>
<td></td>
<td>0.65</td>
</tr>
<tr>
<td>Breeding (^2)</td>
<td>1.4</td>
<td>1.6</td>
</tr>
<tr>
<td>-----------------</td>
<td>-----</td>
<td>-----</td>
</tr>
<tr>
<td>d 110(^4)</td>
<td>1.8</td>
<td>1.6</td>
</tr>
<tr>
<td>Back fat gain</td>
<td>0.33</td>
<td>0.02</td>
</tr>
<tr>
<td>Lactation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Back fat, cm</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wean</td>
<td>1.4</td>
<td>1.3</td>
</tr>
<tr>
<td>Back fat loss</td>
<td>-0.4</td>
<td>-0.3</td>
</tr>
<tr>
<td>Piglets born</td>
<td></td>
<td></td>
</tr>
<tr>
<td>alive</td>
<td>13.3</td>
<td>12.3</td>
</tr>
<tr>
<td>Piglets stillborn</td>
<td></td>
<td>0.62</td>
</tr>
<tr>
<td>Mummified</td>
<td></td>
<td></td>
</tr>
<tr>
<td>fetuses</td>
<td>0.50</td>
<td>0.38</td>
</tr>
<tr>
<td>Colostrum(^5)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>protein, %</td>
<td>15.3</td>
<td>17.3</td>
</tr>
</tbody>
</table>

\(^1\) Gilts on the Constant feeding regimen were fed a standard diet (1.7 g SID Lys/ kcal ME, 3276 kcal/kg feed) at a constant rate of 2.21 kg/d throughout gestation. Gilts assigned to the Bump feeding regimen were fed the standard diet at 2.21 kg/d during early gestation (d 0 - 89) and at 2.61 kg/d in late gestation (d 90 - 112). Gilts assigned to the Phase feeding regimen were fed a reduced lysine: energy diet (1.5 g SID Lys/ kcal ME, 3275 kcal ME/kg feed) at 2.21 kg/d from d 0 - 89 and an increased lysine: energy diet (2.1 g SID Lys/ kcal ME, 3290 kcal ME/kg feed) at 2.61 kg/d from d 90 - 112. All gilts received the lactation diet (3380 kcal ME/kg, 0.88 % SID Lys) from d 113 of gestation to weaning.
Gilt BW and back fat were measured 3 d prior to breeding and monthly during gestation.
Gilts and piglets were weighed within 24 h of farrowing and weekly until weaning.
Gilt back fat measured on d 110 of gestation represented back fat at farrowing.
Colostrum samples were taken from as many teats as possible (approximate final volume of 10 mL) after the first piglet was farrowed.
Table 2.4 Effect of gilt gestation feeding regimen\(^1\) on measures of piglet quality and piglet growth.

<table>
<thead>
<tr>
<th>Feeding regimen</th>
<th>Cord blood cortisol(^2), ng/mL</th>
<th>Piglet liver glycogen(^3), mg/100g</th>
<th>Piglet muscle glycogen(^3), mg/100g</th>
<th>Piglet d 3 immunocrit, %</th>
<th>Piglet d 3 IGF-1, ng/mL</th>
<th>Piglet BW(^4), kg</th>
<th>Piglet ADG, g/d</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant feed</td>
<td>68.15</td>
<td>95.82</td>
<td>89.46</td>
<td>13.88</td>
<td>42.73</td>
<td>1.46</td>
<td>5.98</td>
</tr>
<tr>
<td>Bump feed</td>
<td>70.87</td>
<td>117.02</td>
<td>98.61</td>
<td>12.69</td>
<td>45.29</td>
<td>1.45</td>
<td>5.66</td>
</tr>
<tr>
<td>Phase feed</td>
<td>84.53</td>
<td>127.77</td>
<td>89.05</td>
<td>12.99</td>
<td>46.02</td>
<td>1.40</td>
<td>5.69</td>
</tr>
<tr>
<td>SEM</td>
<td>7.26</td>
<td>13.49</td>
<td>11.41</td>
<td>0.70</td>
<td>3.36</td>
<td>0.14</td>
<td>0.14</td>
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</table>

\(^1\) Feeding regimen \(P\)-values

<table>
<thead>
<tr>
<th>Feeding regimen</th>
<th>Period</th>
<th>Feeding regimen*period</th>
</tr>
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<tbody>
<tr>
<td>Constant feed</td>
<td></td>
<td>0.13</td>
</tr>
<tr>
<td>Bump feed</td>
<td></td>
<td>0.21</td>
</tr>
<tr>
<td>Phase feed</td>
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<td>0.76</td>
</tr>
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<td>SEM</td>
<td></td>
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</tr>
<tr>
<td>Birth</td>
<td>0.47</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Wean</td>
<td>0.30</td>
<td>&lt;0.001</td>
</tr>
</tbody>
</table>

Piglet growth
<table>
<thead>
<tr>
<th>Week</th>
<th>195&lt;sup&gt;a&lt;/sup&gt;</th>
<th>161&lt;sup&gt;b&lt;/sup&gt;</th>
<th>178&lt;sup&gt;ab&lt;/sup&gt;</th>
<th>10</th>
</tr>
</thead>
<tbody>
<tr>
<td>Week 3</td>
<td>252</td>
<td>229</td>
<td>235</td>
<td>10</td>
</tr>
<tr>
<td>Change</td>
<td>59</td>
<td>77</td>
<td>56</td>
<td>2</td>
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</table>

1 Gilts on the Constant feeding regimen were fed a standard diet (1.7 g SID Lys/ kcal ME, 3276 kcal/kg feed) at a constant rate of 2.21 kg/d throughout gestation. Gilts assigned to the Bump feeding regimen were fed the standard diet at 2.21 kg/d during early gestation (d 0 - d 89) and at 2.61 kg/d in late gestation (d 90-d 112). Gilts assigned to the Phase feeding regimen were fed a reduced lysine: energy diet (1.5 g SID Lys/ kcal ME, 3275 kcal ME/kg feed) at 2.21 kg/d from d 0 - 89 and an increased lysine: energy diet (2.1 g SID Lys/ kcal ME, 3290 kcal ME/kg feed) at 2.61 kg/d from d 90 to d 112. All gilts received the lactation diet (3380 kcal ME/kg, 0.88 % SID Lys) from d 113 of gestation to weaning.

2 A blood sample containing both arterial and venous blood was collected from the cord as soon as the piglet was born.

3 One piglet per litter was euthanized as soon as it was born to collect liver and longissimus muscle samples.

4 Birth weight represents the mean birth weight of born alive piglets per litter. Wean weight represents mean weight of 10 piglets/ litter after standardization within 48 h after parturition.
Figure 2.1. Piglet birth weight distribution (%) in litters from gilts fed different gestation feeding regimen.

1Gilts on the Constant feeding regimen were fed a standard diet (1.7 g SID Lys/ kcal ME, 3276 kcal/kg feed) at a constant rate of 2.21 kg/d throughout gestation. Gilts assigned to the Bump feeding regimen were fed the standard diet at 2.21 kg/d during early gestation (d 0 - 89) and at 2.61 kg/d in late gestation (d 90 - 112). Gilts assigned to the Phase feeding regimen were fed a reduced lysine: energy diet (1.5 g SID Lys/ kcal ME, 3275 kcal ME/kg feed) at 2.21 kg/d from d 0 - 89 and an increased lysine: energy diet (2.1 g SID Lys/ kcal ME, 3290 kcal ME/kg feed) at 2.61 kg/d from d 90 - 112. All gilts received the lactation diet (3380 kcal ME/kg, 0.88 % SID Lys) from d 113 of gestation to weaning.
3.0 EFFECTS OF PHASE FEEDING GILTS DURING GESTATION ON WEANED PIG GROWTH PERFORMANCE AND ROBUSTNESS

3.1 Abstract

The current practice is to increase gestation ration a few weeks before farrowing, but based on the National Research Council (NRC 2012) sow gestation nutrient requirement model, there is a greater requirement for amino acids than for energy in late gestation. To determine the effects of increasing the dietary Lys: energy ratio in gilt diets during gestation on weaned pig performance, a total of 51 gilts were randomly assigned to 3 feeding regimens: Constant, 2.21 kg/d of a standard diet from breeding to d 112 (1.7 g Lys/Kcal ME; 3276 Kcal ME/kg); Bump feeding (Bump-f), the standard diet at 2.21 kg/d from breeding to d 89 and 2.61 kg/d from d 90 to 112; Phase feeding (Phase-f), 2.21 kg/d from breeding to d 89 (1.5 g Lys/Kcal ME; 3275 Kcal ME/kg) and 2.61 kg/d from d 90 to 112 (2.1 g Lys/Kcal ME; 3290 Kcal ME/kg). All sows received a common (3368 Kcal ME/kg, 0.88 % SID Lys) diet during lactation. Litters were equalized to 10 piglets within 72 hours of birth by cross fostering within the same treatment. At weaning (19.6 ± 0.6 d), 8 pigs/sow were placed into 2 pens such that initial BW variation was <10% per pen. All pigs received a commercial pig starter diet (i.e. pelleted) for the first week post-weaning and an early grower diet (i.e. meal form) in weeks 2, 3 and 4. Feed intake and BW were measured weekly. One pig per pen was immunized with OVA and CAA and immune response and serum concentration of IGF-1 measured at d 5, d 19 and d 26 post wean. Data were analyzed using the Mixed and Correlation procedures in SAS with a model in which gilt feeding regimen was fixed and gilt nested within feeding regimen and block [gilt (feeding regimen*block)] was random. The gilt was the
experimental unit. Maternal diet did not affect the post-weaning growth performance. Overall ADG, ADFI and gain: feed, were $322 \pm 18$ g/d, $497 \pm 25$ g/d and 0.69 respectively. During the transition from the pelleted to the meal diet, the pigs from Phase-f gilts consumed more feed ($P = 0.03$) than pigs from Constant-f gilts. Serum IGF-1 concentration and immune response were not affected by maternal feeding regimen overall, but on d 26, pigs from Bump-f gilts tended to have a lower serum concentration of IGF-1 than pigs from Constant-f and Phase-f. Based on the at d 26, weaned pigs from Bump-f gilts may have reduced growth potential over time. Although the weaned pigs had similar growth performance, weaned pigs from Phase-f gilts performed better than pigs from Bump-f and Constant-f gilts under a nutritional challenge.

**Key words:** Phase feeding, robustness, weaned pig,
3.2 Introduction

The nutritional environment experienced by the fetus in-utero has long term effects on postnatal wellbeing and performance. Undernutrition is linked with small and IUGR which have fewer muscle fibers (Rehfeldt et al., 2004) and greater fat and collagen in muscle (Karunaratne et al., 2005). This puts these piglets at a disadvantage in that they are not able to grow as fast and gain lean tissue at the same rate as their normal birth weight littermates (Karunaratne et al., 2005). The long-term success of a swine operation hinges on production of full value market hogs and it is desirable that weaned pigs not only grow at a uniform rate but that they are robust so as not to fall back when faced with the challenges associated with weaning. Given the impact fetal nutrition has on offspring performance, it is of interest to study sow feeding strategies with the aim of improving piglet performance. Very few studies examine the effects of gestation nutrition on long term piglet performance past the neonatal period.

Late gestation is when nutrition is most likely to be limiting; additional nutrients are needed for the rapidly growing fetuses and mammary tissue development (McPherson et al., 2004; Ji et al., 2006). It has been established that the amino acid requirement increases in late gestation (Kim et al., 2009; Levesque et al., 2011; Samuel et al., 2012) and according to the current NRC nutrient requirement model for primiparous sows, amino acid requirement increases to a greater extent than energy in late gestation (NRC 2012). The current industry practice of increasing feed intake (bump feeding) in late gestation to increase nutrient supply has shown mixed results and there is need to evaluate the effects of increasing not just the nutrient supply, but increasing the ratio of protein: energy in late gestation on gilt and piglet performance.
The objective of the study was to compare offspring post-wean growth performance and robustness under different gestation feeding regimens; constant feed allocation, increased feed allocation in late gestation and increased feed allocation in late gestation with increased Lys: energy ratio.

3.3 Material and methods

The research protocol was approved by the South Dakota State University (SDSU) Institutional animal care and use committee (IACUC No. 13-005A). Daily animal care followed standard SDSU swine unit protocol, and the Guide for the Care and Use of Agricultural Animals in Research and Teaching (Third Ed., 2010).

3.3.1 Gilt and piglet management

Fifty-one gilts (149 ± 5 kg), distributed among 6 groups and housed at the South Dakota State University Swine Research facility were randomly assigned to one of 3 gestation feeding regimens: Constant, Bump and Phase feeding, at breeding. Section 2.3.1 describes the feeding procedures in detail. Farrowing was induced by intramuscular injection of 2 mL Dinoprost tromethamine (Lutalyse, Zoetis, Pasippany, New Jersey) on d 113 to ensure that farrowing was attended by trained technicians. All piglets were weighed and ear notched within 24h of birth, received 0.5 mL Excede (Zoetis, Kalamazoo, MI) and 2 mL Iron dextran within 48 hours after birth and were processed (i.e. tail docked and castrated) on d 4 ± 1 of age. Litters were equalized to 10 piglets within 72 h of farrowing by cross fostering within the same maternal feeding regimen and were weighed weekly. Sections 2.3.2 describes the gilt management in more detail and section 2.3.3 describes the piglet management in more detail.
3.3.2 Piglet weaning procedures and diets

Pigs were weaned at 19.6 ± 0.6 d and were transported to a nursery facility located approximately 1 mile from the sow barn. From each litter, four birth littermates were placed in a nursery pen (1.2 m wide and 1.7 m long), targeting a BW coefficient of variation (CV) of <10% per pen. A maximum of 8 pigs per sow were used to assess weaned pig performance. Cross-fostered pigs were removed from this study and raised separately.

Pigs received commercial pelleted early wean diets during the first week (Ultra Care 100 from d 0 – 3 and Ultra Care 200 from d 4 – 7; Land O'Lakes Purina Feed LLC, Saint Paul, MN). To serve as a nutritional stressor, an early grower meal form diet was fed starting on d 8 post weaning. The grower diet was a simple diet (corn-soybean meal based; Table 2.2) for this stage of growth where complex diets containing whey, fishmeal and other highly digestible nutrients are typically provided. The grower diet was fed until the end of the study on d 28 post wean. Feed and water were supplied ad libitum. There was a single feeder with 3 openings (36 cm by 36 cm each) and a single nipple drinker in each pen.

3.3.3 Pig measurements and procedures

Weekly pig weights and feed disappearance were obtained to calculate average daily gain (ADG), average feed intake (ADFI) and feed efficiency (gain:feed) which were used to assess weaned pig growth performance and robustness.
Weaned pig robustness was also assessed by measuring antibody-mediated and cell-mediated immune responses. At d 5 post weaning (26 ± 2 d of age), one pig per pen was randomly selected as the ‘immunized’ pig and used in the antibody-mediated/cell-mediated immune response protocol as described (Heriazon et al., 2009) with modifications. Briefly, at d 5 post wean a blood sample was drawn into a non-heparinized blood collection tube (BD vacutainer®, Franklin Lakes, NJ) to determine initial anti-OVA IgG antibody levels and the pig was inoculated with ovalbumin (OVA) and killed Candida albicans (CAA) by intramuscular injection of 0.5 mg OVA (Sigma Aldrich Co., St. Louis, MO), 0.5 mg killed CAA (Greer, Lenoir, NC), and 0.5 mg Quil A adjuvant (Brenntag Biosector, Denmark) in 1 mL saline. Two weeks later, at d 19 post wean, blood was similarly drawn from the ‘immunized’ pigs to determine the primary anti-OVA antibody levels. A booster dose was administered by intramuscular injection of 0.5 mg OVA, 0.5 mg killed CAA, and 0.5 mg Quil A adjuvant in 1 ml saline. At d 26 post wean, blood was drawn from the ‘immunized’ pigs to determine secondary anti-OVA antibody levels.

The cell-mediated response was assessed in the ‘immunized’ pig and one non-immunized pig per pen based on a hypersensitivity response to CAA at d 26 post wean. Each pig (while restrained in dorsal recumbency) received an intradermal injection of 200 μg CAA in 50μL saline and 50 μL of saline in two separate locations on the right ear administered using a 26-gauge needle. Skin thickness measurements at the injection sites were taken in triplicates before injection and at 6 and 24 h post injection using skin-fold callipers (Model RH15 9LB, Creative Health Products Inc., Ann Arbor, MI). The percentage change in skin thickness over time was calculated.
Serum concentration of IGF-1 was measured in the blood samples collected from the ‘immunized’ pigs at d 5, 19 and 26 post wean.

3.3.4 Sample handling and analysis

Blood samples were allowed to clot at room temperature, then centrifuged at 3,000 × g for 20 min.; serum was removed and stored at -20°C until analysis. Anti-OVA IgG were quantified using an indirect ELISA method. High-affinity binding 96 well clear flat bottom Costar® assay plates (Corning Inc, Corning, NY) were coated with 100 μL of 1.44 mg/ml OVA dissolved in carbonate-bicarbonate buffer (pH 9.6) and incubated at 4°C for 24 h. The plates were washed 5 times with 150 μL of 0.05% Tween 20 in PBS wash buffer (pH 7.4). To prevent non-specific binding of immunoglobulins, 200 μL of Ultrablock solution (AbD Serotec; Raleigh, NC) was added and incubated for 1 h at RT. Plates were washed five more times with 150 μL of 0.05% Tween 20 in PBS wash buffer. Serum samples were diluted to 1/1600 using wash buffer. Reference/quality control and diluted serum samples were added as triplicates and incubated at RT for 2 h. Alkaline phosphatase-conjugated rabbit anti-sheep IgG (Bethyl Laboratories, Montgomery, TX), diluted with 0.05 % Tween PBS buffer (1:10,000), was added and incubated at RT for 1 h . The plates were washed five times and 80 μL of p-Nitrophenyl phosphate substrate system (Sigma-Aldrich, St. Louis, MO) was added and incubated at RT for 30 min. The optical density (OD) was measured at 405 nm using a Spectramax 190 plate reader (Molecular devices, Sunnyvale, CA). The OD readings for plates were corrected using a correction factor described below.

Correction factor = (Overall mean of reference samples from all plates) / (Actual mean of individual plate reference sample).
Serum concentrations of IGF-1 were quantified by radioimmunoassay following Echternkamp et al., (1990). See section 2.3.4 for more description.

3.3.5 Data analysis

Data were analyzed using the Mixed and correlation procedures of SAS (SAS Inst. Inc., Cary, NC) with a model in which gilt feeding regimen was fixed and gilt nested within feeding regimen and block [gilt (feeding regimen*block)] was random. The gilt was the experimental unit and gilt was considered synonymous with litter. BW, ADG, ADFI, feed efficiency, serum concentration of IGF-1 and anti-Ova IgG were analyzed as repeated measures. The correlation procedure was used to examine correlations between IGF and wean weight. Differences were considered significant at \( P \leq 0.05 \) and a trend \( P \leq 0.1 \). Least squares means and SEM are reported.

3.4 Results

3.4.1 Weaned pig growth response

Over all, post-weaning growth performance was not affected by maternal feeding regimen (Table 3.1). At weaning BW was 6.1 ± 0.4 kg and BW at d 27 post wean was 14.9 ± 0.4 kg. Overall ADG, ADFI and gain : feed from weaning - d 27 post wean were 322 ± 18 g/d, 497 ± 25 g/d, and 0.69 ± 0.02, respectively. However, during the transition from the nutritionally complex pelleted diet to the simple meal form diet at the end of the first week post wean, all pigs had a reduction in daily gain (Table 3.1), which approached a tendency (\( P = 0.12 \)) for pigs from constant -f gilts falling back more than Phase-f pigs. During this period, feed disappearance was greater (\( P = 0.03 \)) in pigs from Phase-f gilts
compared to pigs from Constant-f gilts. Over the 4 week post-wean period, there was a
general increase ($P < 0.001$) in BW and ADFI. There was a decrease in ADG in week 2
but it picked up in week 3, while gain : feed generally decreased ($P < 0.001$) but the
decrease was greatest in week 2.

Serum concentration of IGF-1 was not affected by maternal feeding regimen but they
increased ($P < 0.001$) over time (70.7, 79.2, and 96.7 ± 5 ng/mL on d 5, 19 and 26 post
wean, respectively). There were no differences in serum concentration of IGF-1 at d 5
and 19 but by d 26 pigs from Bump-f gilts tended ($P = 0.08$) to have a lower serum
concentration of IGF-1 than pigs from Constant-f and Phase-f gilts. There was a positive
correlation between the serum concentration of IGF-1 on d 5 and wean weight ($r=0.23$, $P$
= 0.03) and there tended to be a positive correlation between the serum concentration of
IGF-1 on d 26 and wean weight ($r=0.20$, $P = 0.07$).

3.4.2 Weaned pig immune response

Anti-OVA IgG levels increased over time (Table 3.1). The IgG levels before
immunization, measured at d 5 post wean were not different from the IgG levels after the
initial dose, measured at d 19; however, the IgG levels after the booster dose, measured at
d 26 were higher ($P < 0.001$) than IgG levels at d 5 and 19. Maternal gestation feeding
regimen did not influence anti-OVA IgG levels (Table 3.1). Skin thickness increased by
10.3 ± 6.5 % during the first 6 h post injection and the increase in skin thickness at 24 h
post injection was 16.06 ± 6.6 % (Figure 3.1), but this hypersensitivity response was not
affected by maternal gestation feeding regimen. Immunized pigs had a greater ($P <$
0.001) hypersensitivity response to CAA than non-immunized pigs at the CAA site (13.6
vs 8.0 ± 4.2 %) at 6 h and tended to have a greater ($P = 0.07$) hypersensitivity response
than non-immunized pigs at 24 h (17.5 vs 12.8 ± 4.6%). The increase in skin thickness at the site of saline injection was not different between the immunized and non-immunized pigs.

3.5 Discussion

The objective of the study was to determine the effects of maternal phase-feeding during late gestation on offspring post-wean growth performance and robustness. We hypothesized that increasing the dietary Lys : energy ratio in maternal diets during late gestation would be beneficial for post wean offspring growth performance and robustness.

Overall, growth performance of the weaned pigs was not affected by maternal gestation feeding regimen. The pigs were kept together as littermates and there were only 4 pigs of about similar size per pen. This minimized the stress of weaning on the pigs. Post weaning stress such as mixing of different litters and competition for social hierarchy (Campbell et al., 2013) can impact piglet wellbeing and performance. The more robust piglets would be expected to perform better than less robust ones under stressful conditions. When a nutritional stressor was applied in week 2, in the form of a simple diet in meal form, all pigs had a reduction in ADG. The reduction in ADG; however, tended to be more pronounced in pigs from Constant-f gilts. Switching to a simple diet from a complex diet reduced ADG even when the simple diet was provided at a more advanced age (Whang et al., 2000). The reduction in ADG in the present study can be attributed to reduced feed intake. Feed intake is expected to increase with time, but in all the pigs feed intake increased slightly from week 1 to week 2, and feed intake in week 3 was nearly
double that in week 2. Pigs from gilts on the Phase-f regimen had a greater increase in feed intake from week 1 to week 2 compared to pigs from Constant-f gilts during the nutritional challenge period. This suggests that pigs from Phase-f gilts were more robust than pigs from the Constant-f gilt by being able to adapt more quickly to the simple meal form diet. Maternal nutrition impacts offspring gut morphology and physiology. It was reported that pigs from sows that received a higher nutrient supply during gestation had more developed small intestines post weaning than pigs from the low nutrition group (Cao et al., 2014). It is possible that piglets from Phase-f gilts had a more developed gut than pigs from Constant-f gilts.

Insulin-like growth factor-1 is the key control point for nutritional regulation of growth and the levels of IGF-1 are reduced when there is arrest of growth due to inadequate nutrition (Straus, 1994). While ADG reduced after the nutritional stressor was applied at d 8, no similar reduction in serum concentration of IGF-1 was observed and may be because the serum concentration of IGF-1 was measured at d 19 when the growth performance of the pigs had already started to recover in week 3. IGF-1 is also considered a biomarker for growth (Slifierz et al., 2014). In the present study, the serum concentration of IGF-1 increased with age as observed by Lee et al. (1991). However, it is puzzling that serum concentration of IGF-1 at d 5 and d 26 was correlated with wean weight but serum concentration of IGF-1 at d 19 was not correlated with weaning weight. At d 26, pigs from Bump-f gilts tended to have lower than pigs from Constant-f and Phase-f gilts. This observation taken together with a numerically lower ADG and ADFI in pigs from Bump-f gilts throughout the study could be an indication that pigs from
Bump-f gilts have a lower growth performance potential than pigs from Constant-f and Phase-f gilts.

There was no detectable antibody response to the priming dose given at d 5 because the antibody levels measured at d 19 were not different from the antibody levels at d 5 prior to immunization. This level of response to the immunization at d 5 post wean could be attributed to the nutritional and health status of the pigs (Salak-Johnson and McGlone, 2007). Weaned pigs typically scour between d 5 and 20 post weaning (Barnett et al., 1989) as did the pigs in the present study, and from d 8 the pigs in this study experienced lower feed intake due to the imposed nutritional challenge. Adequate nutrition is necessary to maintain immune function (Chandra, 1997; Rooke and Bland, 2002). The low level of immune response might also reflect a low capacity to synthesize antibody at this age. The dermal sensitivity test was measured at 6 and 24 h. There was an immediate response within the first 6 h and a response was still detectable at 24 h. Immediate and delayed responses to CAA were observed, which is consistent with Kabe et al. (1971) where different antigens (lipopolysaccharide and protein fractions) from CAA elicited immediate and delayed type responses, respectively, in the respiratory tract of guinea pigs, unlike Heriazon et al. (2009) where CAA caused a delayed type hypersensitivity in cattle.

Constant feeding, Bump feeding or Phase feeding gilts during gestation resulted in equivalent pig growth performance in the first 4 weeks post-wean. However, in stressful conditions, the pigs from Phase-f gilts could perform better than pigs from Constant-f gilts as evidenced by the differences in feed intake when nutritionally challenged.
3.6 Implication

Phase feeding in gestation improved offspring ability to handle post-weaning nutritional stress, indicating that phase feeding resulted in more robust pigs which are likely to have greater or steadfast performance under stressful conditions. This could result in greater overall performance and more full-value pigs.
Table 3.1 Post wean growth performance and robustness of weaned pigs from gilts fed different gestation feeding regimens\(^1\).

<table>
<thead>
<tr>
<th></th>
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<th>Bump feeding</th>
<th>Phase feeding</th>
<th>Pooled SEM</th>
<th>Regimen P-value</th>
<th>Period P-value</th>
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<tr>
<td>d 26</td>
<td>101.53</td>
<td>89.19</td>
<td>99.26</td>
<td>5.3</td>
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<tr>
<td>Anti-Ovalbumin IgG², optical density at 405 nm</td>
<td>0.79</td>
<td>&lt;0.0001</td>
<td>0.89</td>
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<tr>
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<td>0.260</td>
<td>0.38</td>
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<tr>
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<td>3.330</td>
<td>0.37</td>
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</tbody>
</table>

¹Gilt assigned to the Constant feeding and Bump feeding regimen received the standard diet (1.7 g digestible Lys/ kcal ME, 3276 kcal/kg feed) from breeding to d 112 of gestation. Gilt assigned to the Phase feeding regimen received the Phase feeding early diet (1.5 g digestible Lys/ kcal ME, 3275 kcal ME/kg feed) from d 0 - 89 and the Phase feeding late diet (2.1 g digestible Lys/ kcal ME, 3290 kcal ME/kg feed) from d 90 to d 112 of gestation. All gilts received the lactation diet (3380 kcal ME/kg, 0.88 % digestible Lys) from d 113 of gestation to weaning.

²Up to two pigs per litter received a prime and booster dose of ovalbumin and *Candida albicans* antigens (0.5mg Ovalbumin, 0.5 mg *Candida albicans* and 0.5 mg Quil A adjuvant in 1 ml saline) on d 5 and 19 post wean, respectively. Blood samples were collected before immunization, before the booster dose and 1 week after the booster dose to determine pre, primary and secondary anti-Ovalbumin IgG.
Figure 3.1 Dermal hypersensitivity response (% change in ear thickness) to killed *Candida Albicans* at 0 – 6 h (SEM=6.5) and 0 – 24 h (SEM = 6.6) in weaned pigs from gilts assigned to different gestation feeding regimen.\(^1\)

\(^1\)Gilts assigned to the Constant feeding and Bump feeding regimen received the standard diet (1.7 g digestible Lys/ kcal ME, 3276 kcal/kg feed) from breeding to d 112 of gestation. Gilts assigned to the Phase feeding regimen received the Phase feeding early diet (1.5 g digestible Lys/ kcal ME, 3275 kcal ME/kg feed) from d 0 - 89 and the Phase feeding late diet (2.1 g digestible Lys/ kcal ME, 3290 kcal ME/kg feed) from d 90 to d 112 of gestation. All gilts received the lactation diet (3380 kcal ME/kg, 0.88 % digestible Lys) from d 113 of gestation to weaning.
4.0 EFFECTS OF PHASE FEEDING GILTS DURING GESTATION ON THEIR PERFORMANCE AS SECOND PARITY SOWS

4.1 Abstract

To determine the effects of phase feeding gilts during gestation on second parity performance, gilts were randomly assigned to 1 of 3 feeding regimens during first parity: Constant daily feed allowance (Constant-f), 2.21 kg/d of a standard diet (1.7 g SID Lys/kcal ME) from breeding to d 112 of gestation; Bump feeding (Bump-f), 2.21 kg/d of the standard diet from breeding to d 89 and 2.61 kg/d from d 90 to 112; Phase feeding (Phase-f), a reduced Lys : energy diet at 2.21 kg/d (1.5 g SID Lys/kcal ME) from breeding to d 89 and an increased Lys : energy diet 2.61 kg/d (2.1 g SID Lys/kcal ME) from d 90 to 112 of gestation. Total SID Lys intake over gestation was equivalent between Bump-f and Phase-f regimen. Sows received a common lactation diet from d 113 to weaning and a standard gestation diet until breeding. The sows received their respective feeding regimens from breeding through d 112 of gestation during the second parity gestation. Sow BW and back fat, litter size, piglet BW and growth from birth to 4 weeks post wean and liver and muscle glycogen at birth were measured. Piglets within a litter were assigned a weight category based on birth weight. Data were analyzed using the Mixed procedure in SAS with a model in which sow feeding regimen was fixed and sow nested within feeding regimen and block was random and sow was the experimental unit. Feeding regimen did not influence litter characteristics, back fat tended to increase \((P = 0.06)\) in Phase-f and Bump-f sows between d 60 and 110 of gestation. There was a tendency \((P = 0.06)\) for BW gain in Constant-f sows while Bump-f and Phase-f lost weight between d 1 and 14 of lactation and the lactation feed intake was higher \((P = 0.05)\)
in Constant-f than Phase-f and Bump-f sows (7.0 vs 5.3 vs 6.3 ± 0.5 kg, respectively).

There was a gestation feeding regimen interaction with lactation period in piglet BW ($P = 0.02$) and ADG ($P = 0.005$) whereby there were no differences in BW or ADG in weeks 1 and 2 but in week 3 of lactation, piglets from Phase-f sows had higher BW and ADG than piglets from Bump-f and Constant-f sows. Similarly, pigs from Phase-f sows had a higher ($P = 0.05$) ADG and tended to have a higher ($P = 0.06$) feed intake than pigs from Constant-f sows during the post-weaning period. Feeding regimen did not impact second parity sow performance but piglets from Phase-f sows performed better than piglets from Constant-f sows.

**Key words**: Post-weaning, pig-performance, second-parity performance
4.2 Introduction

A major problem in swine production is a phenomenon termed ‘second litter syndrome’ where by second parity sows have reduced reproductive performance compared to their first parity performance (Morgan Morrow et al., 1992; Saito et al., 2010). This is characterized by an extended weaning to service interval (Reese et al., 1982), smaller litter size (Eissen et al., 2003) and reduced farrowing rate (Koketsu et al., 1997). Second litter syndrome is thought to be due to excessive weight loss in the previous lactation (Thaker and Bilkei, 2005; Schenkel et al., 2010) because of inadequate lactation feed intake (Baidoo et al., 1992; Prunier et al., 2010). First and second parity sows are at greater risk because they are still growing compared to older sows and have been reported to consume less fed than older sows during lactation (Koketsu et al., 1996). Sows are bred at the first estrus after weaning which is typically within a week; therefore, they may not have adequate time to fully recover body reserves prior to breeding. It has been reported that sows which had excessive weight loss during lactation have fewer implantation sites in the uterus (Hoving et al., 2012) and poor oocyte quality (Zak et al., 1997; Clowes et al., 2003) which may result in a high rate of early embryonic death.

Nutrition during gestation and body condition of the sow influence lactation feed intake (van den Brand et al., 2000; Mejia-Guadarrama et al., 2002; Weldon et al., 1994). Sow body condition is also associated with piglet performance and high feed intake during lactation is associated with higher milk yield, hence improved piglet growth. Piglet growth during lactation also impacts growth during the post wean period (Sell-Kubiak et al., 2013).
Sow reproductive performance during the second parity is considered an indication of subsequent performance or even lifetime performance (Hoving et al., 2011). Poor performance in the second parity increases the probability of culling because of repeat breeding (Lucia Jr et al., 2000) and sows that have smaller litters during the second parity are more likely to have small litters in parity 3 (Hoving et al., 2011). The objective of this study was to determine the effects of gestation feeding regimen on sow and weaned pig performance during the second parity.

4.3 Materials and methods

Twenty-five sows which had been part of a study on the effects of phase feeding gilts during gestation on reproductive performance, piglet quality and robustness (first 4 blocks; see Chapter 2 and 3) were followed through a second parity. First parity litters were weaned at 19.6 ± 0.6 days of age and from weaning until breeding, sows were fed a standard gestation diet (Table 2.2) at approximately 2-3 kg per day based on body condition. Estrus detection begun at d 3 post wean and service by artificial insemination were carried out by a trained technician beginning. On the day of breeding, the sows were returned to the respective gestation feeding regimen as during first parity gestation (Table 2.1). Management and measurements were carried out as described in section 2.3, except that when litters were equalized, there was some cross fostering across feeding regimen when there were not enough piglets within a block to cross-foster within the same feeding regimen (1Constant-f sow got 4 piglets from a nurse sow, 1 Bump-f sow got 1 piglet from a Constant-f sow, 1 Phase-f sow got 3 piglets from a nurse sow, 1 Phase-f sow got 2 piglets from a Constant-f sow). Sows were allowed 10-12 piglets during lactation. Post wean, the feeding and measurements were as described in section 3.3.
4.4 Results

Of the 25 sows started on trial, 2 Constant-f sows did not show estrus, 7 sows (2 Constant-f, 2 Bump-f and 3 Phase-f) were bred but did not carry a pregnancy to term, hence the farrowing rate was 72%. One sow (Phase-f) was removed from trial because of refusal to nurse the piglets but was included in sow gestation performance data. Two sows (1 Bump-f and 1 Phase-f) were removed from trial because of very small litter sizes (4 and 5 piglets respectively). Therefore 14 sows successfully completed the second parity (3 Constant-f, 7 Bump-f and 5 Phase-f).

There were no differences in sow BW (176 ± 7.1 kg) and back fat (1.2 ± 0.2 cm) at second parity breeding or the wean to estrus interval (5.7 ± 0.8 d). Overall BW and back fat during gestation were not impacted by feeding regimen (Table 4.1). All sows progressively gained BW and at farrowing BW and back fat were 215 ± 9 kg and 1.2 ± 0.2 cm, respectively (Table 4.1), however back fat tended ($P = 0.06$) to be reduced in Constant-f sows while it increased in Bump-f and Phase-f sows from d 60 - 110 of gestation (-0.1 vs 0.28 and 0.22 ± 0.07 cm change respectively). No difference in back fat or BW was observed between d 90 and 110.

Serum urea nitrogen at d 110 of gestation (11.5 ± 1.3 mg/100mL) was not different between feeding regimens and there were no differences in number of piglets born alive (12 ± 1.6), stillborn (0.71 ± 0.4) or mummified fetuses (0.57 ± 0.5). During lactation, all sows progressively lost BW and back fat, and there was no overall difference in sow BW and back fat between feeding regimen (Table 4.1). However, there was a tendency ($P = 0.06$) for a feeding regimen difference in the change in BW between
d1 and d 14 of lactation. Constant-f sows gained (1.3 ± 3.6 kg) while Bump-f and Phase-f sows lost BW (-8.6 ± 3.6 and -10.8 ± 3.6 kg, respectively). Lactation daily feed intake was higher ($P = 0.05$) in Constant-f sows compared to Bump-f and Phase-f sows (7.0 vs 5.3 vs 6.3 ± 0.5 kg, respectively) and not different between Bump-f and Phase-f sows.

Piglet birth weight (1.56 ± 0.16 kg), cord cortisol concentration (70 ± 31ng/mL) and muscle and liver glycogen levels at birth (107 ± 21.9 and 118 ± 13 mg/100g of tissue, respectively) were not different between feeding regimen. There were no differences in piglet birth weight distribution (Figure 4.1) but 16% of all piglets were below 1 kg BW at birth. All piglets progressively gained BW during lactation, but overall piglet growth was not affected by gestation feeding regimen (Table 4.2). However, there was a gestation feeding regimen interaction with lactation period in piglet BW ($P = 0.02$) and ADG ($P = 0.005$) whereby there were no feeding regimen differences in BW or ADG in weeks 1 and 2 but in week 3 of lactation, piglets from Phase-f sows had higher ($P = 0.02$) BW than piglets from Bump-f and Constant-f sows, higher ($P = 0.02$) ADG than piglets from Bump-f and tended to have higher ($P = 0.07$) ADG than piglets from Constant-f sows (Table 4.2).

Litters were weaned at 20 ± 0.5 days of age and there were no feeding regimen effects on wean weight among the pigs that remained in the study post wean. Pigs from Phase-f sows had higher ($P = 0.02$) ADG than pigs from Constant-f sows and tended to have higher ($P = 0.10$) ADG than pigs from Bump-f sows over the post wean period. During week 2 post wean when the feed was changed from the complex pelleted starter diet to the simple meal form diet ADG was reduced in all weaned pigs but compared to pigs from Phase-f sows, the reduction in ADG was more pronounced in pigs from
Constant-f \((P = 0.05)\) and Bump-f sows \((P = 0.007)\). During week 3 post wean, pigs from Constant-f sows had lower ADG than pigs from Bump-f sows \((P = 0.007)\) and pigs from Phase-f sows \((P = 0.02)\). Maternal gestation feeding regimen tended to impact overall weaned pig ADFI \((P = 0.06)\) where pigs from Constant-f sows consumed less \((P = 0.02)\) feed than pigs from Phase-f and tended to consume less \((P = 0.09)\) feed than pigs from Bump-f overall \((448 \text{ vs } 582 \text{ vs } 529 \text{ g/d, respectively})\). There was a feeding regimen by period interaction \((P = 0.007)\) in weaned pig ADFI where there were no differences due to feeding regimen in weeks 1 and 2 but in week 3 pigs from Constant-f sows consumed less \((P = 0.01)\) feed than pigs from Phase-f sows and tended \((P = 0.07)\) to consume less feed than pigs from Bump-f sows (Table 4.2). In week 4 post-weaned pigs from Constant-f sows consumed less feed than pigs from Phase-f and Bump-f sows \((P = 0.001)\). There was a gestation feeding regimen by period interaction \((P = 0.03)\) in gain : feed due to a tendency \((P = 0.09)\) for greater gain : feed in pigs from Phase-f sows compared to pigs from Bump-f sows in week 1, a tendency \((P = 0.10)\) for a greater week 2 reduction in gain : feed in pigs from Bump-f compared to pigs from Constant-f sows and a tendency \((P = 0.07)\) for greater gain : feed in pigs from Constant-f sows compared to pigs from Phase-f sows in week 4 (Table 4.2).

4.5 Discussion

The farrowing rate in the present study was low, \((72\% \text{ in the present study vs } 84\% \text{ Pig Champ})\) and the average mummies comparable to the average for 411 farms in USA reported for 2015 (Pig CHAMP, 2016), which could be attributed to the fore mentioned second parity dip in performance, the Pig Champ data included all sows not just second parity sows. The low farrowing rate could also be due to low feed intake
during the previous lactation period, and poor estrus detection and breeding management. The average number of still born piglets were low compared to the average reported in Pig CHAMP, likely because farrowing was attended by trained technicians who dried the piglets off at farrowing. There were no differences due to feeding regimen observed in measures of piglet quality at birth; liver and muscle glycogen and cord cortisol. Studies aimed at increasing piglet glycogen reserves at birth and hence, improve piglet survival, by manipulating the sow diet have shown mixed results (Bishop et al., 1985; Newcomb et al., 1991; Thiel et al., 2014), but most of the studies were focused on increasing energy in the diet not protein. The lack of feeding regimen difference in cord cortisol could be related to the lack of differences in birth weight category distribution which indicates a lack of effect of feeding regimen on piglet survivability in second parity. Both BW and cord cortisol are associated with piglet survivability (Leenhouwers et al., 2002; Mitchell, 2007). The lack of difference in cord cortisol could also be due to high variability and low sow numbers.

Feeding regimen did not influence litter characteristics in the present study. The effects of maternal nutrition on litter characteristics are inconsistent, for example Gonçalves et al. (2016) reported a reduced probability of number of piglets born alive when high energy diets were fed during gestation due to increased stillborn piglets, yet Heo et al. (2008) reported no effects of energy on number born. Yang et al. (2009) reported increase in litter birth weight when Lys levels in the diet were increased yet Gonçalves observed no differences due to amino acid levels but saw an increase in piglet birth weight when energy was increased.
In the present study, there were no differences due to feeding regimen observed in back fat and BW during the previous lactation, which could partly explain the lack of difference in litter characteristics. Hoving et al. (2012) explained that the body condition of the multiparous sows was associated with litter characteristics because sows with high BW loss during lactation have fewer implantation sites and when bred experience high embryonic loss, which would lead to smaller litter sizes.

Back fat tended to increase in Phase-f and Bump-f sows between d 60 and 110, an indication of nutrient supply (especially energy) above maintenance and fetal requirements. Increasing feed intake in late gestation has been shown to increase BW and back fat (Cromwell et al., 1989; Miller et al., 2000; Gonçalves et al., 2016), because the sows do not mobilize body reserves to meet the increased nutrient demand in late gestation, but Miller et al. (2000) reported reduced back fat in the low feed intake group and no change in back fat in the high intake group of sows.

There was a tendency for BW gain in Constant-f sows while Bump-f and Phase-f lost weight between d 1 and 14 of lactation and the lactation feed intake was higher in Constant-f sows. It has been reported that increasing feed intake in late gestation increases weight loss during lactation (Cromwell et al., 1989). The Constant-f sows received lower nutrition during gestation and would be expected to compensate during lactation by increasing feed intake (Weldon et al., 1994), but in the present study there were no differences in overall BW and back fat, it is not clear why lactation feed intake was higher in Constant-f sows. Some other indicator of body energy status such as hormonal levels not BW and back fat could be responsible for increased intake in the Constant-f sows.
The higher ADG in piglets from Phase-f sows than piglets from Bump-f sows during week 3 of lactation could be due to increased milk production in Phase-f sows. Mammary gland development occurs in late gestation when there is increased demand for amino acids (Ji et al., 2006) and increased protein during gestation is thought to increase subsequent milk production (Farmer and Sørensen, 2001). Additionally, milk production in sows peaks at about 3 weeks of lactation (King et al., 1996).

Pigs from Phase-f sows had higher overall post wean ADG than pigs from Constant-f and higher ADG than both Constant-f and Bump-f during the nutritional challenge which suggests that pigs from Phase-f sows were more robust post wean. Weaned pigs from Constant-f sows had reduced post wean feed intake probably related to gut function. There is some evidence that maternal over and under nutrition impacts gut morphology in weaned pigs. In sows fed an adequate, 75% below requirement and 150% above NRC (98) requirement the weight to length ratio of small intestine was higher in the over nutrition group than the control, and the over-nutrition group had increased messenger RNA expression for glucose transporters in the jejunum of newborn piglets and weaned pigs while the under-nutrition group piglets and weaned pigs had lower small intestine weight, length, weight to length ratio and villus height in jejunum and ileum (Cao et al., 2014).

In the present study, feeding regimen did not impact second parity sow reproductive performance but the farrowing rate was low. Pigs from Phase-f sows had better lactation growth performance as evidenced by heavier BW and ADG than pigs from Constant-f and Bump-f sows during week 3 of lactation, and greater ADG and
ADFI than pigs from Constant-f sows post wean. Pigs from Phase-f sows were more robust by having higher ADG than Constant-f and Bump-f when nutritionally stressed.
Table 4.1 Second parity gestation and lactation performance of gilts fed different gestation feeding regimen\(^1\) over two reproductive cycles.

<table>
<thead>
<tr>
<th>Item</th>
<th>Feeding regimen</th>
<th></th>
<th></th>
<th>Pooled SEM</th>
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<th>Period</th>
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<tr>
<td></td>
<td>n = 3</td>
<td>n = 6</td>
<td>n = 5</td>
<td></td>
<td></td>
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<tr>
<td>Gestation BW, kg</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Breeding(^2)</td>
<td>181</td>
<td>173</td>
<td>174</td>
<td>9</td>
<td>0.86</td>
<td>&lt;0.001</td>
<td>0.84</td>
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<tr>
<td>d 110</td>
<td>216</td>
<td>212</td>
<td>216</td>
<td>9</td>
<td>0.78</td>
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<td>42</td>
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<td>Lactation BW, kg</td>
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<tr>
<td>Farrowing(^3)</td>
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<td>207</td>
<td>205</td>
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<td>0.92</td>
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<tr>
<td>Wean</td>
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<td>195</td>
<td>196</td>
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<td>Breeding(^2)</td>
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<td>1.1</td>
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<td>0.63</td>
<td>0.73</td>
<td>0.91</td>
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<td>d 110(^4)</td>
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<td>1.3</td>
<td>1.2</td>
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<td>0.1</td>
<td>0.2</td>
<td>0.55</td>
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<tr>
<td>Lactation back fat, cm</td>
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<tr>
<td>Wean</td>
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<td>1.1</td>
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<td>0.20</td>
<td>0.68</td>
<td>0.03</td>
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<td>12.4</td>
<td>1.60</td>
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<td>Stillborn</td>
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<td>0.67</td>
<td>0.8</td>
<td>0.43</td>
<td>0.96</td>
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</tr>
<tr>
<td>Mummified</td>
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<td>0.17</td>
<td>1.2</td>
<td>0.30</td>
<td>0.17</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

\(^1\) Sows were assigned to gestation feeding regimen at breeding as gilts (i.e. first parity) and received the same feeding regimens at breeding in the second parity. The feeding regimen were: Constant feeding, a standard diet (1.7 g SID Lys/ kcal ME, 3276 kcal/kg feed) at a constant rate of 2.21 kg/d throughout gestation; Bump feeding, the standard diet at 2.21 kg/d during early gestation (d 0 - 89) and at 2.61 kg/d in late gestation (d 90 - 112); Phase feeding, a reduced lysine: energy diet (1.5 g SID Lys/ kcal ME, 3275 kcal ME/kg feed) at 2.21 kg/d from d 0 - 89 and an increased lysine: energy diet (2.1 g SID
Lys/ kcal ME, 3290 kcal ME/kg feed) at 2.61 kg/d from d 90 - 112. Sows received a common lactation diet (3380 kcal ME/kg, 0.88 % SID Lys) from d 113 of gestation to weaning in both parities.

2 Sow BW and back fat were measured 3 d prior to breeding and monthly during gestation.
3 Sows and piglets were weighed within 24 h of farrowing and weekly until weaning.
4 Sow back fat measured on d 110 of gestation was taken to be representative of farrowing back fat.
Table 4.2 Second parity growth performance of piglets from gilts fed different gestation feeding regimens\(^1\) across two reproductive cycles.

<table>
<thead>
<tr>
<th>Item</th>
<th>Feeding regimen</th>
<th>P-values</th>
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<td></td>
<td></td>
<td>Regimen</td>
<td>Period</td>
</tr>
<tr>
<td>Item</td>
<td>Constant feeding</td>
<td>Bump feeding</td>
<td>Phase  feeding</td>
</tr>
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<td>Constant feeding</td>
<td>3</td>
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<td>5</td>
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<tr>
<td>Lactation BW, kg</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Birth</td>
<td>1.3</td>
<td>1.5</td>
<td>1.5</td>
</tr>
<tr>
<td>d 7</td>
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<tr>
<td>d 14</td>
<td>3.9</td>
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<td>4.2</td>
</tr>
<tr>
<td>d 21</td>
<td>5.6(^a)</td>
<td>5.7(^a)</td>
<td>6.3(^b)</td>
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<tr>
<td>Lactation ADG, g/d</td>
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<tr>
<td>Week 1</td>
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<td>184</td>
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<tr>
<td>Week 2</td>
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<td>235</td>
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<tr>
<td>Week 3</td>
<td>251(^ab)</td>
<td>222(^a)</td>
<td>288(^b)</td>
</tr>
<tr>
<td>Post wean BW, kg</td>
<td>0.08</td>
<td>&lt;0.0001</td>
<td>0.3</td>
</tr>
<tr>
<td>----------------</td>
<td>------</td>
<td>---------</td>
<td>-----</td>
</tr>
<tr>
<td>Wean(^2)</td>
<td>6.0</td>
<td>6.3</td>
<td>7.0</td>
</tr>
<tr>
<td>d 7</td>
<td>7.7</td>
<td>8.0</td>
<td>9.1</td>
</tr>
<tr>
<td>d 14</td>
<td>8.8(^a)</td>
<td>9.0(^a)</td>
<td>11.0(^b)</td>
</tr>
<tr>
<td>d 21</td>
<td>11.6(^a)</td>
<td>12.3(^a)</td>
<td>14.1(^b)</td>
</tr>
<tr>
<td>d 28</td>
<td>14.9(^a)</td>
<td>16.0(^a)</td>
<td>17.9(^b)</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Post wean ADG, g/d</th>
<th>0.05</th>
<th>&lt;0.0001</th>
<th>0.13</th>
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<tbody>
<tr>
<td>Week 1</td>
<td>235</td>
<td>243</td>
<td>292</td>
</tr>
<tr>
<td>Week 2</td>
<td>162(^a)</td>
<td>136(^a)</td>
<td>250(^b)</td>
</tr>
<tr>
<td>Week 3</td>
<td>362(^a)</td>
<td>474(^b)</td>
<td>473(^b)</td>
</tr>
<tr>
<td>Week 4</td>
<td>473</td>
<td>527</td>
<td>537</td>
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</table>

<table>
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<tr>
<th>Post wean ADFI, g/d</th>
<th>0.06</th>
<th>&lt;0.0001</th>
<th>0.007</th>
</tr>
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<tbody>
<tr>
<td>Week 1</td>
<td>283</td>
<td>254</td>
<td>280</td>
</tr>
<tr>
<td>Week 2</td>
<td>322</td>
<td>333</td>
<td>427</td>
</tr>
<tr>
<td>Week 3</td>
<td>552(^a)</td>
<td>652(^b)</td>
<td>718(^b)</td>
</tr>
</tbody>
</table>
Sows were assigned to gestation feeding regimen at breeding as gilts (i.e. first parity) and received the same feeding regimen at breeding in the second parity. The feeding regimen were: Constant feeding, a standard diet (1.7 g SID Lys/ kcal ME, 3276 kcal/kg feed) at a constant rate of 2.21 kg/d throughout gestation; Bump feeding, the standard diet at 2.21 kg/d during early gestation (d 0 - 89) and at 2.61 kg/d in late gestation (d 90 - 112); Phase feeding, a reduced lysine: energy diet (1.5 g SID Lys/ kcal ME, 3275 kcal ME/kg feed) at 2.21 kg/d from d 0 - 89 and an increased lysine: energy diet (2.1 g SID Lys/ kcal ME, 3290 kcal ME/kg feed) at 2.61 kg/d from d 90 - 112. Sows received a common lactation diet (3380 kcal ME/kg, 0.88 % SID Lys) from d 113 of gestation to weaning in both parities.

A maximum of 8 pigs per litter continued in the study at weaning in order to have 4 pigs per pen in the nursery.
Sows were assigned to gestation feeding regimen at breeding as gilts (i.e. first parity) and received the same feeding regimens at breeding in the second parity. The feeding regimen were: Constant feeding, a standard diet (1.7 g SID Lys/ kcal ME, 3276 kcal/kg feed) at a constant rate of 2.21 kg/d throughout gestation; Bump feeding, the standard diet at 2.21 kg/d during early gestation (d 0 - 89) and at 2.61 kg/d in late gestation (d 90 - 112); Phase feeding, a reduced lysine: energy diet (1.5 g SID Lys/ kcal ME, 3275 kcal ME/kg feed) at 2.21 kg/d from d 0 - 89 and an increased lysine: energy diet (2.1 g SID Lys/ kcal ME, 3290 kcal ME/kg feed) at 2.61 kg/d from d 90 - 112. Sows received a common lactation diet (3380 kcal ME/kg, 0.88 % SID Lys) from d 113 of gestation to weaning in both parities.

Figure 4.1. Piglet birth weight distribution (%) in second parity litters from gilts fed different gestation feeding regimen. 

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1 Sows were assigned to gestation feeding regimen at breeding as gilts (i.e. first parity) and received the same feeding regimens at breeding in the second parity. The feeding regimen were: Constant feeding, a standard diet (1.7 g SID Lys/ kcal ME, 3276 kcal/kg feed) at a constant rate of 2.21 kg/d throughout gestation; Bump feeding, the standard diet at 2.21 kg/d during early gestation (d 0 - 89) and at 2.61 kg/d in late gestation (d 90 - 112); Phase feeding, a reduced lysine: energy diet (1.5 g SID Lys/ kcal ME, 3275 kcal ME/kg feed) at 2.21 kg/d from d 0 - 89 and an increased lysine: energy diet (2.1 g SID Lys/ kcal ME, 3290 kcal ME/kg feed) at 2.61 kg/d from d 90 - 112. Sows received a common lactation diet (3380 kcal ME/kg, 0.88 % SID Lys) from d 113 of gestation to weaning in both parities.
5.0 GENERAL DISCUSSION

The hypothesis behind the present study was that because in late gestation the requirement for amino acids increases to a greater extent than the requirement for energy, increasing the ratio of dietary protein (indicated by SID lysine) when the fetuses are rapidly growing and retaining protein in tissues (McPherson et al., 2004), would result in gilts that are in good body condition at the beginning of lactation, due to reduced mobilization of body tissues (Yang et al., 2009), and result in higher quality piglets with improved growth and robustness. The study determined the effects of phase feeding gilts during gestation over two reproductive cycles on maternal and piglet performance.

5.1 Gilt and second parity sow performance

A tendency for lower BW increase in Constant-f gilts than Bump-f and Phase-f gilts from d 0 – 110 of gestation was observed during first parity, due to a lower BW increase in Constant-f gilts from d 0 – 30. This was not observed in second parity. Because Constant-f and Bump-f regimens provided the same diet until d 90 of gestation, the changes in BW and back fat suggest that other factors other than nutrient supply affected the body condition of the gilts in early gestation during first parity. Some studies report initial BW and final BW and the body weight change over gestation but not the changes that take place within different time periods. If in the present study, we only monitored the gilt BW and backfat at the beginning and end of gestation, we would have found that the Constant-f gilts tended to gain less weight than Bump-f and Phase-f which would have verified the expectation that increasing the ration volume in late gestation helps maintain the body condition of sows (Heo 2008; Yang 2009). However, in the present study the reason for
the reduced BW gain in Constant-f gilts was early gestation not late gestation changes. This underscores the need to measure BW and backfat at different time points of gestation.

Feeding regimen affected gilt BW in a similar pattern during lactation in both parities but not at the same time points. During first parity, Constant-f gilts gained BW while both Bump-f and Phase-f lost BW in week 1 of lactation, but the loss in BW was greater in Bump-f gilts. In second parity, Constant-f sows tended to gain while both Bump-f and Phase-f sows tended to lose BW in the period from day 1 to week 2 and from day 1 to week 3 of lactation. In both parities no differences due to feeding regimen were observed in lactation back fat. The increase in BW in Constant-f is likely due to feed intake because Constant-f gilts and sows were more restricted during gestation, they likely compensated during lactation, as evidenced by the higher feed intake in Constant-f compared to Bump-f and Phase-f sows during second parity. Gilts have low feed intake in general (Koketsu et al. 1996) and the feed intake in the present study was lower than average intake which probably explains the lack of difference due to feeding regimen in first parity feed intake. Other factors such as high ambient temperature during the Summer months likely restricted lactation feed intake during first parity.

The number of piglets born alive were the same in both parities, stillborn piglets were reduced but mummified fetuses were increased and the proportion of born alive piglets which were < 1 kg BW at birth doubled in second parity. These results taken together with the low farrowing rate observed in second parity show that reproductive performance was reduced in second parity and suggest a second parity dip in reproductive performance (Morgan Morrow et al., 1992; Saito et al., 2010), but none of the litter characteristics mentioned above were affected by feeding regimen. In first
parity, more piglets from Phase-f than piglets from Constant-f and Bump-f were distributed in an intermediate birth weight category which indicated that they might have an advantage for piglet survival, as both small and large pigs have reduced survivability (Mitchell, 2007; Canario et al., 2007; Liggins, 1994). In the second parity, there were no differences in piglet birth weight distribution. Also during first parity cord cortisol tended to be higher in Phase-f than in Constant-f which suggested a higher probability of piglet survival in Phase-f, however, in second parity cord cortisol was not different between feeding regimen. Muscle and liver glycogen levels were not affected by feeding regimen in both parities. Taken together, the lack of feeding regimen effect on piglet birth weight distribution and cord cortisol levels, and a high proportion of piglets <1 kg birth weight in second parity suggests that while Phase-f improved piglet survivability in first parity, it did not improve piglet survivability in second parity.

5.2 Piglet and weaned pig growth and robustness

During first parity, maternal feeding regimen only impacted piglet growth in the first week of lactation where piglets from Bump-f gilts had lower ADG than piglets from Constant-f and Phase-f. In second parity, feeding regimen influenced piglet growth in week 3 of lactation and post wean, with piglets and wean pigs from Phase-f sows having better growth performance than Constant-f and Bump-f. In both first and second parity, weaned pigs from Phase-f sows tended to consume more feed when nutritionally challenged with a less complex, meal form diet which suggests that pigs from Phase-f sows were more robust. Greater feed consumption during the post-wean nutritional challenge resulted in a lesser ADG reduction in pigs from Phase-f gilts than Constant-f in first parity. The reduction in ADG (change in ADG between week 1 and week 2) was not
different between feeding regimen in second parity could be higher ADG in week 1 during second parity compared to week 1 ADG in first parity.

During first parity, the lower ADG in the first week of lactation in piglets from Bump-f gilts taken together with the finding that Bump-f gilts had a more negative BW change than Constant-f gilts during the first week of lactation, suggests that Bump-f gilts produced less milk and/or colostrum than Constant-f gilts during the first week of gestation. Constant-f gilts; therefore, performed better than Bump-f gilts in this regard. During second parity, Constant-f sows tended to have a positive BW change but this did not influence piglet ADG likely because the BW change in second parity was not as big as that during first parity. During first parity, piglets from Bump-f gilts tended to have reduced serum concentration of IGF-1 than piglets from Constant-f and Phase-f gilts at d 26 post wean, which taken together with a numerically lower ADG and ADFI in piglets from Bump-f gilts indicated that piglets from Bump-f gilts had a lower growth performance potential than piglets from Constant-f and Phase-f gilts. In second parity there were no differences in serum concentration of IGF-1, but overall, pigs from Constant-f had lower ADG and ADFI indicating a lower growth potential than pigs from Phase-f.

In conclusion, feeding regimen had minimal effects on maternal BW and back fat during late gestation but differences in BW without concomitant differences in back fat during lactation indicate body protein changes which underscores the need to focus on protein: energy ratios in diets during late gestation. Phase feeding had potential positive effects on piglet survival during first parity, positive effects on piglet growth during
second parity and positive effects on piglet robustness in both first and second parities.

Based on these results, Phase feeding is recommended to improve piglet performance.
6.0 BIBLIOGRAPHY


Cao M., C. Lianqiang, J. Wang, M. Yang, G. Su, Z. Fang, Y. Lin, S. Xu, D. Wu. 2014. Effects of maternal over- and undernutrition on intestinal morphology, enzyme
activity, and gene expression of nutrient transporters in newborn and weaned pigs.

Nutr. 30:1442-1447.

the somatotrophic axis in pigs born naturally or by Caesarian section. Domest.

Nutr. 66: 460s-463s.

loss in lactating sows is associated with reduced litter growth and ovarian

Cromwell, G. L. et al. 1989. Effects of additional feed during late gestation on

factors associated with nursery pig performance. Canadian J. Vet. Res. 69: 241-
245.

De Vos, M., L. Che, V. Huygelen, S. Willemen, J. Michiels, S. Van Cruchten, and C.Van
Ginneken. 2014. Nutritional interventions to prevent and rear low-birthweight

2013. Changes in back fat thickness during late gestation predict colostrum yield

Devillers, N., C. Farmer, J. Le Dividich, and A. Prunier. 2007. Variability of colostrum


doi:10.2527/jas.2010-2970


