

## ABSTRACT

LANNOM, KAYLA ELIZABETH. Effect of Suckling Pigs on Sow Lactation. (Under the direction of Dr. William Flowers).

The primary objective of this study was to determine whether teats that were not nursed during one lactation differ in their colostrum and milk composition and their ability to support piglet growth during subsequent lactations. A secondary objective was to determine whether the anatomical location of teats affected the composition of colostrum and mature milk and piglet growth characteristics. Forty-five sows were selected to be studied over three consecutive lactations. During the first lactation piglet nursing behavior was observed on days 3, 5, 7, 14 and 21 days of lactation while their body weights were recorded on days 1, 7, 14 and 21. Based on the data from the first lactation, one pair of teats from each sow was selected to be sampled for colostrum and then wrapped with elastic tape to prevent piglets from nursing. A second pair of teats from each sow was selected to be sampled for colostrum and mature milk (day 14) and remained available for piglets to nurse. Nursing observations and piglet weights were recorded for all piglets following the schedule from the first lactation. During the third lactation, piglets were allowed to nurse the pair to teats covered during the previous lactation. Colostrum and mature milk samples; nursing observations; and piglet weights were collected in a similar fashion as was done in the second lactation. There were no differences in the composition of colostrum with the exception of total protein; the composition of mature milk; or in piglet growth characteristics, nursing activity, and survival between teats that were nursed or not nursed in the previous lactation ( $p \geq 0.11$ ). There was a tendency for protein to be higher ( $p=0.09$ ) in colostrum from teats not nursed in the previous lactation ( $16.6 \pm 0.2\%$ ) compared with their counterparts that were suckled ( $16.1 \pm 0.3\%$ ). In contrast, the anatomical location of the teat did affect piglet growth characteristics, nursing activity, survival as well as the composition of colostrum and mature milk.

There was a general trend for most of the dependent variables studied to decrease ( $p \leq 0.05$ ) as the location of the teat became more posterior with the first two pair of teats producing higher quality colostrum and mature milk and, thus, promoting superior piglet growth performance compared to the last two pairs of teats. These results indicate that the anatomical location of the teat that piglets nurse was more important to their growth and survival than whether the teat was nursed or not in a previous lactation.

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Effect of Suckling Pigs on Sow Lactation

by  
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## **DEDICATION**

To my fiancé, family and friends who have given their full support during my graduate studies. For those who have a passion for further educating themselves on lactation and mammary development of swine.

## **BIOGRAPHY**

Kayla Lannom was born in Murfreesboro, Tennessee on July 17, 1987 to Ronald Lannom and Marilyn Sanderson. Her younger sibling, David, came along two short years later. At the age of thirteen, her mother re-married Ed Jacobs. She attended grade school and high school in Murfreesboro, Tennessee. She went to Oakland High School and transferred to Siegel upon opening of the school and graduated from Siegel High School in May 2005.

She attended Middle Tennessee State University and began her undergraduate studies in August 2005. In May of 2009, she graduated with a Bachelor of Science degree in Animal Science with a minor in Biology. In September of 2009, she moved to Clayton, North Carolina in hopes to attend graduate school at North Carolina State University. In September 2010, she began working at the Swine Educational Unit as a Research Technician and assumed responsibilities as the Farrowing Barn Manager. In the Spring of 2015, she entered into the graduate program in the Animal Science Department at North Carolina State University.

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## **Literature Review**

Lactation presents unique challenges for both the sow and her piglets. Each of the sow's nipples is expected to produce the same amount of high quality colostrum and milk and the piglets are expected to imprint on a nipple early after birth and then nurse it exclusively for the remainder of lactation. Unfortunately, this probably doesn't happen on a consistent basis. Instead, there usually are several mammary glands that are not nursed during each lactation since sows typically have at least 14 functional nipples but often only wean 10 to 11 piglets. A common belief is that any "unused" glands will have reduced production in subsequent lactations which will affect piglet growth. This has not been studied extensively in swine and was the main reason for conducting this study. Secondary objectives were to evaluate whether piglets nurse the same nipple throughout lactation and whether milk quality is affected by the anatomical location of the mammary gland. These too are generally accepted as biological facts that haven't been critically evaluated in swine. Consequently, a review of the current literature with regards to lactation and milk composition in sows and nursing behavior in piglets is a logical starting point in order to address these questions.

### **Anatomy of Adult Porcine Mammary Glands**

Mammary tissue is composed of two types of cells. Epithelial cells are the secretory cells during lactogenesis and comprise about eight percent of the total mammary tissue. The second type of cells are the stroma cells which provide support and structure for the complex mammary gland. Stroma cells comprise about twenty percent of the total mammary tissue. The mammary glands do not hold large amounts of colostrum or milk due to the small size of the glands and their teat cisterns (Hurley, 2018). Collectively, the epithelial tissue, ducts, and glands are referred

to as parenchymal tissue. Likewise, stromal cells that support the glands are often referred to as extraparenchymal tissue.

Porcine mammary glands are classified as complex glands because each teat is connected to two functional areas each of which has its own lactiferous duct and teat opening as shown in Figure 1 (Jones, 2001). Within each of these areas alveoli are grouped together forming lobules. Milk stored within the alveoli empties into these lobules which then drains into the lactiferous ducts. Once the milk has reached the lactiferous ducts it is ejected through the teat opening during nursing events. The biggest difference between cow and sow mammary glands is the size of the teat cistern and the storage capacity for milk. Cattle have a much longer teat than swine creating more length to the teat cistern itself and these canals can be three to four millimeters in length. In contrast, in the sow the teat cistern is short and often difficult to distinguish from the gland cistern (Quesnel et al., 2015). The mammary glands receive their vascular supply from several major blood vessels. The front or anterior mammary glands are supplied by the common carotid artery and the hind or posterior teats are supplied by a portion of the abdominal aorta (Comparative Lactation-Swine, 2018).

### **Mammary Gland Development, Growth, and Function**

Mammary glands originate from the ectoderm of the inner cell mass of the blastocyst which forms from fertilized ova around two weeks after conception. By day 70 of gestation, the first indications of mammary development are seen in the fetus. These are organized in two rows along the abdomen and are called milk lines. Along each milk line there are several protuberances which are predecessors of teats. At parturition, the mammary glands and duct systems in the baby piglet are still underdeveloped (Spinka and Illmann, 2015). However, their

anatomical location between the front and rear legs is established at this time. Typically, there are two rows of mammary glands spaced equidistantly between the junction of the ribs with the sternum on the anterior end and the pelvic region of the sow on the posterior end.

In the adult animal, mammary glands undergo cyclical changes in their structure and function during each lactation. These three stages are mammogenesis, lactogenesis, and involution. Mammogenesis is the growth of mammary tissue and generally is thought to begin with the onset of puberty and estrous cycles in gilts. Increased estrogen production at 75 days of age and then again between 90 to 180 days of age, prior to puberty, has been shown to stimulate the growth of parenchymal tissue within the mammary gland (Farmer and Hurley, 2015). After puberty and during estrous cycles, development and ovulation of follicles create corpora lutea which then regress after 12 to 14 days. Corpora lutea contain relaxin which is released into the general circulation when they regress. Relaxin is a polypeptide hormone which also stimulates parenchymal growth (Farmer and Hurley, 2015). Consequently, the number of estrous cycles a gilt has before she is bred should have a positive relationship with the amount of parenchymal tissue present in her mammary glands even though she has yet to lactate. This is because she is exposed to increases in both estrogens from growing follicles and relaxin at luteolysis during each estrous cycle. When corpora lutea regress at the end of pregnancy, relaxin is also released and its stimulation of parenchymal cells probably is directly related to the milk production potential of each mammary gland.

After conception and for the majority of gestation, mammogenesis occurs at a slow rate. However, during late pregnancy, there are significant increases in estrogen, relaxin, and prolactin. Each of these is important in the final stages of mammogenesis. Estrogens along with relaxin are potent mitogens and increase the growth of parenchymal tissue within the mammary

gland. This process occurs at a high rate during the last 30 days of the pregnancy (Farmer and Hurley, 2015). Prolactin is the most influential hormone for the final stages of mammary development during late gestation. A female will naturally have a large sustained increase in prolactin which begins a few days pre-partum and ends a few days postpartum (Farmer and Hurley, 2015). Prolactin stimulates both mammogenesis and lactogenesis. If this increase of prolactin does not occur or begins only during the postpartum period, then the female will have difficulty feeding the piglets due to reduced mammary development and low milk production.

Lactogenesis begins when colostrum is ejected from the teats which occurs between 2 to 7 days before parturition. Colostrum is secreted in small amounts initially and gradually increases during the first 24 hours after parturition. It then transitions to mature milk which begins about a week after parturition. It is interesting to note that the mammary gland is the only organ which goes through most of its development after parturition (Panzardi et al., 2013). As a result, production of mature milk is dependent on a several factors including the number of pigs nursing, their suckling intensity, and the nutrient intake level of the sow.

As mentioned previously, prolactin increases in late gestation and early parturition while progesterone decreases. Any delay of the prolactin surge will severely reduce the amount of colostrum produced which is critical for piglet weight gain and survivability (Spinka and Illmann, 2015). In addition, once progesterone decreases, oxytocin concentrations increase significantly. Oxytocin is responsible for stimulating strong uterine contractions which assist with the delivery of piglets as well as contractions in the myoepithelial cell which facilitate milk ejection. After birth, when the piglet noses along the underline of the sow a neural signal is transmitted to the posterior pituitary gland from the pressure receptors in the nipple and stimulates the release of oxytocin and prolactin. The release of oxytocin causes the myoepithelial

cells surrounding the alveoli to contract. The contraction of the myoepithelial cells causes the milk that is stored within the alveoli to be ejected. Increases in prolactin which occur at the same time stimulate production of new milk from the parenchymal cells in the mammary lobes. In contrast to effects in cattle, growth hormone in sows does not significantly affect milk yield or composition in sows.

Glucose appears to be utilized by sow mammary glands during lactogenesis compared with other energy sources (Farmer et al., 2015). In addition, transporter proteins channel amino acids and control their uptake in the mammary tissue. Finally, the presence of receptors for leptin, glucocorticoids, and insulin in mammary tissue has been well documented and all of these play important roles in the uptake of plasma substrates during lactogenesis (Farmer et al., 2015).

Mammary involution occurs once the offspring have been weaned. Involution is characterized by the regression of the parenchymal tissue within the mammary gland. When milk stops being removed from the mammary gland, milk stasis occurs. Milk stasis is defined as the accumulation of milk in the mammary gland that results in inflammation without infection. Milk production stops via an autocrine feedback pathway to the pituitary gland since there is no nursing action to stimulate the release of both oxytocin and prolactin.

When milk production stops there is an accumulation of fat in the mammary tissue. This is the fat that would have been secreted into the milk if lactation continued. Apoptosis increases significantly in the parenchymal tissue and blood flow decreases significantly to the mammary gland during the first sixteen hours post weaning (Kim, 2013). Mammary glands that are not suckled in the early stages of lactation undergo the same physiological changes as those observed during involution after weaning (Farmer and Hurley, 2015). This observation has relevance to cross-fostering which is a common practice within the swine industry. Piglets need to be cross-

fostered within forty-eight hours after parturition. After this period of time unsuckled mammary glands begin the involution process. Involution of the mammary glands can be reversed to a certain degree, but once it begins mammary glands will never function at full capacity compared with those that were suckled from the beginning of lactation. The process of stopping involution is called gland rescue. Glands that have gone unsuckled for three days are no longer capable of being rescued. Rescued glands or mammary glands that are transiently suckled secrete reduced quantities of milk compared with regularly suckled mammary glands (Farmer and Hurley, 2015).

### **Composition of Colostrum and Mature Milk**

Table 1 contains a comprehensive summary of the composition of colostrum and mature milk. Colostrum is defined as the first milk produced by the sow during a twenty-four to thirty-six hour period after birth. It contains the highest concentrations of nutrients as well as other growth factors, hormones, and antibodies. Lactose, fatty acids and some milk protein fractions are made within the mammary gland. Immunoglobulins and serum albumin in colostrum can be synthesized de novo by mammary tissue or transported to the milk from the vascular and circulatory system by active transport and filtration (Comparative Lactation-Swine, 2018). Mature milk is classified as milk produced after the first 7 days of lactation since it no longer contains high levels of immunoglobulins found in colostrum. Changes in milk composition are discussed in detail in the following sections.

### Fat

Fat content of milk increases between day 2 and 4, and then reaches a plateau after day 7 and remains fairly constant for the remainder of lactation. This pattern appears to match the needs of the piglets. Thermoregulation is crucial for a piglet during the first week postpartum and the fat content of the colostrum and milk are the main energy source for piglets during the first week of life and critical for their thermoregulation (Hurley, 2015). During mid- and late lactation, the growth rate of piglets increases significantly and milk produced after the first week has the highest fat content (Herpin and Dividich, 1995). The fat content of both colostrum and milk is influenced by the fat composition of the sow's diet as well as genetics. It has been shown by numerous investigators that changing the ratios of fatty acids in lactation diets causes similar shifts in the fatty acid composition of sow milk (Rosario et al., 2016).

### Protein

The protein content is highest in colostrum during parturition and decreases significantly during the first 24 hours of lactation. It is not uncommon for protein in colostrum to decrease by 50% during this period of time. This change is reflective of changes in secretion of immunoglobulins which are high immediately after birth in colostrum and then decrease rapidly over the next 24 to 36 hours. In contrast, other proteins used mainly for nutritional purposes tend to be low in colostrum and then increase during the first week of lactation. These include casein, beta-lactoglobulin and alpha-lactalbumin (Quesnel et al., 2015). However, because immunoglobulins are so high in colostrum the total whey protein within milk still decreases from 90% to about 70% during the first week of lactation (Hurley, 2015).

### Immunoglobulins

Immunoglobulins in colostrum and milk can either be produced passively via transfer from serum and or actively via de novo synthesis by mammary tissue. The three most common sow immunoglobulins within the milk are IgG, IgA, and IgM. Colostrum contains high levels of immunoglobulins which are mostly IgG and IgM and it is generally assumed that the majority, if not all of these were transported from the serum. The mature milk of a sow contains considerably reduced levels of immunoglobulins. In contrast to colostrum, IgG, IgM, and IgA levels in mature milk are thought to be produced by the mammary glands themselves (Curtis, 1973).

Immunoglobulins in colostrum and milk increase with parity most likely due to the female being exposed over time to various organisms that activate her immune system and tend to be high in milk from sows on farms undergoing disease outbreaks.

The predominant type of immunoglobulin in colostrum is IgG because IgG is the major immunoglobulin isotype within the serum of the sow during late pregnancy and the majority of immunoglobulins in colostrum are transferred from the serum. Recent studies have indicated that IgG antibodies typically have little to no effectiveness against pathogens the piglets normally encounter during lactation (Gaskins and Kelley, 1995). In contrast, IgA protects piglets from pathogens to which the sow has already been exposed and has developed immunity. IgA immunoglobulins are only partially degraded within the intestinal tract of a piglet and thus provide short term enteric protection against viruses and bacterial infections (Gaskins and Kelley, 1995). Acquisition of passive immunity for the piglet occurs over a short period of time after birth. A piglet's intestines will go through a "gut closure" in which the intestinal tract cease to allow antibodies to pass between intestinal cells and enter the vascular or lymph systems

(McKay and Rahnfeld, 1990). This occurs at about 24 hours post-partum which also coincides with high levels of immunoglobulins in colostrum.

Colostrum quality and consumption is particularly important for piglets since they do not acquire any immunity during fetal development through the placenta. The specialized epitheliochorial placenta of swine does not allow for the vascular transfer of antibodies from the sows to her piglets. Consequently, once a piglet is born, it must obtain colostrum in order to acquire any immunity. Therefore, the quality of the colostrum is crucial to the immune status and survivability of the piglet which is why weaning at an early stage is cause for concern (Hurley, 2018). It takes between 7 and 14 days for piglets to increase antibody levels in response to exposure to pathogens in the environment or vaccination. Immunoglobulins in colostrum that piglets receive passively presumably provides protection until their own immune system is able to react to any exposure.

In addition to antibodies, colostrum and milk contain white blood cells such as neutrophils, macrophages, and lymphocytes (Hurley, 2015). The role of these in disease protection and prevention in piglets is still under investigation but in many other biological fluids such as semen they play important roles.

### Lactose and other Carbohydrates

Lactose is the major sugar in sow milk. It appears to have the least variation with regards to stage of lactation in that it typically remains between 3 and 4% from birth (colostrum) through the third week of lactation (Atwood and Hartmann, 1992). Colostrum does tend to have reduced amounts of lactose compared with mature milk but the differences between the two are small typically only 0.5 to 1.0%. Glucose concentrations are low in both colostrum and milk compared

with lactose. It follows a similar pattern with its lowest and highest concentrations occurring at birth and day 3 of lactation, respectively, followed by a gradual decrease through day 7. It has been reported that sow milk contains at least 29 distinct oligosaccharides (Tao et al., 2010). While there is some variation, the general pattern is for these to be high in colostrum; low in mid-lactation; and then high again in late lactation.

### Minerals

Many pathways have been discovered in the epithelial cells within the mammary gland of the female that allow for transportation of minerals into the milk. The most common way this occurs is via eccrine secretion. Eccrine secretion makes use of ion pumps and channels located on the serum and the milk sides of the epithelial cells. These allow for the osmotic pressure to remain balanced and allow for movement of minerals into colostrum and milk. Table 1 summarizes changes in the mineral composition during lactation in sows. Calcium is lowest in colostrum and highest in mature milk. This is in contrast to phosphorous which appears to remain fairly consistent regardless of the stage of lactation. Colostrum tends to have increased concentrations of most other minerals including sodium, potassium, chlorine, sulfur, copper, iron, iodine, selenium, manganese and zinc compared with mature milk. While magnesium does not appear to change much with stage of lactation (Coffey et al., 1982).

### Vitamins

Both colostrum and mature milk contain a variety of vitamins whose concentrations vary with stage of lactation. Vitamins A, C, D, and E all tend to be highest in colostrum and then decrease significantly in mature milk (Csapo et al., 1996). Vitamin C is the highest at 190 and

94, ug/mL in colostrum and milk, respectively; followed by E, 10 and 2.6 mg/mL; A, 1.1 and 0.5 mg/mL; and D, 0.015 and 0.0006 ug/mL. Vitamin K does not seem to be affected by stage of lactation.

Riboflavin, niacin, and folic acid follow similar patterns as those observed for fat soluble vitamins. Concentrations are highest in colostrum and then decrease by about 50% during the first week of lactation. Thiamin appears to remain relatively constant throughout lactation with concentrations in mature milk only being about 10% lower than those in colostrum (Elliot et al., 1971).

#### Other Bioactive Compounds

It has been well documented that milk contains other compounds referred to as being “bioactive” meaning the when consumed they have the potential to stimulate biological changes in piglets. Most hormones, especially ones that are steroid or small polypeptides are transferred from the vascular systems of the sow to her milk. The majority of these including progesterone, estradiol, estrone, IGF-1, EGF, prostaglandins, relaxin and oxytocin are high during late pregnancy and during parturition. Therefore, their concentrations typically are highest in colostrum and then decrease as lactation progresses. It is not clear at the present time what effect these may have on the growth and development of piglets. However, a “lactocrine” hypothesis has been proposed (Bartol et al., 2006) which speculates that many of these found in colostrum may play important roles in the subsequent development of the reproductive tracts in both gilts and boars.

Cytokines have also been identified in sow colostrum and mature milk (Nguyen et al., 2007). These include IL-4, IL-6, IL-10, IL-12, IFN- $\gamma$ , TNF- $\alpha$  and TNF- $\beta$ . Cytokines are small

proteins involved with cellular signaling and are often involved with immunomodulation. They typically are thought to have a paracrine role in other physiological systems. As is the case with other bioactive compounds, highest concentrations are found in colostrum while lowest concentrations are in mature milk.

*Differences in Milk Composition among Teats (anatomical location)*

The spacing between each pair of teats on the underline of a sow is not equidistant. There is more distance between adjacent teats in the anterior and mid-sections of the underline compared with the ones located posteriorly. This advantage in spacing allows for increased storage of colostrum and milk while the lack of space for the hind teats limits their ability to hold colostrum and milk. The location of the teats does not seem to have an influence on the milk composition with the exception of fat. The fat content of milk can differ among glands and this is influenced by overall mammary development and blood flow, especially when sows are fed high fat lactation diets (Comparative Lactation-Swine, 2018). In general, the five anterior pairs of mammary glands tend to produce milk with more fat compared with those located in the posterior portion of the underline (Farmer et al., 2015).

Milk production is increased in teats that are suckled at increased frequencies during previous lactations. Consequently, this could be another explanation for differences in nutrient content among nipples. It also is assumed that anterior teats are nursed more frequently than posterior ones so in addition to de novo synthesis by mammary tissue differences in nursing frequency may also be involved with variation in milk composition among teats (Varley, 1995).

## **Piglet Nursing Behavior**

When the first piglet is born it must hunt for the mother's underside and her teats. This can take between twenty-five and thirty-five minutes. The first piglet usually takes the longest to find the teats and begin nursing, while subsequent offspring find the teats more quickly. The piglets are instinctively attracted to the abdomen of the sow by touch, nuzzling the underline, and presumably olfactory cues from the teats or the area around them. The sow's underline is mostly devoid of hair and the piglets tend to move in the direction of the hair orientation of the sow. The underline of a sow also is two to three degrees warmer compared with her extremities and this increase in temperatures also is thought to attract piglets for nursing and sleeping. During the first day, a piglet tends to suckle anywhere from two to thirteen teats within the first eight hours postpartum (Fraser et al., 1995).

Colostrum production is at its highest in the female during parturition and will cease to be continuous once regular periods of feedings occur. Piglets consume about twenty-five percent of their total colostrum intake within the first three feedings post-partum and which equates to anywhere from 290 to 490 grams on the first day (Herpin and Dividich, 1995). During and shortly after parturition the colostrum will flow freely from the mammary glands until about 50 to 100 milliliters are removed. The intramammary pressure decreases once the initial 50 - 100 mL is removed and after this colostrum no longer freely flows.

A nursing bout entails five stages beginning with nursing initiation. The sow signals the piglets to nurse by a series of grunts. The second stage of a nursing is pre-ejection teat massaging that occurs when piglets put their nose and mouths on the underline. The third stage is milk ejection which is short and can last for up to thirty seconds followed by post-ejection teat massage. Piglets continue nosing, massaging, and nursing the underline during this stage in order

to obtain the highest amount of colostrum or milk. Sows have a brief period of milk ejection. Milk ejection is when piglets actually are able to consume milk and is signaled by grunts from the sow. The last stage is nursing termination which is initiated by the sow when she changes position to lie on her sternum or she stands (Varley, 1995).

The milk ejection phase has been studied the most extensively in sows since it typically controls nursing duration and frequency of piglets. Females eject milk for a brief period of time, ten to twenty seconds. Initially after birth piglets receive at least twenty-four feedings a day with each nursing being less than an hour each time with one study reporting that sows allow piglets to nurse, on average, every 50 minutes (Comparative Lactation-Swine, 2018). After a nursing bout, sows are not able to provide normal amounts of milk again for twenty minutes. A piglet massaging the underline of the sow during this time will not cause the premature release of milk. During the first few days postpartum sows initiate up to eighty percent of the nursing bouts. By the second week of lactation, the percentage of the sow-initiated of nursing bouts drops to fifty percent (Varley, 1995).

Cross-fostering needs to occur within forty-eight hours post-partum in order to recover any teats who have begun the involution process. When piglets are added to a sow the increase in pressure from the piglets' mammary gland stimulation signals the posterior pituitary gland to release oxytocin. A nursing bout typically occurs shortly after the cross-fostering events. Any teats that were not suckled should regain full functionality if it is nursed subsequently on a regular basis.

As piglets mature, nursing intervals increase with the sow ending the nursing period by sitting up or laying on their sternum. The increased interval between consecutive nursing bouts allows for increased milk production and accumulation in the mammary glands. In group

housing, nursing intervals are synchronized based on the grunting of sows. A study was conducted to investigate if using foreign sow grunts, from the same breed, would interrupt nursing intervals (Farmer and Robert, 2006). The findings were that only about 25% of sows would stimulate a nursing bout upon hearing grunts from foreign sows. In the same study, using foreign sow grunts was evaluated as a way to shorten the nursing interval as a way to increase piglet growth and weaning weight. When grunts from foreign sows were played for 40 minutes the nursing interval was decreased, but not when they were played for shorter time periods.

Piglets can place themselves in some peculiar postures when nursing or attempting to reach a teat. A difficult or uncomfortable posture could deter the piglet from continuously suckling a particular teat. In addition, in small litters, an increased amount of nursing or stimulation from the piglets is required for milk letdown (Mallepell et al., 2006). This may cause piglets to move among nipples more frequently in search of milk. Finally, if a sow does not lay down frequently or during nursing bouts decides to stand it becomes difficult for piglets to nurse. All of these factors can influence piglet nursing behavior in addition to the quality and quantity of the milk produced by teats.

#### *Establishment of Dominance (Social Hierarchy during Nursing)*

Once parturition is complete, piglets will begin to establish dominance by sampling multiple teats (Comparative Lactation-Swine, 2018). The establishment of dominance is thought to take up to a week. On the first day following parturition fighting is the most frequent and most intense. However, after this, it gradually diminishes as lactation progresses (Trottier, 2015). During competition for a teat, if a piglet does not defend its place then it will likely not obtain sufficient colostrum or milk for adequate growth and development (Fraser et al., 1995).

When piglets have established their social hierarchy, smaller piglets usually nurse the anterior teats that are small and not as productive (Klobasa et al., 1987). The most desirable and best producing teats are those within the mid-section of the sow's underline. Piglets high in the social hierarchy are able to acquire a teat in this location and often increase their aggressive behaviors towards the littermates that try to displace them from their teat during nursing bouts (Trottier, 2015).

Piglets have two sets of needle teeth: one pair on the upper jaw and a second pair on the lower jaw which they use in establishing dominance. Needle teeth can cause significant injury to other piglets during fights associated with establishing and defending a piglet's place in the social order. A common management practice is to remove the needle teeth to decrease the amount of damage to the other piglets and to the sow's underline. However, it has been suggested that the needle teeth of the runt pigs should be left intact in order to assist them in establishment of dominance (Fraser et al., 1995).

### Teat Selection

Teat selection by piglets is directly related to the dominance hierarchy. Piglets that are the strongest will out compete weak ones for the more desirable teats. As a result, they typically nurse anterior teats while undersized piglets at the low end of the social hierarchy tend to select posterior teats. Posterior teats produce less than mid-section teats. Teats that are in the mid-section of the sow produce the most milk and are often described as the most desirable. Piglets that select a teat within the mid-section of the sow are exposed to the increased amounts of aggressive behavior from littermates (Trottier, 2015). Once the dominance hierarchy is established and piglets have selected a teat then they nurse from that teat about 90% of the time

after the first week of lactation. Piglets will occasionally suckle adjacent teats as well. External factors such as the position of the sow during and immediately after parturition and the farrowing crate design, especially the location of the lowest bar can influence teat selection. If either of these results in a situation in which access to a teat or a group of teats is limited then piglets are less likely to select these, regardless of their anatomical location, than those that are easier to nurse.

#### *Nursing patterns (Consistency of Nursing the Same Teat)*

Nursing patterns have been studied extensively but not in very consistent ways. One study reported that 12% of the piglets nurse more than one teat (Curtis, 1995). However, this appears to be dependent upon when during lactation observations are made. The proportion of piglets establishing ownership of a teat within the first 24 hours after birth varies between 5 and 50%. If observations are made early in lactation then the proportion of piglets nursing the same teat typically is low, due to this variation, compared with when observations are made late in lactation when teat selection and establishment of the social hierarchy has already occurred.

#### *Survival of Piglets during Lactation*

Pre-weaning mortality has averaged between 15 and 20% since 2000 on North American swine farms and is a substantial economic loss for the swine industry. High pre-weaning mortality appears to be linked to poor pre-weaning growth and low weaning weights, in addition to other factors. Birth weight influences pre-weaning mortality since low birth weight piglets have compromised thermoregulatory capabilities and often become chilled after farrowing. This places them at a disadvantage in terms of finding and being able to defend a nipple. Any lack of

colostrum for a piglet results in insufficient antibodies and nutrients which significantly decreases its chance of survival. Approximately 50% of pre-weaning mortalities occur within the first 24 hours of life and it has been suggested that most of these may be related to inadequate colostrum intake. A generally accepted guideline is that piglets need to consume colostrum within 30 minutes of birth in order to have the highest chance of survival. Every hour that passes without colostrum, the chances of survival for a piglet diminishes significantly (Peltoniemi and Oliviero, 2015). Many factors influence the quality of colostrum that sow's produce which, in turn, could affect piglet survival.

## **Conclusion**

Sow lactation, mammary gland development and nursing behavior require additional research to develop management programs that help sows and piglets reach their maximum potential. It is clear that some sows wean big litters of large pigs while other sows do not when both have the same genetic background; are housed in the same environment; are fed the same lactation diet; and are managed by the same individuals. In these situations, an obvious place to look is the sow herself and poses questions such as what roles do variations in milk quality and quantity among teats or among the nursing behavior of piglets contribute to these observed differences. The first step in beginning to answer these questions is to estimate how much, if any, variability exists which was the main objective of research contained within this thesis.

Table 1. Composition of Colostrum and Mature Milk from Sows (adopted from Herpin and Le Dividich 1995)

	Colostrum		
	During Parturition	24 h after parturition	Milk at 15 days
Dry Matter (%)	23.4	22.0	19.2
Crude Protein (Nx6.38) (%)	13.1	9.1	5.5
Fat (%)	5.1	6.8	8.1
Lactose (%)	3.8	3.9	4.8
Energy (kJ g <sup>-1</sup> )	5.93	5.89	5.23
Essential Amino Acids (g per 16g N)			
Arginine	5.53	5.80	6.5
Histidine	2.97	2.99	2.78
Isoleucine	3.77	3.98	3.71
Leucine	9.85	9.40	8.36
Lysine	7.34	7.43	7.42
Methionine + cysteine	3.40	3.02	3.34
Phenylalanine	4.49	4.29	4.08
Threonine	5.90	5.10	5.03
Valine	6.45	6.04	5.68
Fatty Acids (% of total FA)			
C14:0	1.9	1.8	3.4
C16:0	23.5	22.5	38.7
C16:1	4.7	5.2	10.7
C18:0	5.3	5.8	5.5
C18:1	38.7	42.8	23.2
C18:2	20.2	16.9	13.1
C18:3	1.6	1.3	1.1
C20:0	0.2	0.1	0.2
C20:1	0.5	0.5	0.2
C20:2	0.5	0.5	0.2
C20:3	0.3	0.2	0.1
C20:4	1.1	0.9	0.6
Major and trace elements			
Ca (%)	0.066	0.103	0.146
P (%)	0.110	0.127	0.117
Mg (%)	0.007	0.009	0.008
K (%)	0.119	0.143	0.083
Na (%)	0.082	0.048	0.043
Cu (µg g <sup>-1</sup> )	3.21	2.46	1.79
Zn (µg g <sup>-1</sup> )	14.00	8.31	5.88
Mn (µg g <sup>-1</sup> )	0.12	0.11	0.06
Fe (µg g <sup>-1</sup> )	4.68	3.52	2.88

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## **The Effect of Piglet Nursing on Sow Lactation**

## Introduction

One of the biggest concerns in the swine industry today is piglet mortality rates and it is general accepted that improving management of sows and their litters during lactation decreases pre-weaning mortality. Lactation presents unique challenges for both the sow and her piglets. Each of the sow's nipples is expected to produce the same amount of high quality colostrum and milk and the piglets are expected to imprint on a nipple early after birth and then nurse it exclusively for the remainder of lactation. Unfortunately, this probably doesn't happen on a consistent basis. Instead, there usually are several mammary glands that are not nursed during each lactation since sows typically have at least 14 functional nipples but often only wean 10 to 11 piglets. A common belief is that any "unused" glands will have reduced production in subsequent lactations which will affect piglet growth. This has not been studied extensively in swine and was the main objective for this study. Secondary objectives were to evaluate whether piglets nurse the same nipple throughout lactation and whether milk quality is affected by the anatomical location of the mammary gland. Information concerning each of these areas is lacking for swine and, hopefully, increased knowledge in each of these areas will lead to improved lactation management and reduced piglet pre-weaning mortality.

## Materials and Methods

### Animals, Facilities, and General Management

The study was conducted at the Swine Educational Unit (SEU) at North Carolina State University between 10/16/16 and 10/18/17. The SEU is a closed herd, farrow-to-nursery operation with 250 sows. All females used in the study (n=45) were Smithfield Premium Genetics (SPG) maternal-line sows that farrowed litters sired by SPG terminal-line boars. Sows were moved to farrowing crates at approximately day 107 of gestation. Each farrowing room consisted of 12 individuals, bow-bar crates that measured 1.5 m wide by 2.5 m long. The raised flooring under the farrowing crates consisted of cement slats underneath sows, TriBar®, an expanded metal, behind sows and Tenderfoot®, a plastic coated wire, in the piglet creep areas. Each room had a propane heater suspended from the ceiling for general heating purposes and each farrowing crate had either two heat lamps or one heat lamp and heat pads in order to provide supplemental heat for the piglets. Each farrowing room was equipped with a side-wall baffle ventilation system with an evaporative cooling cell and an under-slat flush system for waste removal. During lactation, sows were fed a corn and soybean formulated ration twice per day that met or exceeded NRC recommendations for lactating sows (NRC, 2012). The diet formulation for the sows throughout lactation is shown in Appendix A.

Piglets were processed within 24 hours of parturition. The standard operating procedures for processing piglets included ear notching, clipping needle teeth, tail docking, oral antibiotics (Spectam; Bimeda, Oakbrook Terrace, IL, USA) and iron (Uniferon 100; Pharmacosmos, Inc., Copenhagen, Denmark) and penicillin (Norocillin; Norbrook, Lenexa, KS, USA) injections. Body weight and sex for all piglets were also recorded. Cross fostering occurred after piglets were processed and between 24 and 48 hours after birth. Piglets were distributed in a manner

such that each sow was nursing between 8 and 10 piglets after cross fostering. Male piglets were castrated between 7 and 11 days old and all piglets were weaned at an average of  $22 \pm 1$  days.

### Experimental Procedures

Sows (n=45) in their first through fifth parities were selected to participate in the study which was conducted over three consecutive lactations. During the first lactation of the study, piglet growth and nursing activity were recorded for each sow. Piglets were weighed at processing which was designated as day 1 of lactation and on days 7, 14, and 21. Nursing observations were recorded on days 3, 5, 7, 14, and 21 of lactation. Before each observation period the back of each piglet was marked with a different color in order to facilitate data collection (Figure 2). Colors for each pig were assigned randomly for each observation period. After being colored, the entire litter was returned to their sow and the teat that each piglet nursed was recorded during two consecutive nursing bouts using the diagram shown in Figure 3. A nursing bout was considered to begin when the sow was laying on her side with her underline exposed and all the piglets were attempting to nurse a teat. It was considered to end when the sow rolled over with her underline underneath her body or when she stood and the piglets moved away from her. If a piglet started nursing one teat and then switched to another one, then the piglet was given credit for nursing two teats during that nursing bout and the sequence in which the teats were nursed was recorded. Nursing bouts lasted between 20 and 120 seconds.

Piglet growth and nursing activity collected during the first lactation were used to select teats for each sow studied during the second and third lactations. The main criteria used was to select two pairs of teats from each sow with similar nursing activity and piglet growth data. In Appendix B, the manner of selecting two teats is described in detail. During the second lactation

of the study one of these pairs was selected to be not nursed by blocking their access by piglets. The two pairs of teats were selected in order to represent the entire underline of the sow. One pair was selected from the anterior portion of the sow's underline between the first and fourth pair of teats. The second pair was selected from the posterior underline between the fifth through the seventh pair. Teats were selected based on low variability and piglet overall weight gain and the pairs selected were different for all sows in the study. A pair of teats was blocked by placing a cover with adhesive qualities over each nipple and then covering both of them with several wraps of an elastic bandage material (Figure 4, Elastikon; Johnson & Johnson, New Brunswick, NJ, USA). This was repeated, as necessary, as lactation progressed in order to insure that piglet could not access the blocked pair. Prior to being covered, colostrum was collected from each teat that was blocked as well as each teat in the observational pair that was nursed via manual expression. The second pair of teats served as the nursed control. Samples of both colostrum during farrowing and mature milk on day 14 of lactation were obtained from each teat. However, piglets were allowed to nurse this pair. Colostrum samples were collected without the use of oxytocin anywhere from 1 hour before farrowing until 8 hours after farrowing. Samples of mature milk on day 14 of lactation were collected from the observed pair with the use of oxytocin (20 i.u.) just prior to the nursing activity of the litter but after the litter had been weighed. Colostrum and milk samples were stored in triplicate at 4°C immediately after collection. One of the subsamples from the colostrum and milk samples was sent to a commercial laboratory without being frozen for milk composition analysis in order to examine the effect of freezing and thawing on fat and protein measurements. The remaining subsamples were frozen at -20°C for subsequent analyses. One of the remaining subsamples that was frozen was sent to the same commercial laboratory for milk composition while a second was used for

determination of immunoglobulins. Body weights and nursing activity of all piglets in the litter of each sow were recorded as described previously for the first lactation of the study.

During the third lactation of the study all the procedures that occurred during the second lactation were performed with two differences: piglets were allowed to nurse the teats which had been blocked previously and samples of mature milk from these teats were collected on day 14 of lactation. This experimental design produced piglet growth and nursing activity for each teat from the same sow over three consecutive lactations. In addition, it created a situation in the third lactation where piglet growth, nursing activity and milk composition could be compared from teats that were either nursed or not nursed during the previous lactation from the same sow. Sows that did not complete all three lactations were eliminated from the final data analyses.

#### *Colostrum and Milk Composition Analyses*

The commercial laboratory was a GLP certified facility and used techniques in accordance with the Association of Official Analytical Chemists for determination of dry matter, ash, fat, protein and lactose composition of samples (AOAC, 1990). The laboratory used the Babcock method to estimate the percentage of fat. Protein was determined by measuring nitrogen using pyrolysis and quantification of N<sub>2</sub> (Dumas method) and then multiplication of the N content by 6.38. Lactose was assayed using an enzymatic method (LECO TFE-2000). Estimation of fat composition in 25 paired fresh ( $7.4 \pm 0.5\%$ ) and frozen ( $7.1 \pm 0.8\%$ ) samples were not statistically different ( $p=0.32$ ). Immunoglobulins G, A, and M were analyzed by ELISA using commercially available kits (Bethyl Laboratories, Montgomery, TX) for total porcine IgG and IgA and human IgM. Immunoglobulins were assayed in duplicate. The intra- and interassay

coefficients of variation were 3.5 and 8.0% for IgG; 2.9 and 6.1% for IgA; and 3.8 and 6.4% for IgM, respectively.

### Statistical Analyses

The experimental unit in this study was considered to be a pair of teats. The dependent variables evaluated were as follows: birth weight (kg); weaning weight (kg); weight gain between days 1 and 7 (kg); weight gain between days 7 and 14 (kg); weight gain between days 14 and 21 (kg); weight gain between days 1 and 21 (kg); percentage of piglets that survived from birth to weaning (piglet survival); percentage of nursing bouts in which one piglet nursed the same nipple (suckling activity); concentrations of total IgG (ug/mL), total IgA (ug/mL) and total IgM (ug/mL) in colostrum; and percentages of dry matter, ash, fat, protein, and lactose in colostrum and mature milk. Piglet data represent the average for all piglets that nursed a pair of teats.

The effect of teat location on piglet growth characteristics, suckling activity, and piglet survival was analyzed with mixed model procedures for repeated measures using SAS (Proc Mixed; SAS; SAS Institute, Cary, N.C.). The statistical model included teat location; parity group (parities 1 & 2; parities 3-6; and parities  $\geq 7$ ); study lactation (1, 2, or 3) and appropriate interactions. Number of pigs born alive and number of pigs weaned were used as covariates in the model. The variance/covariance structure used for the repeated measures analyses was determined by finding the appropriate structure with the lowest fit statistics. The error term for teat location nested within sow by parity was used to test for the main effect of teat location and its interactions. Teat location nested within sow by parity group was considered to be a random effect. When significant main effects were present, Student-Newman Kuels multiple range test

was used to determine differences among individual means (Snedecor and Cochran, 1989). Data from the third lactation for the teat pairs which were blocked and not nursed during the second lactation were excluded from these analyses.

The effect of teat location on colostrum composition was analyzed with mixed model procedures for repeated measures using SAS (Proc Mixed; SAS; SAS Institute, Cary, N.C.). The statistical model included teat location; parity group (parities 3-6; and parities  $\geq 7$ ); study lactation (2, or 3) and appropriate interactions. Number of pigs born alive and number of pigs weaned were used as covariates in the model. The variance/covariance structure used for the repeated measures analyses was determined by finding the appropriate structure with the lowest fit statistics. The error term for teat location nested within sow by parity group was used to test for the main effect of teat location and its interactions. Teat location nested within sow by parity group was considered to be a random effect. When significant main effects were present, Student-Newman Kuels multiple range test was used to determine differences among individual means (Snedecor and Cochran, 1989). Data from the third lactation for the teat pairs which were blocked and not nursed during the second lactation were excluded from these analyses.

The effect of teat location on milk composition was analyzed with mixed model procedures for repeated measures using SAS (Proc Mixed; SAS; SAS Institute, Cary, N.C.). The statistical model included teat location; parity group (parities 3-6; and parities  $\geq 7$ ); study lactation (2 or 3) and appropriate interactions. Number of pigs born alive and number of pigs weaned were used as covariates in the model. The variance/covariance structure used for the repeated measures analyses was determined by finding the appropriate structure with the lowest fit statistics. The error term for teat location nested within sow by parity group was used to test for the main effect of teat location and its interactions. Teat location nested within sow by parity

group was considered to be a random effect. When significant main effects were present, Student-Newman Kuels multiple range test was used to determine differences among individual means (Snedecor and Cochran, 1989). Only data from sows that did not have any of their teat pairs blocked were used in this analysis.

The effects of a teat pair being nursed or not nursed during the previous lactation on piglet growth characteristics, suckling activity, piglet survival, and colostrum and milk composition were determined using data only the third lactation of the study. Comparisons were made between the pair of teats that were either nursed or not nursed during the second lactation with mixed model procedures using SAS (Proc Mixed; SAS; SAS Institute, Cary, N.C.). The statistical model included treatment (nursed or not nursed during the previous lactation); parity group and their interaction. Teat location and number of pigs weaned were used as covariates in the model. The variance/covariance structure used for the repeated measures analyses was determined by finding the appropriate structure with the lowest fit statistics.

Finally, multiple regression analyses using SAS (Proc Reg / maximum r-square; SAS; SAS Institute, Inc., Cary, NC) were performed to determine the relative contributions of selected variables on pre-weaning growth rate of piglets. Weight gain from days 1 to 21 was considered to be the response variable and sow parity, teat location, birth weight, total number of pigs born, number of pigs weaned, and suckling activity were treated as main effects. The inclusion criterion for main effects to enter the model was at  $p \leq 0.15$ .

## Results

### *Effect of Teat Location*

Effects of teat location on piglet weight gain, birth and weaning weights, nursing activity and survival are shown in Tables 2 and 3. Teat location had a significant effect ( $p \leq 0.01$ ) on all of these variables. Heavier piglets, based on birth weight, selected teats located in the anterior portion of the underline compared with their lighter counterparts who chose those located in the posterior portion ( $p \leq 0.05$ ). In addition, one piglet nursed the first or second pair of teats more frequently during each nursing bout compared with all other pairs in the underline ( $p \leq 0.05$ ). As a result, growth characteristics, weaning weight and piglet survival followed the same pattern: all of these were highest for piglets nursing the anterior pairs of teats and gradually decreased for their counterparts nursing teats posterior pairs with means often being lowest for the last pair ( $p \leq 0.05$ ).

Effects of teat location on nutritional and immunoglobulin composition of colostrum and nutritional composition of mature milk are shown in Tables 4, 5 and 6, respectively. Protein ( $p=0.0003$ ), dry matter ( $p=0.0043$ ) and total IgG ( $p=0.0431$ ) in colostrum and dry matter ( $p=0.0012$ ), fat ( $p=0.0543$ ) and lactose ( $p=0.0160$ ) in mature milk were all influenced by teat location. The general trend for all of these with the exception of lactose in mature milk was for teats located in the anterior portion of the underline to have the highest concentrations while teats located in the posterior portion of the underline to have the lowest concentrations ( $p \leq 0.05$ ). In contrast, lactose concentrations in mature milk were lower ( $p \leq 0.05$ ) in the third pair of teats compared with all other anatomical locations. Sow parity influenced piglet weights and growth activities (Table 7;  $p < 0.0001$ ) and IgG in colostrum (Table 8;  $p=0.0279$ ) with sows in parity

group 7 and 8 having reduced performance compared with sows in parity group 1 and 2 ( $p \leq 0.05$ ).

#### *Effect of Teat Nursed or Not Nursed in Previous Lactation*

Effects of whether a teat was nursed or not nursed during the previous lactation are shown in Tables 10, 11 and 12. There were no effects on piglet growth, body weights, survival or nursing activity ( $p \geq 0.1114$ ); colostrum composition ( $p \geq 0.4482$ ) with the exception of protein; or mature milk composition ( $p \geq 0.1743$ ). Protein in colostrum tended to be higher in teats not nursed in the previous lactation compared with those that were nursed ( $p=0.0987$ ). During the lactation after which teats were either nursed or not nursed, sow parity group did not affect colostrum (Table 14;  $p \geq 0.1136$ ) or mature milk (Table 15;  $p \geq 0.1357$ ) composition. However, sows in parities 7 and 8 had reduced piglet body weights ( $p \leq 0.0020$ ); piglet growth characteristics ( $p \leq 0.0027$ ); and piglet suckling activity ( $p=0.0046$ ) compared with sows in parities 3 through 6 (Table 13). Piglet survival was not affected by sow parity ( $p=0.2123$ ).

#### *Multiple Regression Analyses for Piglet Pre-Weaning Weight Gain*

Results from the multiple regression analyses are shown in Table 16. Birth weight, teat location, sow parity, total number born and total number weaned in which piglets nurse, and the proportion of the nursing bouts in which one pig nursed a single teat (suckling activity) all significantly contributed to the variation observed in piglet weight gain from birth to weaning ( $p \leq 0.0617$ ) with a total  $R^2$  of 0.2853. Of these birth weight and teat location were highly significant ( $p < 0.0001$ ) and explained the majority of the variation in the model with a partial  $R^2$  of 0.2362.

## Discussion

One of the main objectives of this study was to examine the nursing activity of piglets in conjunction with milk and colostrum composition of the teats they nurse and their subsequent growth. One of the specific questions in this area was whether piglets “imprint” on a teat early after birth and then nurse that teat the remainder of lactation. Piglets fight for dominance and initially select a pair of teats during the first several days after birth (Skok et al., 2014). Results from the present study show that piglets that initially select the first or second pair of teats have the heaviest birth weights and continue to nurse their selected pair for the majority of the time during the rest of lactation. Because piglets on the first pair of teats had the heaviest birth weights they are thought to be the dominant piglets in the litter (Spinka and Illmann, 2015).

In contrast, piglets that initially nursed the third through fifth pairs, changed teats frequently and had reduced growth characteristics. Increased competition among these piglets was observed during the nursing bouts and these piglets had reduced growth characteristics compared with their litter mates that nursed the first two pairs of teats. The assumption for this behavior is that these piglets fight often due to their desire to nurse a teat that fulfills their nutritional needs (Skok et al., 2014). Piglets with the lightest birth weights were often pushed to the sixth or seventh pair of teats during nursing bouts even when they attempted to nurse the anterior teats. As a result, they nursed the same teat with the lowest frequency and had the poorest growth and survival. Dominance hierarchy is directly related to birth weight and the larger piglets at birth have an increased place in the social hierarchy. They tend to select teats in the anterior portion of the underline and nurse them for the majority of the time during the rest of lactation probably because they can defend their position efficiently from other piglets that challenge them. In contrast, lighter piglets compete frequently for teats located in the posterior

portion of the underline and, as a result, are seldom nursing the same teat at the end of lactation. Whether or not piglets “imprint” on a teat and nurse it for the rest of lactation appears to be related to the social hierarchy in the litter which is directly related to their birth weight.

The quality of both colostrum and mature milk was highest in the anterior teats; intermediate in the middle teats; and lowest in the posterior teats. This study is one of the first to provide a comprehensive assessment of the composition of colostrum and mature milk based on teat location in sows. Changes in the composition of colostrum and mature milk from the anterior to posterior teats have a strong positive correlation with piglet growth, nursing activity and survival. Piglets nursing the anterior teats consume colostrum and mature milk with enhanced nutrient value; nurse exclusively these teats throughout lactation; and have the highest growth and survival characteristics. The opposite is true for piglets nursing the posterior teats. Although quantity of milk produced was not evaluated in this study, there are reports that the amount of milk that is produced by teats in the anterior portion of the underline is higher than that of teats located posteriorly. This could be another reason for the increased growth of piglets nursing the anterior teats.

The effect on the mammary gland being nursed or not nursed during the previous lactation essentially had no effect on the composition of colostrum and mature milk or piglet nursing activity, weight gain and survival. The only exception was a tendency for protein concentrations to be higher in colostrum of teats not nursed during the previous lactation. Consequently, failure of a teat to be nursed in the previous lactation should not compromise the quality of colostrum and mature milk in subsequent lactations or piglet growth and survival. If anything, protein in colostrum may be a slightly increased which should be viewed as being positive. Previous studies have suggested that when about 50% of the underline was not nursed

in first parity sows that mammary growth and development were reduced in these glands in the next lactation (Hurley, 2018). While these changes may occur, it does not appear that they influence physiological measurements associated with milk production and piglet growth, at least, based on the results of the present study. It is important to note that blocking 50% of teats during lactation probably has a much more dramatic effect on oxytocin and prolactin release compared with restricting access to a single pair.

Concentrations of total IgG in colostrum was one of the few quality parameters that was affected by sow parity. It decreased with increasing parity as did piglet growth and nursing activity. Since immunoglobulin concentrations in colostrum are established prior to the birth of pigs (Gaskins and Kelley, 1995) one interpretation of this observation is that this process becomes less efficient in older sows and the survival and growth of their litter suffers as a result.

Multiple regression analyses revealed that piglet birth weight and location of the teat that piglets nurse explained almost 83% of the variation in piglet pre-weaning growth associated with 7 different production variables known to affect lactation performance in sows. As discussed previously, it appears that the manner in which dominance is established shortly after birth in piglets may be associated with this observation in that pigs with heavier birth weights are dominant to their lighter counterparts. They initially select and defend their nursing of anterior teats which have higher quality colostrum and milk compared with posterior teats. And as a result, they have enhanced growth and survival.

From a management perspective, results from this study have some interesting implications. It has been well established that modern sow genetic lines produce large litters which negatively affect birth weights. Reduced birth weights decrease survivability and pre-weaning growth so management practices such as cross-fostering are becoming increasingly

important to prevent a high mortality loss. When fostering, several things need to be considered. First, fostering should occur such that all piglets receive adequate colostrum which is highest in quality shortly after farrowing (Farmer and Robert, 2006). Results from the present study indicates that, perhaps, the largest piglets should be fostered off because they are more effective at establishing themselves in the new social hierarchy. Teats that were not nursed in previous lactations should be considered to be just as productive as their counterparts that were nursed in terms of their ability to produce quality nutrition and support piglet growth. Finally, if after farrowing, the anterior teats of sows are not being nursed, then attempts to get piglets to suckle these should be attempted since they have the most potential for supporting piglet pre-weaning growth and survival.

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## Figures and Tables

Table 2. Effect of Teat Location on Piglet Growth (mean  $\pm$  s.e.)<sup>1</sup>

Teat location <sup>2</sup>	Weight gain, days 1-7 (kg)	Weight gain, days 7-14 (kg)	Weight gain, days 14-21 (kg)	Weight gain, days 1-21 (kg)
1	1.07 $\pm$ 0.03 <sup>x</sup> (100)	2.13 $\pm$ 0.03 <sup>w</sup> (98)	2.24 $\pm$ 0.04 <sup>v</sup> (98)	5.44 $\pm$ 0.08 <sup>v</sup> (98)
2	0.94 $\pm$ 0.03 <sup>y</sup> (104)	2.01 $\pm$ 0.03 <sup>w,x</sup> (103)	2.18 $\pm$ 0.04 <sup>v,w</sup> (102)	5.15 $\pm$ 0.08 <sup>w</sup> (102)
3	0.86 $\pm$ 0.03 <sup>y</sup> (87)	1.95 $\pm$ 0.03 <sup>x</sup> (85)	2.07 $\pm$ 0.04 <sup>w,x</sup> (85)	4.90 $\pm$ 0.09 <sup>w,x</sup> (85)
4	0.78 $\pm$ 0.03 <sup>z</sup> (79)	1.82 $\pm$ 0.04 <sup>y</sup> (78)	2.01 $\pm$ 0.05 <sup>x,y</sup> (77)	4.64 $\pm$ 0.11 <sup>x,y</sup> (77)
5	0.76 $\pm$ 0.04 <sup>z</sup> (68)	1.76 $\pm$ 0.05 <sup>y</sup> (66)	1.90 $\pm$ 0.05 <sup>y</sup> (66)	4.64 $\pm$ 0.11 <sup>y</sup> (66)
6	0.70 $\pm$ 0.04 <sup>z</sup> (60)	1.60 $\pm$ 0.06 <sup>z</sup> (56)	1.67 $\pm$ 0.06 <sup>z</sup> (56)	4.03 $\pm$ 0.13 <sup>z</sup> (56)
7	0.69 $\pm$ 0.04 <sup>z</sup> (60)	1.59 $\pm$ 0.06 <sup>z</sup> (58)	1.64 $\pm$ 0.06 <sup>z</sup> (58)	4.04 $\pm$ 0.14 <sup>z</sup> (58)
P-value <sup>3</sup>	<0.0001	<0.0001	<0.0001	<0.0001

<sup>1</sup> numbers in parentheses are the number of observations which were calculated by averaging data from both teats in each pair across all lactations.

<sup>2</sup> Each pair of teats was numbered sequentially beginning with the first pair.

<sup>3</sup> Main effect of teat location

<sup>v,w,x,y,z</sup> means within the same column with different superscripts are different ( $p \leq 0.05$ )

Table 3. Effect of Teat Location on Piglet Birth Weight, Weaning Weight, Nursing Activity, and Survival (mean  $\pm$  s.e.)<sup>1</sup>

Teat location <sup>2</sup>	Birth weight (kg)	Weaning weight (kg)	Nursing activity <sup>3</sup> (%)	Piglet survival <sup>4</sup> (%)
1	1.57 $\pm$ 0.02 <sup>x</sup> (103)	7.01 $\pm$ 0.09 <sup>v</sup> (98)	81.1 $\pm$ 1.6 <sup>x</sup> (103)	95.1 $\pm$ 2.1 <sup>x</sup> (103)
2	1.51 $\pm$ 0.02 <sup>x,y</sup> (109)	6.67 $\pm$ 0.09 <sup>w</sup> (102)	71.3 $\pm$ 1.5 <sup>y</sup> (109)	93.6 $\pm$ 1.9 <sup>x</sup> (109)
3	1.54 $\pm$ 0.03 <sup>x,y</sup> (94)	6.47 $\pm$ 0.10 <sup>w,x</sup> (85)	65.3 $\pm$ 1.4 <sup>z</sup> (94)	90.4 $\pm$ 2.0 <sup>x,y</sup> (94)
4	1.52 $\pm$ 0.03 <sup>x,y</sup> (86)	6.18 $\pm$ 0.12 <sup>x,y</sup> (77)	62.0 $\pm$ 1.8 <sup>z</sup> (86)	89.5 $\pm$ 2.3 <sup>x,y</sup> (86)
5	1.45 $\pm$ 0.03 <sup>y,z</sup> (76)	5.93 $\pm$ 0.13 <sup>y</sup> (66)	63.4 $\pm$ 2.1 <sup>z</sup> (76)	86.8 $\pm$ 2.5 <sup>y</sup> (76)
6	1.47 $\pm$ 0.03 <sup>y,z</sup> (66)	5.55 $\pm$ 0.13 <sup>z</sup> (56)	63.5 $\pm$ 2.3 <sup>z</sup> (66)	84.8 $\pm$ 2.7 <sup>y</sup> (66)
7	1.42 $\pm$ 0.03 <sup>z</sup> (68)	5.45 $\pm$ 0.15 <sup>z</sup> (58)	65.0 $\pm$ 2.3 <sup>z</sup> (68)	85.3 $\pm$ 2.9 <sup>y</sup> (68)
P-value <sup>5</sup>	0.0132	<0.0001	<0.0001	0.0023

<sup>1</sup> numbers in parentheses are the number of observations which were calculated by averaging data from both teats in each pair across all lactations.

<sup>2</sup> Each pair of teats was numbered sequentially beginning with the first pair.

<sup>3</sup> Percentage of time teat pair was nursed by one piglet

<sup>4</sup> Percentage of piglets weaned from teat pair

<sup>5</sup> Main effect of teat location.

<sup>v,w,x,y,z</sup> means within the same column with different superscripts are different ( $p \leq 0.05$ )

Table 4. Effect of Teat Location on Nutritional Composition of Colostrum (mean  $\pm$  s.e.)<sup>1</sup>

Teat location <sup>2</sup>	Fat (%)	Protein (%)	Lactose (%)	Ash (%)
1	7.2 $\pm$ 0.3 (24)	17.8 $\pm$ 0.3 <sup>x</sup> (24)	2.7 $\pm$ 0.2 (24)	0.60 $\pm$ 0.02 (24)
2	6.8 $\pm$ 0.3 (20)	17.1 $\pm$ 0.4 <sup>x,y</sup> (20)	2.5 $\pm$ 0.2 (20)	0.56 $\pm$ 0.02 (20)
3	7.0 $\pm$ 0.3 (16)	15.7 $\pm$ 0.3 <sup>y,z</sup> (16)	2.5 $\pm$ 0.2 (16)	0.58 $\pm$ 0.03 (16)
4	6.4 $\pm$ 0.3 (26)	15.8 $\pm$ 0.3 <sup>y,z</sup> (26)	2.6 $\pm$ 0.1 (26)	0.58 $\pm$ 0.03 (26)
5	6.6 $\pm$ 0.3 (14)	16.4 $\pm$ 0.5 <sup>y,z</sup> (14)	2.2 $\pm$ 0.3 (14)	0.61 $\pm$ 0.04 (14)
6	6.8 $\pm$ 0.5 (8)	16.0 $\pm$ 0.6 <sup>y,z</sup> (8)	2.5 $\pm$ 0.3 (8)	0.64 $\pm$ 0.04 (8)
7	5.8 $\pm$ 0.6 (4)	14.8 $\pm$ 0.8 <sup>z</sup> (4)	2.5 $\pm$ 0.6 (4)	0.65 $\pm$ 0.06 (4)
P-value <sup>3</sup>	0.5184	0.0003	0.9403	0.4967

<sup>1</sup> numbers in parentheses are the number of observations which represent colostrum pooled from each pair of teats.

<sup>2</sup> Each pair of teats was numbered sequentially beginning with the first pair.

<sup>3</sup> Main effect of teat location

<sup>x,y,z</sup> means within the same column with different superscripts are different ( $p \leq 0.05$ )

Table 5. Effect of Teat Location on Immunoglobulin Composition of Colostrum (mean  $\pm$  s.e.)<sup>1</sup>

Teat location <sup>2</sup>	Dry matter (%)	IgG (mg/mL)	IgA (mg/mL)	IgM (mg/mL)
1	26.5 $\pm$ 0.4 <sup>x</sup> (24)	71.8 $\pm$ 2.7 <sup>x</sup> (24)	13.4 $\pm$ 0.5 (24)	6.7 $\pm$ 0.3 (24)
2	26.1 $\pm$ 0.4 <sup>x</sup> (20)	63.3 $\pm$ 2.1 <sup>y,z</sup> (20)	12.8 $\pm$ 0.5 (20)	6.5 $\pm$ 0.3 (20)
3	24.9 $\pm$ 0.6 <sup>x,y</sup> (16)	64.7 $\pm$ 3.1 <sup>y,z</sup> (16)	12.6 $\pm$ 0.6 (16)	6.4 $\pm$ 0.5 (16)
4	24.3 $\pm$ 0.4 <sup>x,y</sup> (26)	65.8 $\pm$ 1.3 <sup>x,y,z</sup> (26)	13.5 $\pm$ 0.3 (26)	6.8 $\pm$ 0.3 (26)
5	22.9 $\pm$ 0.6 <sup>y,z</sup> (14)	66.8 $\pm$ 2.7 <sup>x,y,z</sup> (14)	12.1 $\pm$ 0.6 (14)	7.1 $\pm$ 0.4 (14)
6	23.5 $\pm$ 0.9 <sup>y,z</sup> (8)	62.9 $\pm$ 1.8 <sup>z</sup> (8)	12.9 $\pm$ 0.5 (8)	7.0 $\pm$ 0.8 (8)
7	21.7 $\pm$ 0.6 <sup>z</sup> (4)	68.4 $\pm$ 1.4 <sup>x,y</sup> (4)	13.0 $\pm$ 0.7 (4)	6.8 $\pm$ 0.7 (4)
P-value <sup>3</sup>	0.0043	0.0431	0.8489	0.6734

<sup>1</sup> numbers in parentheses are the number of observations which represent colostrum pooled from each pair of teats.

<sup>2</sup> Each pair of teats was numbered sequentially beginning with the first pair.

<sup>3</sup> Main effect of teat location

<sup>x,y,z</sup> means within the same column with different superscripts are different ( $p \leq 0.05$ )

Table 6. Effect of Teat Location on Nutritional Composition of Milk (mean  $\pm$  s.e.)<sup>1</sup>

Teat location <sup>2</sup>	Dry Matter (%)	Fat (%)	Protein (%)	Lactose (%)	Ash (%)
1	19.1 $\pm$ 0.5 <sup>x,y</sup> (17)	7.9 $\pm$ 0.4 <sup>x</sup> (17)	5.8 $\pm$ 0.3 (17)	5.4 $\pm$ 0.2 <sup>x</sup> (17)	1.02 $\pm$ 0.05 (17)
2	19.6 $\pm$ 0.4 <sup>x</sup> (16)	7.7 $\pm$ 0.3 <sup>x</sup> (16)	6.2 $\pm$ 0.3 (16)	5.6 $\pm$ 0.2 <sup>x</sup> (16)	0.93 $\pm$ 0.05 (16)
3	18.8 $\pm$ 0.5 <sup>x,y</sup> (12)	7.2 $\pm$ 0.3 <sup>x,y</sup> (12)	5.0 $\pm$ 0.3 (12)	4.2 $\pm$ 0.2 <sup>y</sup> (12)	0.92 $\pm$ 0.05 (12)
4	17.6 $\pm$ 0.4 <sup>y,z</sup> (19)	7.4 $\pm$ 0.3 <sup>x,y</sup> (19)	5.3 $\pm$ 0.2 (19)	4.7 $\pm$ 0.2 <sup>x,y</sup> (19)	0.82 $\pm$ 0.05 (19)
5	16.5 $\pm$ 0.3 <sup>z</sup> (11)	7.1 $\pm$ 0.5 <sup>x,y</sup> (11)	5.1 $\pm$ 0.4 (11)	5.0 $\pm$ 0.3 <sup>x,y</sup> (11)	0.86 $\pm$ 0.10 (11)
6	17.3 $\pm$ 0.6 <sup>y,z</sup> (6)	6.2 $\pm$ 0.7 <sup>y,z</sup> (6)	4.8 $\pm$ 0.3 (6)	4.7 $\pm$ 0.5 <sup>x,y</sup> (6)	0.83 $\pm$ 0.11 (6)
7	16.3 $\pm$ 0.8 <sup>z</sup> (3)	4.3 $\pm$ 1.3 <sup>z</sup> (3)	5.0 $\pm$ 0.6 (3)	5.3 $\pm$ 0.3 <sup>x</sup> (3)	0.86 $\pm$ 0.09 (3)
P-value <sup>3</sup>	0.0012	0.0543	0.1453	0.0160	0.1117

<sup>1</sup> numbers in parentheses are the number of observations which were calculated by averaging data from both teats in each pair from samples taken on day 14 across all lactations.

<sup>2</sup> Each pair of teats was numbered sequentially beginning with the first pair.

<sup>3</sup> Main effect of teat location

<sup>x,y,z</sup> means within the same column with different superscripts are different ( $p \leq 0.05$ )

Table 7. Effect of Sow Parity on Piglet Growth, Nursing Activity and Survival (mean  $\pm$  s.e.)<sup>1</sup>

Production Variables	Parity Group			P-value <sup>2</sup>
	1 & 2	3 - 6	$\geq 7$	
Birth weight, (kg)	1.52 $\pm$ 0.02 <sup>x</sup> (162)	1.52 $\pm$ 0.01 <sup>x</sup> (369)	1.38 $\pm$ 0.03 <sup>y</sup> (73)	<0.0001
Weight gain, days, 1-7 (kg)	0.88 $\pm$ 0.02 <sup>x</sup> (153)	0.87 $\pm$ 0.02 <sup>x</sup> (340)	0.70 $\pm$ 0.04 <sup>y</sup> (65)	<0.0001
Weight gain, days 7-14, (kg)	1.92 $\pm$ 0.03 <sup>x</sup> (147)	1.91 $\pm$ 0.02 <sup>x</sup> (334)	1.66 $\pm$ 0.05 <sup>y</sup> (63)	<0.0001
Weight gain, days 14-21, (kg)	2.12 $\pm$ 0.03 <sup>x</sup> (147)	2.01 $\pm$ 0.02 <sup>y</sup> (334)	1.82 $\pm$ 0.04 <sup>z</sup> (63)	<0.0001
Weight gain, days 1-21, (kg)	4.98 $\pm$ 0.07 <sup>x</sup> (146)	4.81 $\pm$ 0.05 <sup>x</sup> (333)	4.22 $\pm$ 0.12 <sup>y</sup> (63)	<0.0001
Weaning weight, (kg)	6.52 $\pm$ 0.08 <sup>x</sup> (146)	6.35 $\pm$ 0.06 <sup>x</sup> (333)	5.65 $\pm$ 0.13 <sup>y</sup> (63)	<0.0001
Suckling activity, (%) <sup>3</sup>	69.6 $\pm$ 1.4 (162)	68.9 $\pm$ 0.9 (369)	68.9 $\pm$ 0.9 (73)	0.5679
Piglet survival, (%) <sup>4</sup>	91.2 $\pm$ 2.0 (162)	90.9 $\pm$ 1.0 (369)	83.8 $\pm$ 3.0 (73)	0.9998

<sup>1</sup> numbers in parentheses are the number of observations which were calculated by averaging data from both teats for all pairs across all lactations.

<sup>2</sup> Main effect of parity group.

<sup>3</sup> Percentage of time teat pair was nursed by one piglet

<sup>4</sup> Percentage of piglets weaned from teat pair

<sup>x,y,z</sup> means within the same row with different superscripts are different ( $p \leq 0.05$ )

Table 8. Effect of Sow Parity on Nutritional and Immunoglobulin Composition of Colostrum (mean  $\pm$  s.e.)<sup>1</sup>

Milk Composition Variables	Parity Group			P-value <sup>3</sup>
	2	3 - 6	$\geq 7$	
Dry matter (%)	24.5 $\pm$ 0.7 (13)	24.7 $\pm$ 0.3 (83)	25.8 $\pm$ 0.5 (16)	0.1930
Fat (%)	7.4 $\pm$ 0.6 (13)	6.7 $\pm$ 0.1 (83)	6.6 $\pm$ 0.4 (16)	0.3714
Protein (%)	17.5 $\pm$ 0.5 (13)	16.2 $\pm$ 0.2 (83)	16.9 $\pm$ 0.5 (16)	0.1319
Lactose (%)	2.5 $\pm$ 0.2 (13)	2.5 $\pm$ 0.1 (83)	2.4 $\pm$ 0.3 (16)	0.3556
Ash (%)	0.60 $\pm$ 0.03 (13)	0.59 $\pm$ 0.02 (83)	0.59 $\pm$ 0.02 (16)	0.8032
Immunoglobulin G (mg/mL)	69.7 $\pm$ 3.5 <sup>x</sup> (13)	66.3 $\pm$ 1.1 <sup>x,y</sup> (83)	63.3 $\pm$ 1.9 <sup>y</sup> (16)	0.0279
Immunoglobulin A (mg/mL)	13.2 $\pm$ 0.5 (13)	13.0 $\pm$ 0.2 (83)	12.5 $\pm$ 0.4 (16)	0.3862
Immunoglobulin M (mg/mL)	6.5 $\pm$ 0.5 (13)	6.8 $\pm$ 0.2 (83)	6.6 $\pm$ 0.4 (16)	0.5642

<sup>1</sup> numbers in parentheses are the number of observations which represent colostrum pooled from each pair of teats for each animal within their respective parity group.

<sup>2</sup> data collected second and third lactations after study began for all sows so none were parity 1

<sup>3</sup> Main effect of parity group.

<sup>x,y</sup> means within the same row with different superscripts are different ( $p \leq 0.05$ )

Table 9. Effect of Sow Parity on Nutritional Composition on Mature Milk (mean  $\pm$  s.e.)<sup>1</sup>

Production Variables	Parity Group			P-value <sup>3</sup>
	2 <sup>2</sup>	3 - 6	$\geq 7$	
Dry matter (%)	18.0 $\pm$ 0.7 (6)	18.3 $\pm$ 0.2 (65)	18.2 $\pm$ 0.7 (13)	0.2562
Fat (%)	7.2 $\pm$ 0.5 (6)	7.1 $\pm$ 0.2 (65)	8.2 $\pm$ 0.3 (13)	0.1723
Protein (%)	5.5 $\pm$ 0.7 (6)	5.3 $\pm$ 0.1 (65)	6.1 $\pm$ 0.3 (13)	0.3325
Lactose (%)	4.5 $\pm$ 0.6 (6)	5.0 $\pm$ 0.1 (65)	5.0 $\pm$ 0.1 (13)	0.1357
Ash (%)	0.88 $\pm$ 0.08 (6)	0.91 $\pm$ 0.03 (65)	0.89 $\pm$ 0.07 (13)	0.5331

<sup>1</sup> numbers in parentheses are the number of observations which were calculated by averaging data from both teats in each pair from samples taken on day 14 across all lactations.

<sup>2</sup> data collected from second lactation after study began for all sows so none were parity 1

<sup>3</sup> Main effect of parity group.

<sup>x,y,z</sup> means within the same column with different superscripts are different ( $p \leq 0.05$ )

Table 10. Effect of Teat Pairs being Nursed or Not Nursed during Previous Lactation on Piglet Growth, Suckling Activity, and Survival (mean  $\pm$  s.e.)<sup>1</sup>

Production Variables	Previous Lactation Treatment		Main Effect P-value	Teat Location Covariate P-value
	Nursed	Not Nursed		
Birth weight, (kg)	1.50 $\pm$ 0.05 (51)	1.51 $\pm$ 0.05 (54)	0.6005	0.2480
Weight gain, days, 1-7 (kg)	0.86 $\pm$ 0.05 (50)	0.83 $\pm$ 0.06 (52)	0.8755	0.0001
Weight gain, days 7-14, (kg)	1.86 $\pm$ 0.07 (49)	1.84 $\pm$ 0.07 (52)	0.1388	0.0009
Weight gain, days 14-21, (kg)	1.95 $\pm$ 0.07 (49)	2.01 $\pm$ 0.08 (52)	0.8694	0.0001
Weight gain, days 1-21, (kg)	4.67 $\pm$ 0.17 (49)	4.69 $\pm$ 0.19 (52)	0.8882	0.0001
Weaning weight, (kg)	6.18 $\pm$ 0.20 (49)	6.21 $\pm$ 0.20 (52)	0.7965	0.0001
Suckling activity, (%) <sup>2</sup>	66.9 $\pm$ 3.2 (52)	63.3 $\pm$ 3.1 (54)	0.1114	0.0001
Piglet survival, (%) <sup>3</sup>	94.2 $\pm$ 3.3 (52)	96.3 $\pm$ 2.6 (54)	0.8568	0.0754

<sup>1</sup> numbers in parentheses are the number of observations which were calculated by averaging data from both teats within each pair.

<sup>2</sup> Percentage of time teat pair was nursed by one piglet

<sup>3</sup> Percentage of piglets weaned from teat pair

\* different from nursed in previous lactation

† tendency to be different from nursed in previous lactation

Table 11. Effect of Teat Pairs being Nursed or Not Nursed during Previous Lactation on Colostrum Composition (mean  $\pm$  s.e.)<sup>1</sup>

Production Variables	Previous Lactation Treatment		Main Effect P-value	Teat Location Covariate P-value
	Nursed	Not Nursed		
Dry matter (%)	24.6 $\pm$ 0.5 (27)	24.6 $\pm$ 0.5 (28)	0.9799	0.0001
Fat (%)	6.8 $\pm$ 0.2 (27)	6.5 $\pm$ 0.3 (28)	0.7726	0.1521
Protein (%)	16.1 $\pm$ 0.3 (27)	16.6 $\pm$ 0.2 <sup>†</sup> (28)	0.0987	0.0075
Lactose (%)	2.4 $\pm$ 0.1 (27)	2.6 $\pm$ 0.2 (28)	0.4482	0.5383
Ash (%)	0.59 $\pm$ 0.02 (27)	0.57 $\pm$ 0.02 (28)	0.6711	0.0718
Immunoglobulin G (mg/mL)	65.1 $\pm$ 1.6 (27)	62.3 $\pm$ 1.7 (28)	0.5568	0.1801
Immunoglobulin A (mg/mL)	13.2 $\pm$ 0.3 (27)	12.9 $\pm$ 0.3 (28)	0.7358	0.7215
Immunoglobulin M (mg/mL)	6.7 $\pm$ 0.3 (27)	6.7 $\pm$ 0.3 (27)	0.8191	0.6952

<sup>1</sup> numbers in parentheses are the number of observations which represent colostrum pooled from each pair of teats.

\* different from nursed in previous lactation

<sup>†</sup> tendency to be different from nursed in previous lactation

Table 12. Effect of Teat Pairs being Nursed or Not Nursed during Previous Lactation on Milk Composition (mean  $\pm$  s.e.)<sup>1</sup>

Production Variables	Previous Lactation Treatment		Main Effect P-value	Teat Location Covariate P-value
	Nursed	Not Nursed		
Dry matter (%)	18.6 $\pm$ 0.2 (28)	18.1 $\pm$ 0.3 (28)	0.6079	0.0001
Fat (%)	7.0 $\pm$ 0.4 (28)	7.1 $\pm$ 0.3 (28)	0.7544	0.0001
Protein (%)	5.5 $\pm$ 0.2 (28)	5.3 $\pm$ 0.3 (28)	0.9708	0.0524
Lactose (%)	5.2 $\pm$ 0.2 (28)	4.9 $\pm$ 0.2 (28)	0.1743	0.2324
Ash (%)	0.94 $\pm$ 0.04 (28)	0.89 $\pm$ 0.05 (28)	0.7107	0.4691

<sup>1</sup> numbers in parentheses are the number of observations which were calculated by averaging data from both teats in each pair from samples taken on day 14 across all lactations.

\* different from nursed in previous lactation

† tendency to be different from nursed in previous lactation

Table 13. Effect of Sow Parity on Piglet Growth, Nursing Activity and Survival for Teats either Nursed or Not Nursed during the Previous Lactation (mean  $\pm$  s.e.)<sup>1</sup>

Production Variables	Parity Group			P-value <sup>3</sup>
	1 & 2 <sup>2</sup>	3 - 6	$\geq 7$	
Birth weight, (kg)	---	1.54 $\pm$ 0.03 (86)	1.34 $\pm$ 0.09* (20)	0.0020
Weight gain, days, 1-7 (kg)	---	0.89 $\pm$ 0.04 (84)	0.64 $\pm$ 0.08* (18)	0.0016
Weight gain, days 7-14, (kg)	---	1.93 $\pm$ 0.05 (83)	1.47 $\pm$ 0.13* (18)	0.0001
Weight gain, days 14-21, (kg)	---	2.04 $\pm$ 0.06 (83)	1.73 $\pm$ 0.10* (18)	0.0027
Weight gain, days 1-21, (kg)	---	4.86 $\pm$ 0.13 (83)	3.85 $\pm$ 0.28* (18)	0.0001
Weaning weight, (kg)	---	6.40 $\pm$ 0.14 (83)	5.24 $\pm$ 0.36* (18)	0.0001
Suckling activity, (%) <sup>4</sup>	---	67.4 $\pm$ 2.5 (86)	55.0 $\pm$ 5.6* (20)	0.0046
Piglet survival, (%) <sup>5</sup>	---	96.5 $\pm$ 2.0 (86)	90.0 $\pm$ 6.9 (20)	0.2123

<sup>1</sup> numbers in parentheses are the number of observations which were calculated by averaging data from both teats within each pair.

<sup>2</sup> data collected from third lactation after study began for all sows so none were parity 1 or 2

<sup>3</sup> Main effect of parity group.

<sup>4</sup> Percentage of time teat pair was nursed by one piglet

<sup>5</sup> Percentage of piglets weaned from teat pair

\* different from parities 3 - 6

† tendency to be different from parities 3 - 6

Table 14. Effect of Sow Parity on Nutritional and Immunoglobulin Composition of Colostrum for Teats either Nursed or Not Nursed during the Previous Lactation (mean  $\pm$  s.e.)<sup>1</sup>

Production Variables	Parity Group			P-value <sup>3</sup>
	2 <sup>2</sup>	3 - 6	$\geq 7$	
Dry matter (%)	---	24.6 $\pm$ 0.4 (45)	24.8 $\pm$ 0.8 (10)	0.6487
Fat (%)	---	6.7 $\pm$ 0.2 (45)	6.3 $\pm$ 0.4 (10)	0.1136
Protein (%)	---	16.4 $\pm$ 0.2 (45)	16.5 $\pm$ 0.6 (10)	0.9785
Lactose (%)	---	2.6 $\pm$ 0.1 (45)	2.3 $\pm$ 0.2 (10)	0.4258
Ash (%)	---	0.58 $\pm$ 0.02 (45)	0.57 $\pm$ 0.03 (10)	0.8972
Immunoglobulin G (mg/mL)	---	63.8 $\pm$ 1.3 (45)	63.4 $\pm$ 3.4 (10)	0.8799
Immunoglobulin A (mg/mL)	---	13.1 $\pm$ 0.3 (45)	12.8 $\pm$ 0.4 (10)	0.6562
Immunoglobulin M (mg/mL)	---	6.6 $\pm$ 0.3 (45)	7.0 $\pm$ 0.5 (10)	0.9571

<sup>1</sup> numbers in parentheses are the number of observations which represent colostrum pooled from each pair of teats for each animal within their respective parity group.

<sup>2</sup> data collected from third lactation after study began for all sows so none were parity 1 or 2

<sup>3</sup> Main effect of parity group.

\* different from parities 3 - 6

† tendency to be different from parities 3 - 6

Table 15. Effect of Sow Parity on Milk Composition either Nursed or Not Nursed during the Previous Lactation (mean  $\pm$  s.e.)<sup>1</sup>

Production Variables	Parity Group			P-value <sup>3</sup>
	2 <sup>2</sup>	3 - 6	$\geq 7$	
Dry matter (%)	18.0 $\pm$ 0.7 (6)	18.3 $\pm$ 0.2 (65)	18.2 $\pm$ 0.7 (13)	0.2562
Fat (%)	7.2 $\pm$ 0.5 (6)	7.1 $\pm$ 0.2 (65)	8.2 $\pm$ 0.3 (13)	0.1723
Protein (%)	5.5 $\pm$ 0.7 (6)	5.3 $\pm$ 0.1 (65)	6.1 $\pm$ 0.3 (13)	0.3325
Lactose (%)	4.5 $\pm$ 0.6 (6)	5.0 $\pm$ 0.1 (65)	5.0 $\pm$ 0.1 (13)	0.1357
Ash (%)	0.88 $\pm$ 0.08 (6)	0.91 $\pm$ 0.03 (65)	0.89 $\pm$ 0.07 (13)	0.5331

<sup>1</sup> numbers in parentheses are the number of observations which were calculated by averaging data from both teats in each pair from samples taken on day 14 across all lactations.

<sup>2</sup> data collected from second lactation after study began for all sows so none were parity 1

<sup>3</sup> Main effect of parity group.

<sup>x,y,z</sup> means within the same column with different superscripts are different ( $p \leq 0.05$ )

Table 16. Multiple Regression Analysis for Piglet Pre-weaning (kg) Gain from Days 1 to 21.

Production Variable	Partial R <sup>2</sup>	Total R <sup>2</sup>	P-value
Birth weight (kg)	0.1381	0.1381	<0.0001
Teat location	0.0981	0.2362	<0.0001
Sow parity	0.0160	0.2522	0.0035
Total number born	0.0150	0.2672	0.0035
Suckling activity (%) <sup>1</sup>	0.0114	0.2787	0.0104
Number weaned	0.0066	0.2853	0.0617

<sup>1</sup> Percentage of time teat pair was nursed by one piglet

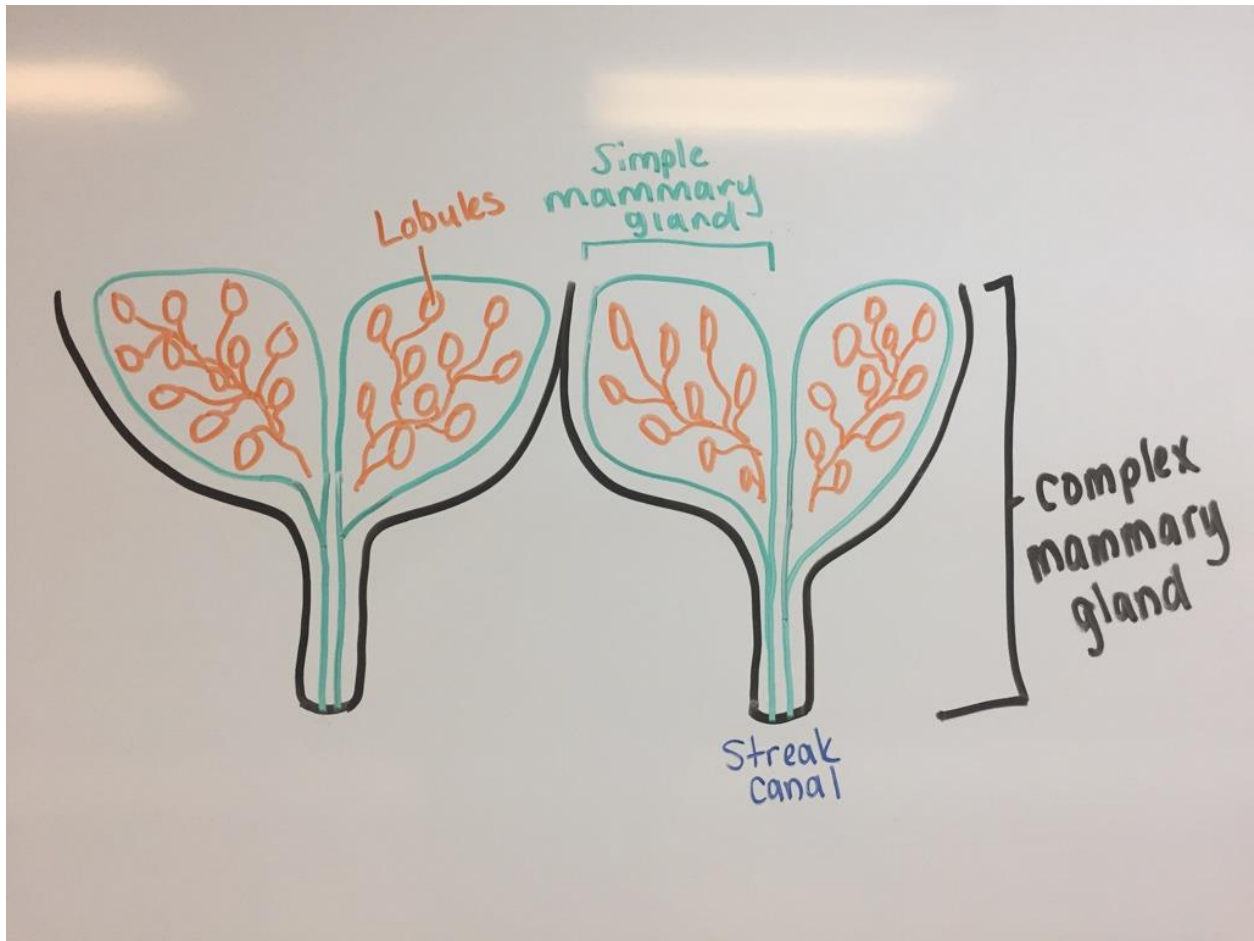


Figure 1. Complex Mammary Glands



Figure 2. Assignment of color codes to piglets for collection of nursing activity data.

Dates \_\_\_\_\_  
 group #s \_\_\_\_\_

Sow ID: \_\_\_\_\_  
 crates: \_\_\_\_\_  
 # of piglets: \_\_\_\_\_  
 Age: \_\_\_\_\_

R L

m- mastitis  
 D- deformed  
 X- non-functional

- Kayla Lannom

Figure 3. Diagram of data recording sheet from nursing observations



Figure 4. Elastikon wrap to block off a pair of teats

**APPENDICES**

### Appendix A

#### NC State SEU Lactation Diet Formulation

FORMULA #		PI	Eric Van Heugten
FORMULA NAME	SEU Lactation	UNIT / LOCATION	SEU
EXPERIMENT		DIET FORM <input checked="" type="checkbox"/>	Mash <input type="checkbox"/> Pellet <input checked="" type="checkbox"/> Crumb. <input type="checkbox"/>
BATCHES NEEDED		PACKAGE IN <input checked="" type="checkbox"/>	Bags <input type="checkbox"/> Box <input type="checkbox"/> Bulk <input checked="" type="checkbox"/>
BATCH SIZE	2000 LB	PI PROJECT ACCT #	
DIET LABEL	SEU Lactation		

INGRD#	INGREDIENT	AMOUNT	EMPLOYEE / MANAGER		NOTES
MAJOR SCALE	Corn NCDA	1460	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	
(WHOLE #S ONLY)	SOYBEAN MEAL 48%	352			
	<b>SUB-TOTAL</b>	<b>1812</b>			
HAND-ADD	CORN (1/8) MICRO-FLUSH	20.00			
MICRO SCALE	LIMESTONE FINE	21.50			
(0.01 LB)	MON-CAL 21% P	47.70			
	BIOLYS 50%	5.00			
	SALT	10.00			
	Swine TM Prmx (KSU)	3.00			
	Swine VTM Prmx (Sow/Pigt)	0.82			
	Threonine	0.19			
LIQUID	POULTRY FAT	79.79			
(0.01 LB)					
	<b>TOTAL BATCH WEIGHT</b>	<b>2000.00</b>			
	REPORT & MIX DATE				
	INITIALS				

**SPECIAL INSTRUCTIONS:** Medication authorized for use in experimental feed only.

**PROJECT LEADER APPROVAL AND AFFIRMATION**

Signature \_\_\_\_\_ Date \_\_\_\_\_

## Appendix B

### Lactation One Teat Selection Analysis:

- 1) Lactation one nursing observations were put into Excel sheet and analyzed by SAS.
- 2) Two pairs of teats were selected; one being an observation or nursed pair and a shut off or not nursed pair.
- 3) Teats were chosen by lactation one nursing data selecting teats in which had the largest piglet growth and least amount of variation.
- 4) In order to represent the entire underline, teats that were similar were selected; one from first pair through the fourth and second from fifth pair through the seventh.
- 5) The Nursed pair of teats were observed, colostrum and milk samples were obtained.
- 6) The Not Nursed pair of teats were observed, colostrum samples obtained and elastikon wrapped around the sow to prevent nursing.