IDENTIFYING THE CHARACTERISTICS OF SLOW GROWING PIGS AND RISK FACTORS ASSOCIATED WITH SLOW GROWTH

A Thesis
SUBMITTED TO THE FACULTY OF
UNIVERSITY OF MINNESOTA
BY

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IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR THE DEGREE OF
MASTER OF SCIENCE

Dr. Yuzhi Li

December 2015

ACKNOWLEDGEMENTS

First and foremost, I would like to express my sincere gratitude to my academic advisor, Dr. Yuzhi Li for accepting me as her graduate student. I'm grateful for her guidance and encouragement throughout my research and for allowing me to grow as a research scientist. I would like to extend my gratitude to Dr. Gerald Shurson and Dr. John Deen for their guidance and continuous support for my master research. They've always provided me with various resources, encouraged me to come up with new ideas and demanded high quality work. Their advice and support on my academics as well as career have been invaluable. I'll never forget where I started, and I'll forever be humble and grateful.

Every result in this thesis was accomplished with the help and support of many collaborators. I would like to thank Dr. Chi Chen and Dr. Duane Keisler for their help with all the blood physiology. I would like to thank Adrienne Hilbrands, Mark Smith and all the staff at the West Central Research and Outreach Center for their assistance with the animal trials. Additionally, I would like to thank Dr. Lee Johnston and Dr. Pedro Urriola for their contribution to my research as well as setting high standards for me as a graduate student. Special thanks to my fellow graduate students, Cassio Villela, and Zhiming Huang, Andrea Hansen, and Erin Harris for their support throughout my master program and for being great companies in graduate school. No matter in classes or in the field, they've helped and taught me immensely. Without their support, my research would not be possible.

Finally, I would like to thank my friends and family for their support. To my mother, thank you for always standing by me and believing in me through good times and bad.

ABSTRACT

Pigs that grow significantly slower (slow-growing pigs) than their contemporaries are problematic for animal well-being and profitability. This study was designed to investigate the physiological and behavioral characteristics of slow growing pigs and risk factors associated with slow growth, and to investigate the effect of feeder space on pig performance. Pigs (n = 440) were farrowed in either a group farrowing system or farrowing crates by 65 sows (parity = 1 to 7) and were weighed individually at birth, weaning (4 wk of age), nursery exit (9 wk of age) and at marketing (between 21 and 24 wk of age). During the nursery period, pigs were allocated to either 2- or 5-space feeder treatments. Pigs were categorized as slow, average, and fast growers based on market weight adjusted to 170 d of age (slow growers < 105 kg, average growers between 105 and 125 kg, and fast growers > 125 kg). Blood samples were collected from a subgroup of pigs (n = 48, from 12 randomly selected pens, representing the 2 heaviest and 2 lightest pigs in their respective pens) at nursery exit and at the first removal for marketing, to analyze serum free amino acids (AA) and plasma hormone concentrations. Slow growing pigs (**SG**) accounted for 10%, average growers (**AG**) for 49% and fast growers (**FG**) for 41% of total pigs in this population. Compared with fast growers, slow growers needed an extra 20 d to reach the target market weight (115 kg). Compared with fast growers, slow growers had lower birth weight (1.13 vs. 1.64 kg, SE = 0.18; P < 0.01), weaning weight (5.1 vs. 8.1 kg, SE = 0.51; P < 0.01) and nursery exit weight (18.6 vs. 28.0 kg, SE = 1.97; P < 0.01). Slow growing pigs had less backfat (1.8 vs. 2.3 cm, SE = 0.05; P < 0.01) and smaller loin muscle area (32.0 vs. 41.8 cm^2, SE = 1.58; P < 0.01)

than fast growers at first removal for marketing at 21 wk of age. Slow growers had the lowest plasma concentration of IGF-1 and insulin among the pig growth categories during the nursery period ($P < 0.05$), and the lowest concentration of leptin and insulin during the grower-finisher period ($P < 0.05$). Serum concentrations of several essential, non-essential, and total AA were lower for slow growers compared with average and fast growers. Sex appeared to be a contributor to slow growth, with gilts being 2 times (odds ratio = 2.17, confidence interval = 1.19 to 3.96; $P = 0.012$) more likely to become slow growers than barrows. Compared to pigs in 5-space feeder treatment, pigs in 2-feeder space treatment were 1.81 times more likely to become slow-growing pigs (confidence interval = 1.00 to 3.29; $P = 0.05$). Litter size and parity of the pigs' dams were not associated with slow growth. These results suggest that light body weights at early stages were the major risk factors for slow growth. Low concentrations of IGF-1, insulin, leptin and total AA were associated with slow growth in pigs.

To identify the behavioral characteristics of slow growth, behavior of pigs (n = 192; 24 pens of 8 pigs) was monitored at first 4-d entering nursery and on d 21 in the nursery. To evaluate the competitive ability at the feeder, rate of feed consumption was measured on 96 focal pigs, consisting of 2 heaviest and 2 lightest pigs from each of 24 randomly selected pens at 8 wk of age. Pigs from the 2-space feeder treatment spent more time standing (9.7% vs. 9.2%, SE = 0.6%, $P < 0.05$), whereas pigs from 5-space feeder spent more time eating (5.0% vs. 4.7%, SE = 0.2%, $P < 0.05$). However, there was no difference in time spent eating between FG and SG pigs. Likewise, eating speed did not differ between FG pigs and SG pigs at nursery exit ($P > 0.10$). These results suggest that

slow growing pigs have similar behavioral characteristics compared with fast growing pigs. Although ample feeder space increased the time spent eating by the pigs, it did not affect growth performance of SG pigs. Therefore, the need to provide ample feeder space during the early stage of growth in order to alleviate slow growth did not appear to be beneficial in growth performance in this study. However, adjunctive behaviors, such as standing and drinking, may be good indicators for slow growing pigs under constraints. Providing more feeder space reduced time spent standing, and tended to increase time spent lying by SG pigs, indicating that SG pigs may benefit from more feeder space and have improved welfare.

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CHAPTER 1 : LITERATURE REVIEW

1.1 Introduction

Market weight of pigs is of great importance and affects producers' decisions on how and when to market pigs. Although one may view that keeping every pig alive contributes to improved productivity and profitability in commercial pork production systems, not all pigs exhibit ideal growth performance and raising slow growing pigs can actually increase production costs. In an all-in/all-out production system, pigs that do not reach desirable slaughter weights at a certain age are often referred to as slow-growing pigs. This special group of pigs are usually sold at much lower market prices, and are also at higher risk of dying at each production phase compared with their contemporaries (Larriestra et al., 2006; Douglas et al., 2013), resulting in economic losses to pork producers.

Some pigs born with average or heavy birth weight may become light weight pigs later in life (Douglas et al., 2014). There are many factors contributing to the growth performance of pigs, and in many cases it is a result of the interactions between the environment, nutrition, health status, and the genetic potential of pigs. However, failure of a pig to thrive in a modern pork production system may very likely result from a stressful environment (Botermans and Svendsen, 2000; Georgsson and Svendsen, 2002), poor genetic potential (Quiniou et al., 2002) or a combination of both.

Feeder space is an important environmental component affecting the growth of pigs (Averos et al., 2012). Studies that have evaluated feeder space per pig have shown that limited access to the feeder can negatively affect growth performance of pigs

(Botermans and Svendsen, 2000; Georgsson and Svendsen, 2002), and force some of the pigs, mostly slow growing pigs, to shift feeding events toward evening hours, which raises animal welfare concerns (Young and Lawrence, 1994).

A number of studies have shown that certain characteristics of pigs, such as low birth weight (Mahan and Lepine, 1991), low weaning weight (Cooper et al., 2001), low nursery exit weight (Douglas et al., 2014), and gender (Larriestra et al., 2006), are associated with slow growth and mortality. However, very few studies have evaluated the physiological characteristics of slow growing pigs, namely, serum hormone and plasma amino acids concentrations. As a result, the underlying mechanisms for slow growth are not clear. The focus of this project was to understand slow growth by investigating the physiological, behavioral and phonotypic characteristics of slow growing pigs, and identifying risk factors for slow growth. Since feeder space plays an important role in the growth of a pig, the effect of providing ample feeder space during early ages on alleviating slow growth was also evaluated. Investigating the effect of feeder space, risk factors associated with poor growth performance, and characteristics of slow growing pigs may provide us useful insight about slow growth so that pork producers can make informed decisions on effective management strategies to improve productivity and animal welfare.

1.2 Swine production in the U.S.

The United States is a major contributor to global pork production. Most U.S. hog operations are concentrated in the Midwestern states and in eastern North Carolina (National Pork Board, 2014). The current U.S. inventory of all hogs and pigs is 65.9

million head (USDA, 2015), and is the world's third-largest producer and consumer of pork and pork products. It is also the world's largest exporter of pork and pork products, with exports averaging over 20 percent of commercial pork production during the last decade. According to 2013 National Pork Board statistics, the average finishing weight in the U.S. was 123.7 kg (272.1 lbs), average daily gain was 0.82 kg/d (1.81 lb/d) and feed conversion was 2.66 (National Pork Board, 2014).

1.3 Economic losses caused by slow growing pigs

Although pork production is highly efficient in the U.S., there are still opportunities for improvement. When pigs reach market age, heavy pigs are selected for market and light weight pigs are fed in the barn for a longer period of time. This usually results in pigs being marketed over a 4 to 5 week period. Some producers may market two times over a 2 to 3 week period if packers accept a wider range of market weight of pigs (Gonyou et al., 1998). The total length of the marketing period for an entire group of pigs affects room or barn usage, which consequently affects production cost. In addition, there is additional labor cost of managing lightweight pigs. Many farms have personnel who have husbandry skills in managing lightweight pigs. It is important to detect subtle fluctuations in health status and environment. Due to the relatively high amount of labor required to perform these management tasks, additional labor is need for the care of lightweight pigs (Sornsen, 1998).

Pork packers require narrow ranges of body weight and use market price discounts to encourage pork producers to deliver more uniform cohort groups (Hurt and Boland, 1995). Marketing the entire group of pigs in a certain period of time will

inevitably result in a certain percentage of pigs in a lightweight group. Many pork packers provide premiums to producers that supply uniform-sized pigs of similar lean quality for slaughter, and discount prices for more variable groups because it takes almost the same amount of time and labor for a processing plant to harvest and process a lightweight pig as it does a heavy pig, and lightweight pigs do not generate as much revenue as heavy pigs (Keeler et al., 1994).

Another hidden cost of pork production is the economic loss due to mortality. Studies have shown that lightweight pigs are at higher risk of dying during the suckling period and after weaning, and are at higher risk of being lightweight at nursery exit and at market, compared with their contemporaries (Quiniou et al., 2002; Larriestra et al., 2006; Wolf et al., 2008). However, these costs are generally unnoticed or ignored at the farm level, and the mortality is simply not reported in most financial records (Deen, 2001).

1.4 Risk factors associated with slow growth

Slow growth can be considered as the failure of a pig to thrive in a modern pork production system. Factors that contribute to slow growth can be generally classified as the poor genetic potential of a pig (Quiniou et al., 2002) and raised in a stressful environment (Botermans and Svendsen, 2000; Georgsson and Svendsen, 2002).

1.4.1 Birth weight

Low birth weight pigs are physically too small to successfully compete with heavier littermates to have access to the teats that produce the most milk during suckling period. For the first couple of hours after birth, piglets push and bite in order to displace their littermates and to avoid being displaced themselves from the teats. This competition

is of great importance for piglet survival and thrift. Smaller piglets may be excluded from obtaining adequate colostrum, especially in large litters. Consequently these lightweight pigs can die within 1 to 3 days after birth due to direct and indirect results of starvation or compromised immune systems (Le Dividich et al., 2005). In addition, newborn pigs have low body fat storage, which is approximately 1.5 to 2.5 percent of body weight (Skorjanc et al., 2007). Therefore, sow colostrum and milk is the only source of energy available to piglets until weaning. Low birthweight pigs are born with lower level of energy stored in their body compared with their heavier counterparts, and consequently, are more sensitive to a cold environment. As a result, they may get crushed by the sow, die from chilling, and are more susceptible to infections (Powell and Aberle, 1980). Quiniou et al. (2002) reported that the viability of low birthweight pigs (birthweight below 0.6 kg) is significantly lower within 24 h of birth compared with piglets with birthweight of 0.8 kg or more.

Low birthweight pigs that do survive may still consume less colostrum and milk than their littermates. The amount of colostrum that a piglet consumes for the first hour of suckling is equal to 5 to 7% of their bodyweight (Fraser and Rushen, 1992). Piglets with heavy birthweight can consume about 30% more milk than their lighter weight littermates (Pluske and Williams, 1996). After the first 3 days, lightweight piglets continue to consume less amount of sow milk compared with their contemporaries (Le Dividich, 1999). The deficit of inadequate consumption of colostrum and milk has long-term effects on the growth performance of these pigs for the remainder of the growth phases. For instance, Marion et al. (1999) reported that whole-body protein synthesis was

reduced in lightweight pigs compared with heavier contemparies. Likewise, Gondret et al. (2006) noted that light birthweight pigs had 31% less ADG compared with heavy birthweight pigs during the suckling period.

To overcome the disadvantages of raising runt pigs, and to increase their productivity, new feeding programs were designed for these light weight pigs. For instance, a study conducted in Kansas State University demonstrated the benefit of a three-phase starter program. Phase one provided pigs with a high nutrient-density diet, phase two, a whey and corn-soybean diet, provided pigs with 1.25% lysine, and phase three, a grain-soybean diet, provided pigs with 1.10% lysine (Nelssen, 1996). The program showed advantages such as increased gains and decreased days to market.

However, despite these improvements, light weight pigs do not grow as fast as their heavy contemporaries and will usually remain slow growers throughout the remainder of their growing period. For instance, Mahan and Lepine (1991) found that low birth weight pigs who were provided with supplemental milk replacer during the suckling period still required more days to reach market weight compared with their littermates (Powell and Aberle, 1980; Herpin et al., 1992; Handel and Stickland, 1987). Results of several other studies have shown that causes of the reduction in growth performance of low birth weight pigs are mainly physiological rather than behavioral. These pigs utilize feed for weight gain less efficiently than their heavier peers, even when competition is reduced or eliminated (Powell and Aberle, 1980). Low birth weight pigs have lower IGF-1 concentrations in the blood (Herpin et al., 1992) and fewer muscle fibres (Handel and Stickland, 1987). Generally, pigs reach 25 kg at 60 days of age, but

pigs born weighing less than 0.6 kg required an extra 21 days (Quiniou et al., 2002). Quiniou (2002) also reported that a 5.4 kg difference at weaning weight between low birth weight pigs and heavy birth weight pigs increased to 11.9 kg at 63 days of age. Results from all of these studies suggest that birth weight is an important component of the growth potential of a pig. However, not all pigs with light birth weight will become slow growing pigs and be light weight at market age (Douglas et al., 2014). Therefore, the complicated interaction between the growth potential of a pig and its environment that results in slow growth needs further investigation.

1.4.2 Weaning weight

Compared to birth weight, weaning weight is a better predictor for market weight (Mahan, 1993; Douglas et al., 2014). In general, weaning weight is an important factor that determines post-weaning growth performance. During the nursery period, pigs with low weaning weight have lower ADG and ADFI than their contemporaries (Wolter and Ellis, 2001). Post-weaning growth performance is affected by the progressive digestive enzyme development that occurs in young pigs between 2 and 8 weeks of age, where lactase activity is decreasing, while protease, amylase, maltase, and sucrase activities are increasing (Kitts et al., 1956). In most cases, the feed transition from liquid milk to solid grain-based diets is stressful for pigs that have a less mature digestive system. As observed in several studies, lightweight pigs at weaning have lower feed intakes and reduced weight gains during the immediate period after weaning than those of heavier weights, suggesting that pigs with light weight at weaning adapt to solid grain-based diet slower than heavy pigs (Mahan, 1993).

Weaning at 21 d of age is a common practice in the U.S. pork industry due to its benefits to growth and health of pigs (Nelssen et al. 1995) and the reproductive performance of the sow. However, weaning is a stressful event for pigs, especially for pigs at younger ages. In addition, pigs with light weight at weaning may be more susceptible to weaning stress than heavy pigs. At weaning, when pigs are regrouped in the nursery barn, they fight aggressively to establish their social hierarchy. Approximately 24 h after re-grouping, pigs generally have established a stable social hierarchy (McGlone et al., 1986). Although regrouping has negative effects on growth performance, it is usually short-lived and the damages caused by regrouping are negligible. Pluske et al. (1996) noted that pigs had reduced growth performance and even lost weight for the first 4 d post-weaning. Likewise, McGlone and Curtis (1985) and Gonyou et al. (1988) reported that the reduction in growth performance was only evident within the first one or two weeks after weaning. However, it is not clear how lightweight pigs are affected by weaning stress. It is possible that lightweight pigs are less competitive at regrouping, and eventually become subordinate within the pen. Whether social hierarchy is related to slow growth when pigs are provided ad libitum access to feed remains a question. Understanding behavior of lightweight pigs may lead to determining the underlying mechanisms of slow growth.

Results from a number of studies found that there is a certain pattern between weaning weight, nursery exit weight, and market weight. For instance, Patience and Beaulieu (2006) found that for every 1 kg increase in weaning weight, there is a 1.9 kg increase in nursery exit weight at 56 days of age. Cooper et al. (2001) reported that for

every 1 kg increase in weaning weight, there is a 4.2 kg increase in market weight. Similar results have also been reported by others (Mahan and Lepine, 1991; Tokach et al., 1992; Mahan, 1993; Kavangh et al., 1997).

Pigs with light weaning weight are at a high risk of dying after weaning (Larriestra et al., 2006). Main et al. (2004) reported that chances of survival increased when weaning weight was greater than 4.2 kg for pigs with weaning age ranging between 12 and 21 d. Likewise, Rademacher et al. (1997) described a drop in mortality when the average weaning weight increased from 3.6 to 5.4 kg. Fangman et al. (1996) concluded that a 5 kg average weaning weight for pigs weaned between 16 and 23 d of age is a desired target.

Generally, studies focusing on increasing growth rate immediately after weaning using improved feeding strategies had limited effect, pigs had improved growth rates during nursery and heavier nursery exit weights, but the subsequent growing-finishing performance was not affected (Mahan and Lepine, 1991; Wolter and Ellis, 2001). Wolter and Ellis (2001) reported that pigs with light or heavy weaning weight had similar ADG, ADFI and feed efficiency during the growing-finishing period (from 35 days of age to 110 kg of body weight).

1.4.3 Gender

During the suckling period, gender has no effect on ADG (Skorjanc et al., 2007). During the nursery period, gender appears to have no effects on ADG (Wolter and Ellis, 2001) or feed efficiency (Bruininx et al., 2001). There are minimal differences between barrows and gilts in growth performance when body weight of pigs is less than 50 kg

(Hyun and Ellis, 2000). Barrows usually grow faster during the finishing period, as a result from greater ADFI than gilts (Wolter and Ellis, 2001; Wolter et al., 2002). Therefore, gender differences in growth performance only become significant when pigs reach puberty.

Gender appears to affect pig survival. There is evidence that barrows have lower chances of survival before weaning (Lay et al., 2002) and during the nursery period (Larriestra et al., 2006) compared with gilts. Such difference in pre-weaning survivability may be a result of higher cortisol levels (Ruis et al., 1997) in barrows than gilts. However, the mechanism for high survival rate of barrows during the nursery period is not clear (Larriestra et al., 2006).

1.4.5 The number of feeder spaces

Under the conditions of modern pork production systems, pig growth performance is not solely affected by nutritional adequacy of diets, feeding programs and management, but is also affected by the effects of the physical environment. Understanding these effects could help producers make decisions about the need to adopt new feeding strategies to improve productivity and efficiency. The physical environment can be defined to consist of several components, including space allowance, group size, flooring conditions, temperature, and feeder characteristics (Averos et al., 2012). For the scope of this review, only feeder characteristics are discussed. The feeder characteristics of importance are feeder size, the number of feeding spaces, and the presence of individual protection barriers within feeders. Although some feeder designs include

providing water within the feeder (wet/dry feeders), this feature is not typically used in nursery feeders, and will not be discussed.

Feeder characteristics affect the behavior and growth performance of pigs. Pigs housed in groups can exhibit synchronized feeding behavior, which stimulate feed intake (Thompson and Fraser, 1988). Despite the benefit of synchronized feeding, social facilitation may also lead to competition for access to the feeder when the animals are provided suboptimal feeding space, which is a common practice in most commercial pork production systems (Baxter, 1983; Hsia and Wood-Gush, 1983).

Traditionally, one feeder space per four growing pigs and one feeder space for four or five finishing pigs has been recommended (MWPS, 1991). However, the recommendation did not specify dimensions of the feeder space or other factors that affect a pig's feeding environment. Guidelines for Australian pork producers are more specific by recommending one space for four growing pigs, and each space is recommended to be 250 mm in length (Farrin, 1990). The Canadian recommendations suggest that the feeder width be 25.5 cm/pig for pigs weighing 55 kg, and 31.1 cm/pig to 33.9 cm/pig for pigs weighing 100 kg to 130 kg (Canadian code of practice, 2014).

Although many feeders have divisions or barriers between the feeding spaces, they may not accurately reflect the feeding space required by the pig. Baxter (1991) suggested that the minimum width of a feeding space should be the shoulder width of the pig, plus 10% to accommodate pig variability and movement. The shoulder width of a pig, in centimeters, is approximately $6.1 \times BW^{0.33}$, with body weight expressed in kilograms (Petherick, 1983). Thus, the width of feeder spaces for 5, 25, 50, and 120 kg

pigs should be 11.1, 19.8, 24.8, and 32.8 cm, respectively, if this recommendation is used.

Some previous studies on the number of pigs fed per feeder space failed to demonstrate any effects of feeder space on the growth performance of the pigs (Hansen et al., 1982; Nielsen et al., 1995a). On the other hand, McGlone et al. (1993) provided one, two, or three feeder spaces for 20 pigs per pen from 61 to 104 kg live weight. When feeding a meal diet, they concluded that the feeder space requirement is one space per 10 pigs. Bates et al. (1993) conducted a study in a commercial swine unit and showed that that 10 growing-finishing pigs per feeder space was adequate. Likewise, Morrow and Walker (1994) recommended that two single-space feeders are adequate when used in pens of 20 finishing pigs when ad libitum access to meal diets are provided. Nielsen (1992) reported that there were no negative effects on performance of 14 growing-finishing pigs fed with only one feeder, compared to three feeders (number of feeder spaces was not reported). Gonyou and Lou (2000) and Spoolder et al. (1999) showed that feeder space allowance ranging between 3 and 20 pigs per feeder space did not have any effect on growth performance. It is possible that although feeder occupation is greater in younger pigs, their ability to access the feeder simultaneously is also greater. In addition, feeder protection also has a role in affecting feeding behavior. Brumm and Gonyou (2001) confirmed the positive impact of individual protection in feeders on the feeding behavior patterns and improved growth performance because these barriers provide fewer disturbances while pigs are eating, and consequently these pigs had higher feed intake compared with pigs without protection at the feeder.

Botermans and Svendsen (2000) and Georgsson and Svendsen (2002) demonstrated that a highly competitive feeding environment (one feeder for a group of 16 pigs) causes a large variation in ADG of growing-finishing pigs. In addition, Hsia and Wood-Gush (1983) and Brumm and Gonyou (2001) reported that under conditions of restricted feeder space, pigs increased ingestion rate, and reduced the duration of visits to the feeder and total time spent eating. These results suggest that pigs can adjust their feeding behavior to adapt to the restricted feeder space.

Georgsson and Svendsen (2002) reported an interactive effect between the body weight difference within a group of pigs at introduction and number of feeder spaces provided. They found that small and large pigs competed at the feeder differently. The small pigs in pens with a high level of competition at the feeder (access to one feeder) consumed less feed than the small pigs in pens with less competition (access to two feeders). In contrast to the small pigs, the large pigs in pens with a high level of competition consumed more feed than those experiencing a lower level of competition. This could explain why greater variation in growth performance is observed among pigs subjected to a high level of competition for feed (Hansen et al., 1982; Botermans and Svendsen, 2000; Georgsson and Svendsen, 2002).

It appears that the restriction on feeder space also affect the circadian rhythm of pig eating behavior. Young and Lawrence (1994) found that restricting feeder access (10 pigs per feeder space) increased competition and consequently, resulted in feeding behavior change that caused pigs to be unsuccessful in competing for feeder access.

These less competitive pigs change their behavior to eat during night time hours, when more competitive pigs are sleeping, which maybe a welfare concern.

Walker (1991) reported that pigs housed in pens of 30 occupied a feeder, where only one pig can enter at a time, 92% of the time. However, these pigs displayed diurnal eating behavior that was not normally seen in pigs without feeder restriction. Specifically, the biphasic eating pattern usually displayed by group housed pigs disappeared as the animals fed through the night. In addition, the almost continuous occupation of the feeder is an indication that the pig to feeder ratio (30: 1) had reached its maximum for single-space feeders without causing adverse effects on growth performance. This maximum stocking rate per feeder also resulted in increased feeding rates (53 g/min vs. 28 g/min for pig to feeder ratio of 30:1 vs. 10:1, respectively; Morrow and Walker, 1994).

1.5 Feeding behavior of pigs

The feeding activity of pigs is mainly caused by light intensity changes (Renaudeau et al., 2005). Studies have found that pigs older than 6 weeks of age express certain diurnal feeding patterns (Labroue et al., 1999; Quiniou et al., 1999). For instance, Labroue et al. (1999) found that only 30% of daily feed intake occurs between 20:00 and 08:00 h. Furthermore, some studies reported two peaks of feeding events, one at the beginning and one at the end of the light period (Montgomery et al., 1978; Feddes et al., 1989). On the other hand, Young and Lawrence (1994) reported only one peak in the middle of the light period.

The differences observed in feeding activity may be attributed to the adaptation of pigs to the environment to maximize the chances of receiving the necessary amount of

feed. For instance, Labroue et al. (1994) suggested that the existence of a range of eating patterns in pigs varying from meal eaters (few long meals every day) to nibblers (many short meals every day). The difference between meal eaters and nibblers may be a result of competition at the feeder, social facilitation and social stress. For instance, group housed pigs change their eating behavior by eating less frequently, consuming larger-sized meals at a time, and consuming feed faster compared to pigs housed individually (de Haer and Merks, 1992). On the other hand, Gonyou et al. (1992) found that pigs housed individually gained more weight and had greater feed intake than pigs housed in groups of five.

Several experiments have shown that increased competition for feed, resulting from restricted feeding space per animal, has led to increased aggression, reduced feeding time, poorer weight gains and greater weight variation within a pen (Hansen et al. 1982; Baxter 1983). A study found that pigs with the greatest ADG in a pen are most likely the pigs that eat the most feed and spend more time at the feeder than pigs with low ADG (Brown-Brandl et al., 2013). For instance, Baxter (1985) found that 34% of aggressive interactions were initiated by subordinates and suggested that possession of a feeding site was a prerequisite for initiating aggression. Therefore, providing increased feeding space or the use of barriers in the feeder may decrease the aggression and competition for feed.

Nielsen et al. (1995) demonstrated that the feeding rate is highly consistent across individual pigs for a given diet, and pigs have a preferred feeding rate. Normally, at around 40 kg body weight, the rate of feed intake of individually housed pigs has been reported to be 12 g/min (Bigelow and Houpt, 1988). However, for group housed pigs, the

rate of feed intake has been reported to be 24 g/min (Labroue et al., 1995), 32 g/min (Nielsen et al., 1995) and 34 g/min (Quiniou et al., 1998), respectively. Therefore, change in the feeding environment could have a long-term effect on feeding rate, and animals that previously had restricted feeding may have an increased feeding rate (Nielsen, 1998).

1.6 Maternal characteristics

1.6.1 Litter size

Large litter size is very important for modern pork production systems. It represents high productivity of the sow and improved profitability for the producers. During the last 5 years, the number of piglets born alive has increased from 12.3 per litter in 2007 to 13.4 per litter in 2012 (National Pork Board, 2012). This achievement has been a result of genetic selection and the introduction of hyperprolific dam lines into commercial production systems, along with improvements in nutrition, housing conditions, and better management (Beaulieu et al., 2010). However, this high prolificacy has also resulted in the issue of more low birth weight pigs. Several studies have shown that mean birth weight decreases as litter size increases, and the decrease in mean birth weight is caused by an increased number of low birth weight pigs (Handel and Stickland, 1987; Quiniou et al., 2002; Gondret et al., 2005). It has been estimated that an increase of one pig in litter size results in a decrease of approximately 33 g per pig in average birth weight (Beaulieu et al., 2010). It is worth mentioning that although birth weight declined as litter size increased, Beaulieu et al. (2010) observed that the standard deviations were identical among different litter sizes. Therefore, the decreased mean birth weight induced

by increased litter size causes a shift in the normal distribution curve toward lighter birth weights while the shape of the curve remained unchanged.

During the prenatal period, maternal blood flow provides glucose, amino acids, and other essential nutrients for the developing fetuses, and consequently, prenatal growth of the fetus largely depends on the supply of these nutrients (Robinson et al., 1999). However, as litter size increases, the increase in the uterine blood flow is not proportional to the increase in the number of fetuses, causing insufficient blood flow and therefore, reduced nutrient supply per fetus (Pere and Etienne, 2000). Rehfeldt et al. (2000) reported that lightweight piglets tended to exhibit the lowest blood glucose concentration at birth, indicating that they were not adequately supplied with nutrients in utero. Decreased maternal blood flow can negatively affect the number of muscle fibers of the fetus, resulting in restricted postnatal lean growth, increased fat deposition, and poor pork quality (Rehfeldt and Kuhn, 2006). Furthermore, the amount of milk produced by a sow is not proportional to the number of pigs it nurses, leading to insufficient milk intake for some of pigs (Auldist et al., 1998). Large litter size increases competition, which affects lightweight pigs the most since they are disadvantaged in body weight compared to heavier littermates (Milligan et al., 2002).

However, some researchers (Clowes et al., 2007; Beaulieu et al., 2010) argue that large litter size is beneficial to pork production systems because it only determines pig growth from birth to weaning. During this period, individual pigs in large litters are more likely to have poor growth performance (Beaulieu et al., 2010). However, the impact of litter size on post-weaning performance appears to be negligible (Douglas et al., 2013).

Over the entire period from birth to market, litter size appears to have no effect on days to market (Beaulieu et al., 2010). In addition, total litter weight increased with litter size (Beaulieu et al., 2010). Likewise, Clowes et al. (2007) noted that large litters have the potential to produce more pork per sow per year because more pigs were weaned and marketed from the larger litters compared with small or medium litters.

1.6.2 Parity

Parity has significant effects on several measures including number of piglets born, number of piglets born alive, percent of stillborn piglets, mean birth weight, and variation in birth weight within litter.

Compared with younger sows (parity = 1 or 2), old sows (parity > 5) usually farrow and wean smaller litters (D' Allaire et al., 1992). The decrease in numbers of piglets born live for old sows may be due to decrease in uterine muscle tone, leading to a high rate of intrapartum deaths (Bille et al., 1974). The optimal productivity is achieved in the middle, litter size was greatest from middle-aged sows (English et al., 1977; Milligan et al., 2002). This increase in litter size is likely due to an increase in ovulation rate and embryonic survival with parity (Wrathall, 1971). The increase in birth weight between first and second parity litters was likely due to an increase in available uterine space (Gama and Johnson, 1993). The subsequent decline in mean birth weight was likely due to increased litter size and a consequent decrease in uterine space per piglet. Intrauterine growth retardation and birth weight variation are evident by 35 days post-implantation and are likely a consequence of foetus spacing (Gama and Johnson, 1993; Van der Lende et al., 1990).

Progeny from first parity dams have decreased growth rates compared with progeny from second or greater parity dams (Mahan, 1998; Moore, 2001; Le Dividich et al., 2005). At birth, pigs are completely dependent on colostrum immunoglobulins for initial immune protection (Blecha, 2001). The reduction in performance during suckling period may be a result of stress, poor passive immunity and susceptibility to pathogens. Passive transfer of immunity and progeny microbial ecology can be affected by dam parity, resulting in differences in progeny performance (Carney-Hinkle et al., 2013). Studies showed that IgA and IgG concentrations are greater in colostrum from old dams compared with young dams (Inoue et al., 1980; Inoue, 1981; Klobasa et al., 1986). The parity of sow can also affect milk production, which is likely to affect piglet growth during suckling period. Pigs from mid parity sows have the greatest weaning weights (Milligan et al., 2002). During nursery phase, pigs born to primiparous sows grow slower, have lower feed intake and poor feed efficiency compared to pigs born to multiparous sows. These pigs also show high risk of dying compared with pigs born to multiparous sows (Pineiro and Lisboa, 2013).

1.7 Carcass Characteristics

1.7.1 Body composition

The significant individual difference in body composition exists when pigs are born. Lightweight pigs have higher percentage of organs (14.8 vs. 13.4%), bones (37.4 vs. 35.5%), and skin (10.8 vs. 10.0%), but lower percentage of muscle tissue (42.5 vs. 45.2%) compared with heavy pigs at birth. Chemical analysis indicate that lightweight pigs at birth are relatively less mature, supported by the fact that the body of lightweight

pigs contained less fat (0.98 vs. 1.14%), protein (14.6 vs. 15.8) and more water (80.4 vs. 79.2%) compared with heavy pigs (Rehfeldt and Kuhn, 2006).

1.7.2 Muscle development and growth

Lean growth is largely determined by the number of muscle fibres and the size of these fibres. The number of muscle fibers is determined during the prenatal phase. Therefore the postnatal growth of skeletal muscle is mainly realized through increases in length and girth of the muscle fibres (hypertrophy), but not by increase in muscle fibre number.

The number of the prenatally formed muscle fibres determines the rate of postnatal fibre hypertrophy. During postnatal development, the individual muscle fibres generally grow more slowly when the number of fibres is high, and conversely, fibres grow rapidly when the number of fibres is low (Rehfeldt et al., 2000). This has been shown in pigs (Staun, 1972; Fiedler et al., 1997; Larzul et al., 1997). Therefore, pigs with low birth weight are expected to have faster fibre growth and reach the plateau of fiber growth earlier than pigs with heavy birth weight. Indeed, Rehfeldt et al. (2006) found the larger fibers in both the semitendinosus and the longissimus muscle for slaughter pigs with low birth weight (LW) compared with pigs with high birth weight (HW). Live weight (106.1 ± 3.6 vs. 116.0 ± 2.6 kg), carcass weights (84.2 ± 3.1 vs. 92.5 ± 2.2 kg) and loin muscle areas (44.9 ± 2.1 vs. 49.1 ± 1.5 cm^2) were lower (P = 0.02 to 0.08) in LW pigs than in HW pigs. On the other hand, the internal fat percentage was higher in LW pigs than in HW pigs (2.78 ± 0.18 vs. 2.44 ± 0.15%). Likewise, the fat percentage by chemical analysis was numerically high in LW pigs (24.6 ± 1.6 vs. 22.9 ± 1.0 %).

All these studies support the theory that LW pigs increase their fiber size faster because of their low fiber number, and reach the plateau of fiber growth earlier than HW pigs. Consequently, nutrients may no longer be used for muscle accretion, but mainly used to deposit fat in LW pigs. In addition, LW pigs may develop larger size muscle fiber because they probably reach to the plateau of fiber growth at slaughter, whereas the HW pigs are slaughtered before the fibers can grow to the potential size.

1.8 Physiological indicators

Growth is a complex and highly integrated process. It involves interactions between nutrients, environment and many different hormones and the receptors for these hormones in different tissues. For the scope of this study, we will take a look at growth hormone, Insulin-like growth factor 1, insulin and leptin.

1.8.1 Growth Hormone

Growth hormone (GH) is the main regulator of postnatal growth in mammals. It is carried by circulation to tissues where it is active. In circulation, it binds to a binding protein that helps protect it from degradation and increases its stability. It's released from pituitary gland, and the release pattern is pulsatile as it's released in pulses approximately every 30 minutes. Its pulsatile release from anterior pituitary is primarily regulated by two hypothalamic hormones, GH-releasing hormone (GHRH) and somatostatin (SRIH), which play an excitatory and an inhibitory role, respectively.

Ultimately, the growth promoting effect of growth hormone is realized through growth hormone dependent somatomedins. These somatomedins are purely anabolic

agents that stimulate increases in both the number of cells (hyperplasia) and their size (hypertrophy).

In normal animals, simply elevating circulating growth hormone levels by administration of exogenous growth hormone has failed to promote growth (Wheatley et al., 1966; Muir et al., 1983). In animals with different growth rate, pigs with poor growth rate also have similar GH basal levels in plasma compared with pigs with average growth rate (Roberta et al., 2001). Part of the reason for less correlation between growth performance and GH level is believed to be the limited number of receptors, because additional growth hormone requires additional receptors to elicit any significantly increased response.

In addition, it's hard to determine the GH deficiency in farm animals due to various confounding factors such as social stress (Buonomo and Baile, 1991), management and environment (Carroll et al., 1998). Thus, GH levels are usually considered not a good indicator for growth performance evaluation.

1.8.2 Insulin-like growth factor - 1

The insulin-like growth factors (IGFs), including IGF-I and IGF-II, are small polypeptides that control growth of multiple types of cell. It has similar structure to insulin and actually have some of the same metabolic properties that insulin has, hence the name. They are essential in fatal and postnatal growth and development of an animal (David and Louis, 1991).

Porcine IGF-I consists of 70 amino acids and has a molecular weight of 7.5K Daltons and the sequence of amino acids is identical to that of human IGF-I. The

receptors of IGFs exist on almost all cell types, and IGF-1 bound principally by type 1 IGF receptor. The type 1 IGF receptors are located mainly in mesenchymal cells such as fibroblasts and osteoblasts, so it explains why IGF-1 has stimulatory effect on tissues such as muscle and bone (Rinderknect and Humbel, 1978; Honegger and Humbel, 1986). It is also synthesized locally in many tissues in the body, such as muscle, bone and liver. Liver is believed to be the principle organ for producing circulating IGFs and the highest level of IGFs is in the blood (Yakar et al., 1999).

IGFs increase the rate of energy metabolism but more importantly, they act directly to increase the rate of protein accumulation in body tissues and decrease the rate of protein breakdown. IGFs maybe correlated to the growth rate of animals, including pigs. Circulating IGF-I level is proved to positively relate with the body weight of pigs. For example, serum IGF-I concentrations were significantly correlated with body weight of pigs ($r = 0.98$; Saleri et al., 2001).

The different growth rate of pigs at the same age may be related with plasma IGF-I levels. There is evidence that average-growth pigs have significantly higher IGF-I concentration (101.8 ± 9.8 ng/ml vs. 39.5 ± 4.0 ng/ml, respectively) compared with poor growth pigs at 40 days of age (Roberta et al., 2001).

The rate of IGF-I synthesis in tissues and its secretion into the systemic circulation is also related with availability of adequate nutrient intake. Control of IGF synthesis and secretion provides a signaling mechanism to target cells that adequate nutrients have been ingested and are available for protein synthesis and cell division. Nutrition restriction would induce growth hormone resistance and thus limit the anabolic

function of growth hormone. Human fasted for 10 days have 70% fall in plasma IGF-I concentration (Clemmons, 1981). In swine, feed withdrawal for 48 hours could result in a significant decrease in plasma IGF-I (Buonomo and Baile, 1991). Therefore it's of great importance to understand the role of nutritional status in regulating IGF-1 production and action in order to link nutrition with growth.

1.8.3 Insulin

Insulin is an approximately 5.8-kDa peptide hormone synthesized by the β-cells of the islets of Langerhans in the endocrine pancreas.

The primary role of insulin is to control the levels of circulating glucose by taking glucose into cells after meal ingestion. The daily rhythm in plasma insulin concentrations is mainly driven by a circadian pattern in feed intake. Fasting insulin levels in the plasma are low and stable and increase concomitantly with meal ingestion.

Because its secretion is in direct proportion to the amount of body fat, and because it is able to penetrate the blood–brain barrier from the circulation, insulin is considered an adiposity signal that provides information to the CNS that contributes to the homeostatic regulation of body fat. When an individual is food-restricted or voluntarily diets and loses weight, less insulin is secreted and reaches the brain; and the catabolic tone of the hypothalamus is consequently reduced.

Insulin deficiency during the postnatal growth phase has been demonstrated to limit or even prevent growth. The possible reason could be that most cells of the body require insulin for adequate uptake of glucose and amino acids. Without sufficient uptake of these metabolites, growth and development will be limited. During energy deficit,

insulin levels are low, which reduces nutrient deposition into tissue and allows the body to use the available energy for its immediate needs for survival. The low insulin levels lead, in turn, to decreased liver growth hormone receptors thus reducing somatomedin production and retarding growth (Spencer, 1982).

The growth hormone receptors in the liver are now known to be regulated, at least in part, by insulin (Baxter et al., 1980). Thus insulin levels regulate the ability of growth hormone to have its effects on somatomedin production from the liver. This provides an elegant control of metabolism.

1.8.4 Leptin

Leptin is a protein consisted of 146 amino acids and is synthesized primarily by white adipose tissue (Barb et al., 2001a). Leptin is synthesized and secreted from the adipocytes into the blood stream and transported to the brain, where it acts to cause a release of factors, such as neuropeptide Y, which results in reduced food intake (Houseknecht et al., 1998).

Leptin secretion follows a circadian rhythm, with a nadir early in the morning (08:00–09:00 h), an increase during the day, and a peak between 24:00 and 02:00 h. Circulating leptin concentrations are strongly and positively correlated with adiposity in fully fed (positive energy balance) animals. With long-term positive energy balance, leptin steadily increases in plasma to reflect increased adipose tissue mass. Conversely, leptin concentrations in plasma and adipose tissue rapidly and profoundly decrease as a result of food deprivation and negative energy balance (Houseknecht et al., 1998). Thus,

leptin not only functions as an “adipostat” to signal the status of body energy stores to the brain, but also functions as a sensor of energy balance.

It has been hypothesized that hormones and/or metabolites that are altered during food restriction regulate fasting-induced changes in leptin gene expression. Insulin and glucose, which are significantly reduced in the fasting state, are regulators of leptin expression in rodents and humans (Barb et al., 2001b).

1.8.5 Serum Free Amino acids

Free amino acid level in the blood is determined by a complex series of controls including: 1) the influence of carbohydrate in each meal which causes intermittent deposition of amino acids in muscle, 2) the pattern of amino acids passing through the liver after the meal, and 3) changes in hormonal secretory rate. Serum AA concentrations are closely controlled and are subject to homeostasis (Wu, 2009). Serum AA concentrations at any particular time point of sampling are the result of rate of appearance and the rate of disappearance. The rate of appearance in the serum is influenced by feed intake and AA release from the tissue. The rate of disappearance in the serum, on the other hand, is the result of AA metabolism, incorporations of AA into proteins, and losses in urine or feces (Cynober, 2002). Low concentrations of AA in SG pigs may reflect their reduced feed intake compared with AG and FG pigs during nursery period. It is also possible that the low serum concentration of AA in SG pigs was a result of increased rate of AA disappearance (Cynober, 2002), especially under stress situations such as immune challenges (Li et al., 2007).

Several amino acids, such as Arg, Gln, and Leu are secretagogues. For example, supplemental L-arginine (0.1 to 0.3 g/kg body weight over 20 min) can stimulate the secretion of growth hormone from their respective endocrine organs (Wu et al. 2008). Likewise, there is evidence that Gln and Leu can increase insulin release from pancreatic β - cells (Newsholme et al. 2005).

Endocrine function is sensitive to amino acid intake. It is especially noteworthy that methionine and leucine, two amino acids that pass readily through the liver into the general circulation, are particularly potent in causing increased adrenocortical activity a few hours after their administration (Munro, 1970). Notably the branched-chain amino acids act as feedback regulators of secretion of insulin, a hormone that stimulates uptake of amino acids into muscle and thus removes them from the blood. Indeed, it may well turn out that methionine and the branched-chain amino acids act as monitors signaling an influx of amino acids, usually from a meal, and causing transfer of the amino acid load immediately into muscle (insulin) and later removal by a slower increase in catabolic enzymes in the liver (corticosteroid action). But there is insufficient evidence to indicate that normal amplitudes of blood amino acid levels can cause these hormones to be released.

Each meal containing carbohydrate causes release of insulin which results in deposition of amino acids in muscle and lowering of their levels in the plasma. If the meal also contains protein, the release of insulin is augmented and the amino acid deposition is presumably accentuated. Consequently, the diurnal rhythms observed in plasma free amino acids represent mainly a rather complex response to meals, the

changes probably being due to (a) rapid secretion of insulin caused by the carbohydrate in each meal, with deposition of amino acids in muscle, (b) an augmentation in insulin level from the rise in blood amino acid concentrations after the meal.

1.9 Summary

Slow growing pigs are both an economic issue and a welfare concern in the swine industry. Therefore, a better understanding of pigs with different growth is needed to fully address this issue. Growth performance in pigs is a result of complex interactions between the pigs and the environment. Birth weight, weaning weight, gender and maternal characteristics are all factors associated with growth. Moreover, literatures documented that competition at the feeder may be an important factor in determining pigs' feed intake. It's possible that competition could be alleviated by increasing the number of feeder spaces, however, we need to conduct necessary research to evaluate the effect of increased number of feeder space on pigs' performance.

Both GH and IGF-1 are associated with growth performance. The other two hormones, insulin and leptin, are indicators for nutrient intake status. In addition, serum free amino acids concentrations could potentially reflect the feed intake and health status of pigs. Therefore, it is possible that differences in these physiological indicators exist between pigs that exhibit different growth performance. Then differences in physiological characteristics of slow growing pigs can be readily identified and used to minimize the adverse effect of slow growth. This leads us to investigate the risk factors associated with slow growth and physiological characteristics of slow growing pigs.

CHAPTER 2 **:** IDENTIFYING RISK FACTORS ASSOCIATED WITH SLOW GROWTH IN PIGS

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SUMMARY

Pigs that grow significantly slower (slow-growing pigs) than their contemporaries are problematic to animal well-being and profitability. Results from studies on causes of slow growth are not conclusive, thus interventions are limited. The objectives of this study were to identify characteristics of slow growing pigs and factors associated with slow growth. Pigs (n = 440) farrowed by 65 sows (parity = 1 to 7) were weighed individually at birth, weaning (4 wk of age), nursery exit (9 wk of age) and at marketing (between 21 and 24 wk of age). Pigs were categorized as slow, average, and fast growers based on market weight adjusted to 170 d of age (slow growers < 105 kg, average growers between 105 and 125 kg, and fast growers > 125 kg). Blood samples were collected from a subgroup of pigs (n = 48, from 12 randomly selected pens, representing the 2 heaviest and 2 lightest pigs in their respective pens) at nursery exit and at the first removal for marketing to analyze serum free AA and plasma hormone concentrations. The Mixed Procedure of SAS with repeated measures was used to analyze growth performance, AA, and hormone concentration data, and the Logistic Procedure was used to identify risk factors for slow growth. Slow growing pigs accounted for 10%, average growers for 49%, and fast growers for 41% of the total pigs in this population. Compared with fast growers, slow growers needed an extra 20 d to reach the target market weight (115 kg). Compared with fast growers, slow growers had lower birth weight (1.13 vs. 1.64 kg, SE = 0.18; $P < 0.01$), weaning weight (5.1 vs. 8.1 kg, SE = 0.51; $P < 0.01$) and nursery exit weight (18.6 vs. 28.0 kg, SE = 1.97; $P < 0.01$). Slow growing pigs had less back fat (1.8 vs. 2.3 cm, SE = 0.05; $P < 0.01$) and smaller loin muscle area (32.0 vs. 41.8

cm^2, SE = 1.58; $P < 0.01$) than fast growers marketed at 21 wk of age. Slow growers had the lowest plasma concentration of IGF-1 and insulin among the pig categories during the nursery period ($P < 0.05$), and the lowest concentration of leptin and insulin during the grower-finisher period ($P < 0.05$). Serum concentrations of several essential, non-essential, and total AA were lower for slow growers compared with average and fast growers. Sex appeared to be a contributor to slow growth, with gilts being 2 times (odds ratio = 2.17, confidence interval = 1.19 to 3.96; $P = 0.012$) more likely to become slow growers than barrows. Litter size and parity of the pigs' dam were not associated with slow growth. These results suggest that low body weights at early growth stages were the major risk factors for slow growth. Low plasma or serum concentrations of IGF-1, insulin, leptin, and total AA were positively associated with slow growth in pigs.

Key words: birth weight, hormones, pigs, risk factors, serum amino acids, slow growth

INTRODUCTION

Market weight of pigs is of great importance in affecting pork producers' profitability. Although one may view that keeping every pig alive is productive and beneficial, not all pigs exhibit ideal growth performance and having some lightweight pigs can substantially reduce profitability. In an all-in/all-out production system, pigs that cannot reach desirable slaughter weights at a certain age are often referred to as slow-growing pigs. This subset of a contemporary group of pigs are usually sold at much lower economic value than their counterparts, and are also at higher risk of dying at each

production phase compared with their contemporaries (Larriestra et al., 2006; Douglas et al., 2013), resulting in economic losses to pork producers.

There are many factors that affect growth performance of pigs, and in many cases, it is a result of the interactions between the environment, nutrition, and the genetic potential for lean growth of pigs. However, failure of a pig to thrive in a modern swine production setting may very likely result from a stressful environment (Botermans et al., 2000; Georgsson and Svendsen, 2002), poor genetic potential for growth (Quiniou et al., 2002), or a combination of both.

Feeder space is an important environment component in pork production systems (Averos et al., 2012). Studies on feeder characteristics, such as feeder space per pig, have shown that limited access to the feeder negatively affects growth performance of pigs (Botermans et al., 2000; Georgsson and Svendsen, 2002). In addition, limited feeder space can force some pigs, mostly slow growing pigs, to shift feeding events towards night times, which causes animal well-being concerns (Young and Lawrence, 1994).

Results from several previous studies have shown that certain characteristics such as light birth weight (Mahan and Lepine, 1991), light weaning weight (Cooper et al., 2001), light nursery exit weight (Douglas et al., 2014), and gender (Larriestra et al., 2006) were associated with slow growth and mortality of pigs. However, very few studies evaluated and reported the physiological characteristics of slow growing pigs, namely, serum or plasma hormone and amino acid concentrations. Therefore, investigating the effect of feeder space, risk factors associated with poor growth performance, and characteristics of slow growing pigs may provide useful insight to help pork producers

make decisions on improved management strategies to enhance growth performance, animal well-being, and profitability.

MATERIALS AND METHODS

The protocol of this study was reviewed and approved by the University of Minnesota Institutional Animal Care and Use Committee (Protocol No. 1302-30358A).

Animals, Housing and Management

This study was conducted at the University of Minnesota's West Central Research and Outreach Center (**WCROC**) in Morris, MN. The WCROC utilizes 2 farrowing systems, representing a bedded, group-farrowing system, and a confinement system with farrowing crates. Both farrowing systems have been described previously (Li et al., 2011). Briefly, in the group farrowing system, each room (9.2 m × 9.7 m) accommodated 8 sows and each sow farrowed in individual pens (1.8 m × 2.4 m). At approximately 10 d after farrowing, pens were removed and sows and piglets within each room were co-mingled in a group. Sows had free access to feeders and drinkers in a communal area. In the confinement system, farrowing crates (0.6 m × 2.0 m) were located above plastic-coated, woven-wire floors and equipped with creep areas (0.8 m × 2.0 m) on each side. In both farrowing systems, piglets were processed within 24 h after birth. Piglet processing included iron injection, needle teeth clipping, tail docking, ear notching, and castration of male pigs. Cross-fostering was performed to standardize litter size between 12 and 14 piglets per litter within 24 h after farrowing within each farrowing system. Only piglets that were heavier than the average litter weight at birth were transferred to foster sows.

At approximately 4 wk of age, pigs were weaned and transferred to a confinement nursery facility. The nursery facility had two identical rooms, and each room had 32 pens (2.4 m × 1.2 m). Each pen accommodated 8 pigs and was equipped with a 5-space dry feeder (Hog Slat Inc., Blooming Prairie, MN) and a cup drinker on slatted plastic flooring. Floor space allowance was provided to achieve 0.34 m^2/pig, and excluded the space occupied by the feeder. Room temperature was controlled by exhaust fans and heaters to achieve the desired thermoneutral zone for nursery-aged pigs. The light period was provided for 8 h starting from 0730 h with an emergency light on during the dark period. Each room had windows so that natural light was also provided during day light hours.

At approximately 9 wk of age, pigs were transferred to grower-finisher hoop barns. Each hoop barn (12 m × 24 m) accommodated 220 pigs and was equipped with two 12-space round feeders and two 4-space water fountains on a raised concrete pad (6 m × 12 m). The water fountains were heated during the winter to prevent water from freezing. The lying area (12 m × 18 m) in the hoop barn was bedded with wheat straw to a depth between 20 and 30 cm. Floor space allowance of the bedded area was 0.98 m^2/pig. The hoop barn was naturally ventilated and lighted. Pigs remained in the hoop barns for 12 to 15 wk until they reached desired market weights.

All pigs received diets that were formulated to meet or exceed their nutritional requirements based on the NRC (2012) recommendations. Pigs were checked once daily to ensure that they had free access to feed and water, and were in good health.

Experimental Design

This study consisted of 2 trials conducted in 2013. The first trial was conducted between March and September, and the second trial was conducted between June and December. Each trial consisted of pigs that were born to 30 to 35 sows within one week. To evaluate whether feeder space allowance could alleviate competition at the feeder and improve performance of slow growing pigs at an early age, 2 feeder space treatments were imposed during the nursery period, including 2 feeder spaces per pen vs. 5 feeder spaces per pen. The 2-space feeder was achieved by covering 3 spaces of the 5-space feeder. The area of each feeding space measured 15 cm × 15 cm. With 8 pigs in each pen, the 2-space feeder accommodated 4 pigs/feeder space and the 5-space feeder accommodated 1.6 pigs/feeder space. During each trial, feeders were adjusted to provide an equal setting for each feeder to achieve similar feeder pan coverage (the percentage of feeder trough covered by feed; Simth et al., 2004) between the 2 feeder space treatments.

Pigs were sorted by weight and sex at weaning. Within each sex and weight category, pigs were randomly allocated to pens to achieve an equal number of barrows and gilts in each pen, with similar mean weight and variation (coefficient of variation) within a pen, between the 2 feeder space treatments. Pigs remained in their designated pens for 5 wk until they were 9 wk of age. Then, an equal number of pigs from each feeder space treatment were moved to a grower-finisher hoop barn and remained there until they reached desired market weight. Based on their differences in growth rate, pigs in each trial were marketed twice, approximately at 150 d and 170 d of age when they reached about 115 kg. For any pigs that were removed from the study due to poor health,

the age of the pig and reason for removal were recorded. Mortality and morbidity were recorded throughout the entire study.

Data Collection

Growth performance. A total of 592 pigs (Landrace × Yorkshire × Duroc) farrowed and weaned by 65 sows were evaluated from birth to market weight in the 2 trials. Within each trial, about two-third of the pigs were farrowed in the bedded group pens and one-third of the pigs were farrowed in crates.

At farrowing, the number of total and live born piglets was recorded for each litter. All piglets born alive were weighed individually within 24 h after birth. In addition, the date and location (the bedded group farrowing system vs. farrowing crates) of birth, and dam parity of the piglets were recorded. When piglets were cross fostered, parity and litter size of the dam and nursing sow were recorded. The dam refers to the sow that gave birth to the piglets, and the nursing sow refers to the sow that nursed the piglets after cross-fostering. At weaning, all pigs were weighed individually and the weaning age was calculated for each piglet. Average daily gain and weight per day of age during the suckling period were calculated for each pig. In this study, weight per day of age was used to evaluate growth rate and was calculated using the equation: BW (kg/d of age) = BW (kg)/age (d at weaning, nursery exit, or marketing).

In trial 1, 128 pigs were allocated to 16 pens with 2-feeder spaces and 160 pigs were allocated to 20 pens with 5-feeder spaces in the confinement nursery faciltity. In trial 2, 128 pigs were allocated to 16 pens with 2-feeder spaces and 176 pigs were allocated to 22 pens with 5-feeder spaces in the nursery. Pigs were weighed again 1 wk

after entering the nursery, every 2 wk thereafter, and then at exit from the nursery at 9 wk of age. Average daily gain was calculated for each weigh period as well as for the entire nursery period. In addition, weight per day of age from birth to 9 wk of age was calculated using the equation previously described.

Feed intake was monitored on a pen basis during the nursery period. Feed additions to each pen were recorded, and remaining feed was weighed by vacuuming the feed on the same day that pigs were weighed, and was subtracted from the total amount of feed added to calculate feed disappearance for each pen.

In each trial, 110 pigs from each feeder treatment were randomly selected and then moved to a grower-finisher hoop barn at nursery exit at 9 wk of age. During the growing-finishing period, pigs were only weighed on the day of marketing. For each trial, two marketing group removals were used to market all pigs in the facility. The removal occurred when approximately one-third of the group reached 110 kg BW, which occurred at about 150 d of age, and the second marketing removal was made 3 wk later. All pigs were weighed individually, and ADG during the growing-finishing period was calculated based on the weight difference between weaning and the first removal. In addition, backfat (BF) thickness and loin muscle area (LMA) were measured for all pigs at the first marketing removal using a real-time ultrasound imaging scanner (Aloka 500V SSD; Hitachi-Aloka Medical Ltd., Tokyo, Japan). Measurements were taken at the 10^{th} rib, 25 mm down the right side from the midline of the pig by a certified technician. Pigs that weighed less than 105 kg remained in the barn for an additional 3 wk, and subsequently were weighed again before the final removal. The actual age and weight at marketing

were recorded, and BW per day of age from birth to marketing was calculated for each pig.

Blood Sampling. In the second trial, 48 focal pigs were selected the day before exiting the nursery barn at 9 wk of age for blood sampling. The focal pigs were derived from 12 pens, including 6 pens of each feeder space treatment. Within each pen, the 2 heaviest weight pigs (one barrow and one gilt) and the 2 lightest weight pigs (one barrow and one gilt) pigs were selected as focal pigs. Blood samples of approximately 10 to 15 mL were collected from each focal pig through jugular vein puncture using both serum separator vacutainer tubes coated with silicone, and micronized silica particles and sodium heparin coated plasma vacutainer tubes (Becton Dickson, Franklin Lakes, NJ). Blood samples for serum collection were allowed to clot for 10 to 15 min at room temperature and then placed on ice. Within 2 h after collection, blood samples were centrifuged at 4 ˚C for 15 min at 1400 x g (2373 rpm with 222 mm rotor radius), and serum and plasma were transferred to microcentrifuge tubes and stored at -80˚ C for later analysis. Plasma was used for analysis of hormones and serum was used for analysis of AA.

Plasma Hormone and Serum AA Analysis

Growth hormone (GH). A competitive, liquid-liquid phase, double-antibody radioimmunoassay procedure was used to determine plasma concentrations of GH as described previously (Thomas et al., 1998). The standard curve contained the following concentration points: 0.5, 1, 1.5, 2.5, 4, 6, 10, 17.5, 20, and 25 ng in 300 µL/tube. Plasma concentrations of GH were determined in triplicate using 175 µL aliquots of samples.

Growth hormone antiserum (monkey, 100 µL of 1: 800,000 dilution) was added to assay tubes, along with 100 µL of iodinated porcine GH. Total specific binding was 41 %, the minimum detectable concentration was 0.5 ng/tube, percentage of recovered mass was > 99% across the range of 25 to 300µL of samples, and the inter- and intra-assay CV's were < 8%.

Insulin-like growth factor –1 (IGF-1). A competitive, liquid-liquid phase, double-antibody radioimmunoassay procedure was used to determine plasma concentrations of IGF-1 as described previously by Lalman et al. (2000). Assay validation was performed by first adding 400ul of 1M glycine (pH 3.2) to 10 µL of serum sample, followed by the addition of 500 µL of PABET+P. Then, iodinated IGF-1 (25,000 cpm) was then added and incubated for an additional 16 h. Total specific binding was 39%, the minimum detectable concentration was 1.5 ng/tube, percentage recovery of mass was > 97% across the range of 2.5 to 100uL of samples, and the inter- and intra-assay CV's were < 6%.

Leptin. A competitive, liquid-liquid phase, double-antibody radioimmunoassay procedure was used to determine plasma concentrations of leptin as described previously by Delavaud et al. (2000). Assay validation information consisted of using standard concentrations of recombinant ovine leptin (0.1, 0.2, 0.3, 0.5, 0.8, 1.2, 2.0, 3.5, 5.0, and 7.5 ng in 300 µL/tube) and increasing volumes of serum (25, 40, 60, 100, 175, 250, and 300 µL) from a pool of porcine serum, which were added to assay tubes in triplicate and the total volume balanced to 300 µL per tube with buffer. Then, 175 µL aliquots of the porcine serum samples that were to be quantified were added to assay tubes, and 100 µL of rabbit anti-ovine leptin primary antiserum (dilution of 1:15,000) was added. After

initial incubation, 100 µL of iodinated ovine leptin (25,000 cpm) were added to each tube, and incubation continued for an additional 20 h at 4°C. Total specific binding was 43%, the minimum detectable concentration was 0.1 ng/tube, percentage of recovered mass was > 98% across the range of 25 to 300µL of samples, and the inter- and intra-assay CV's were < 5%.

Insulin. A competitive, liquid-liquid phase, double-antibody insulin radioimmunoassay procedure was used to determine plasma concentrations of insulin. Assay procedures consisted of using standard concentrations of porcine insulin (3.125, 6.25, 12.5, 25, 50, 100, 200 uU/ml in 300 µL/tube) and increasing volumes of serum (25, 40, 60, 100, 175, 250, and 300 µL) from a pool of porcine serum, which were added to assay tubes in triplicate and the total volume of 300 µL per tube was achieved by adding buffer solution. Likewise, 100 µL aliquots of the porcine serum samples to be quantified were added to assay tubes in triplicate and the total volume of 300 µL per tube was achieved by adding buffer solution. An amount of 100 µL of guinea-pig anti-porcine insulin primary antiserum was added, along with 100 µL of ^{125}I-porcine insulin, and incubation commenced for 24 h at 4° C. Total specific binding was 35 %, the minimum detectable concentration was 3.125 uU/tube, percentage of recovered mass was > 99% across the range of 25 to 300µL of sample and the inter- and intra-assay CV were < 5%.

Amino-acids. Concentrations of all AA in serum was determined by liquid chromatography–mass spectrometry (LC-MS) using a modified method based on Márquez et al. (1986). Briefly, each serum sample was prepared with 100 µM p-chlorol-L-phenylalanine as the internal standard. Five µL of each sample and the internal

standard were mixed with 40 µL Na_2CO_3 (10 mM and pH 11) and 100 µL dansyl chloride (3 mg/mL in acetone). The mixture was incubated in a water bath at 60° C for 10 min followed by centrifugation at 10,000 × g for 10 min at 4° C. The supernatant was transferred to a high recovery vial and 5 µL was injected into the LC-MS system (SYNAPT., Waters, Milford, MA) for AA analysis.

Statistical Analysis

Pigs were categorized as slow, average, or fast growers based on their market weights adjusted to 170-d of age. The market weight adjusted to 170-d of age was calculated using the equation: BW at 170-d = BW at first marketing removal + ADG during the growing-finishing period × (170-d – actual day of age at marketing). Pigs with BW adjusted to 170-d of age lower than 105 kg were classified as slow growers (**SG**). Likewise, pigs with the adjusted BW between 105 kg and 125 kg were classified as average growers (**AG**), and pigs with the adjusted BW heavier than 125 kg were classified as fast growers (**FG**).

Residuals of the data were tested for normal distribution using the Univariate Procedure of SAS (SAS Inst. Inc., Cary, NC). Growth performance, hormone, and serum amino acid data were analyzed using the Mixed Procedure of SAS (Version 9.3, SAS Institute, Cary, NC), where individual pig served as the experimental unit. The model included feeder space treatment (2 vs. 5 feeder spaces) and pig category (SG vs. AG vs. FG) as fixed effects. Block (room in the nursery barn) and trial were used as random effects. All means reported are least square means. All differences between means were

tested by PDIFF with the Tukey adjustment. Significant differences were identified at $P < 0.05$ and trends at $P < 0.10$.

The logistic procedure of SAS was used to evaluate contributions of risk factors to slow growth or death. Risk factors analyzed were feeder space allowance during the nursery period, sex, farrowing system (the bedded group farrowing system vs. farrowing crates), alive litter size (≤ 14 vs. > 14) and dam parity (1 vs. > 1). In addition, low BW at early ages was also included as a risk factor. Low BW was defined as pigs that were in the lower 30th percentile for weight at birth (≤ 1.36 vs. > 1.36 kg), at weaning (≤ 6.40 vs. > 6.40 kg), and at nursery exit (≤ 20.0 vs. > 20 kg). Initially, each risk factor was individually fitted to a univariate model to test for its significant contribution to slow growth. Risk factors that were significant at the level of $P < 0.05$ in the univariate model were included in a multivariate model. Lightweights at each early age time point were tested separately in the multivariate model due to high correlation between BW at different stages. For example, when low birth weight was included as a risk factor in the multivariate model along with other risk factors, weaning weight and nursery exit weight were not included in the model. Since all variables in the model were categorical, odds ratios and 95% confidence intervals were used to evaluate each risk factor.

RESULTS AND DISCUSSION

Growth Performance and Carcass Composition

Among the 440 pigs that were monitored for growth performance from birth to marketing, 10 pigs died during grower-finisher period and 27 pigs lost their ear-tags in the group-farrowing system during the suckling period. As a result, 403 pigs were

included in data analysis for individual growth performance determinations from birth to marketing. Among the 403 pigs, 42 pigs were categorized SG pigs, accounting for 10% of all pigs investigated (Table 1). This percentage is similar to the incidence of slow growing pigs reported on large-scale commercial farms. Larriestra et al. (2006) reported that about 10% pigs were slow growing pigs, which did not reach desired market weight at the same age as their contemporaries, and were marketed at lower value in all-in/all-out production systems. In the current study, we estimated that SG pigs would require an extra 20-d to reach the target market weight of 115 kg based on their final weight and ADG during the growing-finishing period, compared with FG pigs.

The current study demonstrated that SG pigs were characterized as low BW at birth, weaning, nursery exit, and at 150 d of age ($P < 0.001$; Table 1). Accordingly, ADG and weight per day of age for each period were the highest for FG pigs, intermediate for AG pigs, and the lowest for SG pigs ($P < 0.001$). These results are consistent with findings in previous studies (De Grau et al., 2005; Larriestra et al., 2006; Paredes et al., 2012). At birth, SG pigs are at competitive disadvantage due to low BW and not able to compete with heavier BW peers (Le Dividich, 1999). Heavy litter mates are more competitive than SG pigs directly for more productive teats (Lay et al., 2002), and indirectly by stimulating the teats more effectively for more milk consumption (Fraser and Rushen, 1992). Consequently, SG pigs may ingest less colostrum and milk, resulting in less nutrients and immune protection for optimal early development and livability. As observed in the current study, SG weighed less at birth and at weaning, indicating that weight differences at birth were maintained until weaning. In addition, our results

indicate that weight differences among the three growth categories were maintained until marketing. These results agree with findings by Quiniou et al. (2002), Gondret et al. (2006) and Mahan and Lepine (1991) who reported that pigs with lightweight at birth or weaning required an extra 10 to 14 d to reach desired market weight. Therefore, our results along with those of other researchers, suggest that lightweight pigs at early ages are more likely to become slow growing pigs.

However, not every pig born with low BW remains slow growing until market weight. In fact, in the present study, 33% of the pigs that had less than 1.1 kg BW at birth (tenth percentile) were marketed as FG pigs. Similar to our study, Douglas et al. (2013) reported that 52% of the lightest birth weight pigs (lightest 12.5% of the population) were able to at least become average growers. This finding suggests that low birth weight is not the sole factor contributing to slow growth in pigs and projecting days to reach market weight based on birth weight may not be accurate.

In U.S. farrow-to-finish operations, 22 to 26 wk (154 d to 182 d of age) is a common rearing period required for a pig to grow from birth to slaughter weight (USDA, 2014). Based on the growth performance of the WCROC herd, 150 d and 170 d of age were chosen as the first and final removal time, respectively, for marketing in this study. Slow growing pigs in this study were not defined based on their body weight at early ages as in most previous studies. For instance, Fix et al. (2010) defined slow growing pigs based on birth weights, and Larriestra et al. (2006) and Mahan and Lepine (1991) defined slow growing pigs based on weaning weights. Because low BW at early ages is not the sole determining factor for slow growing pigs, and some pigs can increase growth rate to

achieve similar BW as faster growing contemporaries at later ages, we defined slow growing pigs based on their actual growth rate from birth to market. As a result, slow growing pigs in this study were defined as pigs weighing less than 105 kg at 170 d of age. For producers, most packers pay a lower price for pigs that weigh less than 105 kg (Hurt and Boland, 1995), for the reason that it takes almost the same time for the plant to dress a light weight pigs as it does a heavy pig, and light weight pigs do not generate as much revenue as heavy pigs (Keeler et al., 1994).

In the current study, SG pigs had the least LMA and BF compared with AG and FG pigs ($P < 0.001$; Table 1). Muscle mass is determined by the number of muscle fibers and the size of these fibers. Slow growing pigs may have fewer muscle fibers, which are determined prenatally during myogenesis (Rehfeldt et al., 2000). Thus, the capability of muscle growth is limited in SG pigs postnatally. As a result, SG pigs reach the plateau of muscle fiber growth earlier compared with pigs in other body weight categories. Subsequently, after SG pigs reach the growth plateau, energy and AA are re-directed toward mainly fat deposition instead of muscle accretion (Rehfeldt et al., 2006). In contrast to our findings, Rehfeldt et al. (2008) and Gondret et al. (2005) reported no differences in BF and LMA among heavy, intermediate and light weight pigs when harvested at 180 ± 8 d of age. One possibility for the discrepancy is that the weight differences among the pig growth rate categories were larger (114 vs. 100 vs. 83 kg at 150-d of age) in the present study, than the weight differences (113 vs. 111 vs. 107 at 180-d of age) in the other studies.

Pig growth performance is affected by feed intake (Plusk and Williams, 1996). Since pigs housed in groups tend to eat at the same time, limited feeder space may lead to competition for feed (Baxter, 1983), and consequently may lead to reduced growth rate (Georgsson and Svendsen, 2002). In the present study, we hypothesized that competition at the feeder may partially contribute to reduced growth performance in pigs, especially for SG pigs. By imposing 2 feeder space treatments (2 vs. 5-space feeder), we attempted to test whether providing ample feeding space would allow SG pigs to consume more feed and grow at a faster rate. However, feeder space treatment did not affect BW at nursery exit (P = 0.18; Table 2), at 150 d of age (P = 0.97) and at 170 day of age (P = 0.73), and there were no interactions between feeder space treatment and pig growth rate category. Likewise, feeder space did not affect ADG between weaning and wk 5 (P = 0.55), wk 5 and wk 7 (P = 0.66), wk 7 and wk 9 at nursery exit (P = 0.73), and between wk 9 and 150 d of age (P = 0.33). One of the reasons for no effect of feeder space treatment could be low competition at the feeder in the present study. It appeared that providing 2 feeding spaces for 8 nursery pigs did not impose severe competition at the feeder, which was consistent with findings of Young and Lawrence (1994). Furthermore, all feeders used in the current study had dividers in the feeder trough which could protect pigs during eating, and consequently, alleviate some of the competition at the feeder (O'Connell et al., 2002).

Risk Factors for Mortality and Slow Growth

The results of univariate logistic regression analysis are shown in Table 3. When tested separately in the univariate model, birth weight, weaning weight, nursery exit

weight, and sex were identified risk factors for mortality or SG, with odds ratios different than 1 and were statistically significant ($P < 0.01$). Dam parity ($P = 0.09$), litter size ($P = 0.06$), and feeder space ($P = 0.05$) tended to be associated with increased risk of mortality or SG. No association was found between farrowing location and mortality or SG ($P > 0.10$).

Results from multivariate models are shown in Table 4. Birth weight, weaning weight, nursery exit weight, and sex were associated with mortality and SG ($P < 0.001$). The risk of dying or being SG was approximately 3.6 times greater (Confidence Interval = 2.00 to 6.64) for pigs with low birth weight (≤ 1.36 kg), 5.5 times higher (CI = 3.00 to 10.29) for pigs with low weaning weight (≤ 6.4 kg), and 17.8 times (CI = 8.00 to 39.91) higher for pigs with low nursery exit weight (≤ 20.0 kg). Gilts were approximately 2 times more likely to die or become SG compared with barrows. Pigs in 2-feeder space treatment were 1.8 times more likely to die or become SG compared with pigs in the 5-feeder space treatment.

The results of logistic regression further demonstrated that birth weight was not the only determining factor for slow growth in pigs. Compared with birth weight, weaning weight and nursery exit weight were better predictors for slow growing pigs. In a similar study, Douglas et al. (2013) reported that pigs weaned at less than 4.55 kg BW were 5.69 times more likely to become SG compared with pigs with heavier weaning weights. In fact, in the present study, 80% of the pigs that had low BW at weaning (less than 6.4 kg) became slow growing pigs at market age, and 88% of the pigs that had low nursery exit weight (less than 20.0 kg) became slow growing pigs at market age.

Previous studies found few differences in growth rates between barrows and gilts during the suckling and nursery periods (Skorjanc et al., 2007; Hyun and Ellis, 2000). Differences in growth performance between genders become significant when pigs reach 44kg (Friesen et al., 1994). In general, barrows have higher ADG compared with gilts during grower-finisher period (Wolter et al., 2002; Wolter and Ellis, 2001). Our results are in agreement with these findings and show that gilts were more likely to be slow growing pigs or die compared with barrows. However, there is evidence that barrows have lower chances of survival compared with gilts before weaning (Lay et al., 2001) and during the nursery period (Larriestra et al., 2006). It's speculated that this difference in survivability before weaning may be a result from higher testosterone and cortisol levels (Ruis et al., 1997) in newborn male pigs. But no explanations are available for nursery pigs. In the present study, it's observed that only 4 out of 18 pigs that died before marketing were gilts (data not shown). Therefore, the results shown are indicating higher possibility for gilts to become slow grower rather than being dead.

Although pigs from 2-feeder space treatment had higher likelihood of becoming SG pigs or dead, we did not observe any growth performance differences. Therefore, it is likely that the difference in mortality is a result from the 2-feeder space, because 12 out of 18 pigs that died before marketing were from 2-feeder space treatment whereas 6 out of 18 pigs that died were from the 5-feeder space treatment. Although competition among pigs could result in reduced growth performance, these negative effects are usually short-lived and negligible ((Pluske and Williams 1996). McGlone and Curtis (1985) and

Gonyou (1988) reported that a reduction in growth performance was only evident during the first one or two wk when competing for dominance after regrouping.

Plasma Hormone Concentrations

There was no difference in plasma GH concentration among pig growth rate categories at either nursery exit or the end of grower-finisher period ($P > 0.10$; Table 5). Roberta et al. (2001) reported that pigs with poor growth rate had similar GH basal levels in plasma compared with pigs with average growth rate. However, concentrations of GH can be affected by many factors, such as social stress (Buonomo and Baile, 1991), management and environment (Carroll et al., 1998). On the other hand, GH secretion occurs episodically (Arbona et al., 1988). Therefore, fixed or consecutive blood sampling over a long period of time is the preferred method to find differences in plasma GH concentrations (Mccusker et al., 1984). In the present study, blood samples were collected at only one time point during both nursery (approximately 63-d of age) and finishing (approximately 150-d of age) phases. In other studies, blood samples were collected at consecutive hours or days (Mccusker et al., 1984; Carroll et al., 1998). Therefore, using only one blood sampling time point may be one of the reasons that we did not detect differences in GH among pig growth rate categories.

In contrast to GH, plasma IGF-1 concentration was significantly different among pig growth rate categories at nursery exit ($P < 0.05$; Table 5), with SG pigs having the lowest IGF-1 concentrations compared with AG and FG pigs. The IGF-1 is considered a regulatory hormone in growth and development of muscle (Roberta et al., 2001). Unlike GH, which is secreted episodically, excess IGF-I that is not used may accumulate in the

blood. Thus, low IGF-1 concentration in the blood may reflect reduced growth and development of muscle in pigs.

Furthermore, the relationship between IGF-1 and GH can change with nutritional status of the animal. Under conditions of fasting or feeding diets that lack adequate amounts of protein or energy, IGF-1 levels decrease (Buonomo and Baile, 1991) and GH levels increase (Carroll et al., 1998). Merimee et al. (1982) observed that after 3-d of fasting, human subjects showed no change in serum IGF-1 in response to GH injections, and confirmed that an uncoupling between GH concentrations and GH action exists. This could be the underlying reason why we observed differences in plasma IGF-1 concentrations but not for GH concentrations among pig growth rate categories. It is possible that SG pigs might have experienced reduced energy and nutrient intake, resulting in reduced IGF-1 concentrations and slower growth compared with AG and FG pigs.

Slow growing pigs also had lower leptin concentrations than AG and FG pigs during the finishing period ($P < 0.001$; Table 5). There is evidence that plasma leptin concentrations are positively correlated with adiposity (Houseknecht and Portocarreo, 1998). Pigs with more adipose tissue generally have higher concentrations of leptin in plasma (Barb et al., 2001). In the current study, SG pigs had less BF compared with AG and FG pigs. Therefore, the lower leptin levels in SG pigs at the end of the finishing period were expected. At nursery exit, however, all pigs likely had very limited adipose tissue and the differences in plasma leptin concentrations among the pig growth rate categories were not evident as during the finishing period. In addition, low leptin

concentrations in plasma could be the result of food deprivation and negative energy balance (Ruiz-Cortes et al., 2000). Therefore, low plasma leptin concentrations in SG observed in the current study may be indicative of suboptimal nutrition, which may have been due to low feed intake.

Insulin concentrations differed among pig growth rate categories, with SG pigs having the lowest concentration of insulin compared with AG and FG pigs during both the nursery and finishing periods. The limited growth and development of SG pigs may result at least partly from low concentrations of insulin, since most cells of the body require insulin for adequate uptake of glucose and amino acids (Ryan et al., 2012). Without sufficient uptake of these metabolites, growth and development can be limited. In addition, there is evidence that decreased leptin mRNA in adipose tissue is associated with decreased plasma insulin concentrations (Barb et al., 2001). Therefore, low insulin concentrations can result in low leptin concentrations which in turn, affect lipid deposition in adipose tissue. In the current study, we observed reduced concentrations of insulin and leptin in SG compared with AG and FG pigs. These results suggest that low concentrations of insulin and leptin are associated with slow growth and can be used as indictors to identify SG at early stages.

There was no difference in any hormone concentrations measured between feeder space treatments at either nursery exit ($P > 0.10$; Table 6) or the end of growing-finishing period ($P > 0.10$). These results were consistent with the effect of feeder space treatment on growth performance.

Serum Amino Acid Concentrations

Serum free amino acids concentrations of different pig growth rate categories are shown in Table 7 and Table 8. Total serum free amino acids concentrations were lower for SG pigs compared with AG and FG during both nursery ($P < 0.05$; Table 7) and growing-finishing ($P < 0.05$; Table 8) phases. During the nursery phase, SG had the lowest concentrations of most essential amino acids, including Met, Lys, Arg, Trp, Thr, Leu, and Ile ($P < 0.05$). Meanwhile, serum concentrations of non-essential amino acids, including Tau, Pro, citruline, Tyr, Asp, and ornithine were lower for SG pigs ($P < 0.05$), compared with pigs in other growth categories. During the growing-finishing phase, no differences were observed in serum essential amino acids concentrations among pig growth categories ($P > 0.05$). However, serum concentrations of non-essential amino acids, including Pro, citruline and ornithine, and total AA concentration were lower for SG pigs ($P < 0.05$) compared with AG and FG pigs.

Serum AA concentrations are closely controlled and are subject to homeostasis (Wu, 2009). Serum AA concentrations at any particular time point of sampling are the result of interactions of many physiological processes. The rate of appearance in the serum is influenced by feed intake and AA release from the tissue. The rate of disappearance in the serum, on the other hand, is the result of AA metabolism, incorporations of AA into proteins, and losses in urine or feces (Cynober, 2002). Therefore, use of a single measurement of serum AA concentrations greatly limits our ability to interpret these effects on the complex systemic physiological characteristics of slow growing pigs. However, the low concentrations of several essential AA in SG pigs may reflect their reduced feed intake compared with AG and FG pigs during nursery

period. It is also possible that the low serum concentration of AA in SG was a result of increased rate of AA disappearance (Cynober, 2002), especially under stress situations such as immune challenges (Li et al., 2007).

Several amino acids, such as Arg, Gln, and Leu are secretagogues. For example, supplemental L-arginine (0.1 to 0.3 g/kg body weight over 20 min) can stimulate the secretion of growth hormone from their respective endocrine organs (Wu et al. 2008). Likewise, there is evidence that Gln and Leu can increase insulin release from pancreatic β - cells (Newsholme et al. 2005). These observations were supported by our data. In the current study, SG had the lowest serum concentrations of Gln and Leu compared with AG and FG, which coincided with their lower levels of insulin.

Amino acids also have an important role in immune function, and a deficiency may increase the susceptibility of animals to disease (Wu, 2009). Therefore, certain concentrations of these amino acids are required for these immune functions. For instance, catabolism of Trp is important for functions of macrophages and lymphocytes (Macchiarulo et al. 2008). On the other hand, the product of Pro metabolism, H_2O_2, has the function of killing pathogens and maintaining intestinal integrity (Shi et al. 2004). In the current study, SG pigs had the lowest serum concentrations of several of these functional AA, which may indicate impaired immune function of these pigs.

In summary, light weight at birth, weaning and nursery exit were risk factors for slow growth. Light weight at nursery exit was a better indicator for slow growth compared with light weight at birth or weaning. Slow growing pigs can be identified by reduced IGF-1 (107.63 vs. 147.24 ng/ml), insulin (6.94 vs. 14.95 ng/ml) and leptin

concentrations (3.55 vs. 6.06 ng/ml). In addition, SG pigs had lower concentrations of a number of serum AA, which may be indications of reduced feed intake and impaired immune functions. Gilts seem to be at higher risk of becoming SG than barrows. While providing ample feeder space during the nursery period did not affect growth performance of pigs, it tended to reduce risk of mortality.

Table 2-1. Effects of pig growth rate category on growth performance

Items	Pig category[1]				
	FG	AG	SG	Pooled SEM	*P*-value
Number of pigs	165	196	42	-	-
Body weight, kg					
At birth[2]	1.62[a]	1.48[b]	1.19[c]	0.18	<.001
At weaning[3]	8.2[a]	7.2[b]	5.5[c]	0.51	<.001
At nursery exit[4]	30.4[a]	23.9[b]	18.1[c]	1.99	<.001
At 150d of age[5]	114.4[a]	99.5[b]	82.5[c]	0.73	<.001
At 170d of age[6]	133.3[a]	116.5[b]	97.0[c]	0.72	<.001
ADG, kg					
Birth to weaning	0.252[a]	0.219[b]	0.168[c]	0.017	<.001
Weaning to 5 wk	0.273[a]	0.205[b]	0.145[c]	0.025	<.001
5 wk to 7 wk	0.391[a]	0.332[b]	0.255[c]	0.019	<.001
7 wk to nursery exit	0.688[a]	0.591[b]	0.486[c]	0.009	<.001
Weaning to nursery exit	0.636[a]	0.479[b]	0.358[c]	0.078	<.001
Grower-finisher[7]	0.943[a]	0.849[b]	0.724[c]	0.021	<.001
Growth Rate, kg/d of age					
Birth to weaning	0.313[a]	0.261[b]	0.197[c]	0.023	<.001
Birth to nursery exit	0.404[a]	0.343[b]	0.265[c]	0.010	<.001
Birth to market	0.739[a]	0.651[b]	0.549[c]	0.018	<.001
Carcass[8]					
BF, cm	2.30[a]	2.08[b]	1.84[c]	0.075	<.001
LMA, cm^2	41.76[a]	37.71[b]	31.99[c]	1.588	<.001

[a,b,c]Least square means within a row without a common superscript differ ($P < 0.05$).
[1]Pigs were categorized into three categories based on adjusted weight at 170-d of age: fast growing (FG) were greater than 125 kg, average growing (AG) were between 105 and 125 kg, and slow growing (SG) were less than 105 kg.
[2]Pigs were weighed individually within 24 h after birth.
[3]Pigs were weaned at approximately 4 wk of age (26-d).
[4]Pigs were kept in the nursery barn for 5 wk (35-d).
[5]Adjusted to 150 d based on formula: nursery exit weight + $ADG_{grower\text{-}finisher}$ × 89-d.
[6]Adjusted to 170 d based on formula: nursery exit weight + $ADG_{grower\text{-}finisher}$ × 109-d.
[7]From 9 wk of age to 22 wk of age.
[8]Backfat thickness (BF) and loin muscle area (LMA) at 10^{th} rib location were measured at the end of grower-finisher period using a real-time ultrasound machine.

Table 2-2. Effects of feeder space treatment on growth performance

Items	Feeder Treatment[1]			
	2-Space feeder	5-Space feeder	Pooled SEM	*P*-value
Number of pigs				
Body weight, kg				
At birth[2]	1.44	1.41	0.04	0.96
At weaning[3]	7.0	6.9	0.12	0.82
At nursery exit[4]	24.5	23.8	0.27	0.18
At 150d of age[5]	98.8	98.8	0.77	0.97
At 170d of age[6]	115.5	115.7	0.55	0.73
ADG, kg				
Birth to weaning	0.215	0.211	0.01	0.04
Weaning to 5 wk	0.214	0.201	0.03	0.55
5 wk to 7 wk	0.328	0.324	0.01	0.66
7 wk to nursery exit	0.590	0.586	0.02	0.73
Weaning to nursery exit	0.500	0.482	0.11	0.60
Grower-finisher[7]	0.835	0.843	0.01	0.33
Growth Rate, kg/d of age				
Birth to weaning	0.293	0.286	0.02	0.03
Birth to nursery exit	0.359	0.360	0.01	0.85
Birth to market	0.645	0.649	0.01	0.51
Carcass[8]				
BF, cm	2.11	2.10	0.049	0.99
LMA, cm^2	38.29	39.04	0.813	0.18

[1]Two feeder space treatments were imposed during the nursery period, including 2 feeder spaces per pen vs. 5 feeder spaces per pen. The 2-feeder space treatment was achieved by covering 3 spaces of the 5-space feeder.
[2]Pigs were weighed individually within 24 h after birth.
[3]Pigs were weaned at approximately 4 wks of age (26-d).
[4]Pigs were kept in the nursery barn for 5 wk (35-d).
[5]Adjusted to 150 d based on formula: nursery exit weight + $ADG_{grower\text{-}finisher}$ × 89-d.
[6]Adjusted to 170 d based on formula: nursery exit weight + $ADG_{grower\text{-}finisher}$ × 109-d.
[7]From 9 wk of age to 22 wk of age.
[8]Backfat thickness (BF) and loin muscle area (LMA) at 10^{th} rib location were measured at the end of grower-finisher period using a real-time ultrasound machine.

Table 2-3. Univariate odds ratios for mortality and risk of being lightweight at 170-d of age

Risk factors[1]	OR	95% CI	P-value
Birth weight (≤ 1.36 kg vs. > 1.36 kg)[2]	3.65	2.06 to 6.45	<0.0001
Weaning weight (≤ 6.40 vs. > 6.40 kg)[3]	6.43	3.52 to 11.72	<0.0001
Nursery exit weight (≤ 20.0 vs. > 20.0 kg)[4]	17.98	8.23 to 39.27	<0.0001
Sex (gilts vs. barrows)	2.27	1.28 to 4.02	0.005
Dam parity (1 vs. > 1)	1.64	0.92 to 2.89	0.09
Litter size (≤ 14 vs. > 14)	1.76	0.97 to 3.17	0.06
Farrowing location (group vs. crates)	1.12	0.63 to 2.01	0.70
Feeder space (2 feeder spaces vs. 5 feeder spaces)	1.75	1.00 to 3.06	0.05

[1]N = 448 pigs. Body weight less than 105 kg at 170-d of age was defined as light weight.
[2]Pigs were weighed individually within 24 h after birth.
[3]Pigs were weaned at approximately 4 wk of age (26-d).
[4]Pigs were kept in the nursery barn till 9 wk of age (35-d in nursery).

Table 2-4. Multivariate model on risk factors associated with slow growing pigs at 170-d of age

Risk factors	OR	95% CI	*P*-value
Trial (1 vs. 2)	0.38	0.20 to 0.73	0.003
Birth weight (≤ 1.36 kg vs. > 1.36 kg)[2]	3.64	2.00 to 6.64	<.0001
Weaning weight (≤ 6.40 vs. > 6.40 kg)	5.54	2.99 to 10.29	<0.001
Nursery exit weight (≤ 20.0 vs. > 20.0 kg)	17.76	7.90 to 39.90	<0.001
Sex (gilts vs. barrows)[3]	2.17	1.19 to 3.96	0.012
Dam parity (= 1 vs. > 1)	1.41	0.76 to 2.61	0.273
Litter size (small vs. large)	1.47	0.77 to 2.79	0.241
Feeder space (2 feeder spaces vs. 5 feeder spaces)	1.81	1.00 to 3.29	0.05

[1]N = 448 pigs. Body weight less than 105 kg at 170-d of age was defined as light weight.
[2]Weight at birth, weaning and nursery exit were included in the models separately due to high correlation. Odds ratio for weight at weaning was 5.54 (Confidence Interval = 2.99 to 10.29, $P < 0.001$), weight at nursery exit was 17.76 (CI = 7.90 to 39.90, $P < 0.001$).
[3]Odds ratio for sex in model included weaning weight was 2.14 (CI = 1.16 to 3.99, P = 0.015), in model included nursery exit weight was 2.69 (CI = 1.40 to 5.18, $P = 0.003$).

Table 2-5. Plasma hormone concentrations of fast-, average-, or slow-growing pigs during nursery and finishing periods

	Pig category[1]			Pooled	*P*-value
	FG	AG	SG	SEM	
Nursery period[2]					
Number of focal pigs	11	23	14		
Growth Hormone, ng/ml	20.9	19.6	20.8	0.89	0.92
IGF-1, ng/ml	147.24[a]	122.08[b]	107.63[b]	9.52	0.03
Leptin, ng/ml	3.13	2.75	2.87	0.24	0.56
Insulin, uU/ml	13.43[ab]	15.57[a]	11.29[b]	1.48	< 0.001
Grower-finisher period[3]					
Number of focal pigs	10	19	8		
Growth Hormone, ng/ml	23.42	25.36	23.56	1.06	0.92
IGF-1, ng/ml	143.5	133.1	132.6	9.8	0.45
Leptin, ng/ml	6.06[a]	5.25[b]	3.55[c]	0.35	< 0.001
Insulin, uU/ml	14.95[a]	14.19[a]	6.94[b]	1.37	< 0.001

[1]Pigs were categorized into three categories based on adjusted BW at 170-d of age: fast growing (FG) were greater than 125 kg, average growing (AG) were between 105 and 125 kg, and slow growing (SG) were less than 105 kg.
[2]Blood samples were collected from 48 focal pigs (consisting of 2 lightest and 2 heaviest pigs in each of the 12 randomly selected pens) at nursery exit.
[3]Blood samples were collected again from the aforementioned 48 pigs 1-d prior to market.

Table 2-6. Nursery and grower-finisher plasma hormone concentrations based on feeder space treatments.

	Feeder treatment[1]		Pooled	*P*-value
	2 Feeder spaces	5 Feeder spaces	SEM	
Nursery period[2]				
Number of focal pigs	23	25		
Growth Hormone, ng/ml	20.18	20.69	0.69	0.62
IGF-1, ng/ml	123.57	127.73	6.34	0.66
Leptin, ng/ml	2.88	2.95	0.22	0.81
Insulin, uU/ml	12.81	14.04	1.15	0.47
Grower-finisher period[3]				
Number of focal pigs	17	20		
Growth Hormone, ng/ml	24.48	23.75	0.84	0.53
IGF-1, ng/ml	140.87	131.88	7.73	0.41
Leptin, ng/ml	4.83	5.07	0.27	0.54
Insulin, uU/ml	12.94	11.11	1.4	0.36

[1]Two feeder space treatments were imposed during the nursery period, including 2 feeder spaces per pen vs. 5 feeder spaces per pen. The 2 feeder space treatment was achieved by covering 3 spaces of the 5-space feeder.
[2]Blood samples were collected from 48 focal pigs (consisting of 2 lightest and 2 heaviest pigs in each of the 12 randomly selected pens) at nursery exit.
[3]Blood samples were collected again from the aforementioned 48 pigs one day prior to market.

Table 2-7. Serum amino acid concentrations of fast-, average-, and slow-growing pigs during the nursery period[1]

	Pig category[2]				
Items	FG	AG	SG	Pooled SEM	*P*-value
No. pigs	12	23	12		
Essential AA, µM/mL					
Meth	85.8[a]	83.2[a]	44.3[b]	4.5	0.01
Lys	239.5[a]	235.1[a]	180.7[b]	13.7	0.05
Arg	249.6[a]	224.0[a]	158.6[b]	10.2	0.01
Trp	78.3[a]	68.8[a]	46.1[b]	5.6	0.01
Thr	337.3[a]	303.4[ab]	248.8[b]	21.9	0.01
Leu	235.0[a]	212.2[ab]	172.0[b]	13.3	0.01
His	95.7	89.5	72.9	7.7	0.30
Ile	114.4[a]	98.0[ab]	76.5[b]	7.1	0.01
Phe	95.3	90.7	80.2	5.3	0.38
Val	252.7[a]	210.2[ab]	168.0[b]	24.8	0.05
Nonessential AA, µM/mL					
Tau	135.1[a]	119.9[a]	72.4[b]	8.1	0.01
Pro	370.0[ab]	381.2[a]	311.2[b]	14.1	0.04
Citrulline	50.6[ab]	56.1[a]	45.0[b]	3.2	0.07
Try	153.5[a]	156.1[a]	112.9[b]	10.3	0.01
Asp	223.5[ab]	239.3[a]	184.5[b]	16.2	0.02
Ornithine	160.5[a]	139.7[a]	120.2[b]	9.0	0.01
Ala	637.2	667.7	582.9	33.4	0.15
Ser	188.4	195.5	162.0	12.5	0.23
Gln	614.6	636.1	587.6	21.5	0.41
Gly	996.0	1149.3	1108.5	62.4	1.00
Glu	290.2	239.5	261.3	19.3	0.88
Asx	19.5	17.6	18.9	1.9	0.99
Total AAs	5622.7[a]	5612.9[a]	4815.4[b]	204.0	0.02

[a,b,c]Least square means within a row without a common superscript differ (P < 0.05).

[1]Blood samples were collected at nursery exit at 9 wk of age

[2]Pigs were categorized into three categories based on adjusted weight at 170-d of age: fast growing (FG) were greater than 125kg, average growing (AG) were between 105 and 125 kg, and slow growing (SG) were less than 105 kg.

Table 2-8. Serum amino acid concentrations during at the end of the finishing period[1].

Items	Pig category[2]				
	FG	AG	SG	Pooled SEM	*P*-value
Number of pigs	12	23	12		
Essential AA, µM/mL					
Meth	19.2	22.9	19.2	7.2	0.90
Lys	93.2	90.1	66.2	16.6	0.85
Arg	116.1	131.2	92.4	16.4	0.91
Trp	70.4	74.8	59.0	6.5	0.81
Thr	222.0	224.0	161.0	18.1	0.36
Leu	173.9	177.0	133.5	15.4	0.43
His	107.8	107.2	86.7	7.5	0.37
Ile	61.8	61.7	54.5	8.2	0.99
Phe	82.2	82.9	71.8	6.4	0.85
Val	277.4	279.4	217.1	21.5	0.51
Nonessential AA, µM/mL					
Tau	73.7	91.0	63.0	13.1	0.46
Pro	272.8[a]	267.6[a]	173.0[b]	22.8	0.01
Citrulline	39.1[ab]	45.4[a]	30.4[b]	3.9	0.02
Try	98.2	103.1	89.1	11.6	0.92
Asp	90.2	93.6	55.6	15.9	0.36
Ornithine	101.6[ab]	102.1[a]	69.8[b]	7.8	0.04
Ala	290.0	340.0	274.0	27.6	0.55
Ser	145.9	146.5	109.5	14.5	0.26
Gln	383.2	427.4	370.7	24.8	0.38
Gly	866.2	1002.2	891.3	73.5	0.81
Glu	86.5	116.6	90.8	18.8	0.86
Asx	9.8	11.0	5.2	2.3	0.29
Total AAs	3681.1[ab]	3997.6[a]	3183.7[b]	235.5	0.05

[a,b,c]Least square means within a row without a common superscript differ (P < 0.05).

[1]Blood samples were collected at the end of Growing-Finishing (GF) period at 22 weeks of age.

[2]Pigs were categorized into three categories based on adjusted weight at 170 d of age: Fast Growers (FG) were greater than 125kg, Average Growers (AG) were between 105 and 125 kg, and Slow Growers (SG) were less than 105 kg.

CHAPTER 3 : BEHAVIORAL INDICATORS OF SLOW GROWTH IN NURSERY PIGS

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SUMMARY

In all-in-all-out production systems, pigs that cannot reach market weight at a desired age are sold at much lower value than their contemporaries. Recognizing and addressing this problem early is essential for optimizing profitability in commercial pork production systems. The objectives of this study were to identify behavioral characteristics and to assess the effect of feeder space on behavior of slow growing pigs. Nursery pigs (n = 592) were housed in pens of 8, with either a 2-space feeder or a 5-space feeder in each pen. Behavior of pigs in 24 pens (12 pens randomly selected for each feeder space treatment) was video-recorded during the first 4-d entering nursery and on d 21 in the nursery, respectively. In addition, rate of feed consumption was measured on 96 focal pigs, consisting of the 2 heaviest and 2 lightest BW pigs from each of 24 video-recorded pens at 9 wk of age. Pigs were categorized as slow growers (SG) and fast growers (FG) based on their market weight adjusted to 170 d of age (SG < 105 kg; FG ≥ 105 kg). Data were analyzed using the Mixed Procedure of SAS to compare behavioral differences between the pig growth rate categories. Logistic Regression Procedure of SAS was used to evaluate contributions of risk factors to the likelihood of pigs expressing eating, lying and standing behaviors. There was no difference between SG and FG pigs in rate of feed consumption and time spent eating, lying, standing, and fighting ($P > 0.10$). However, SG pigs spent more time drinking (1.1% vs. 0.9%, SE = 0.06%, $P < 0.05$) than FG pigs. Compared with pigs from 2-space feeders, pigs from 5-space feeders spent less time standing (9.2% vs. 9.7%, SE = 0.6%, $P < 0.05$) and more time eating (5.0% vs. 4.7%, SE = 0.2%, $P < 0.05$). Moreover, SG pigs provided with access to 5-space feeders

spent less time standing (8.7% vs. 9.9%, SE = 0.7%, $P < 0.05$), and tended to spend more time lying (84.7% vs. 83.9%, SE = 0.59%, $P = 0.08$) compared with SG pigs provided with 2-space feeders. Feeder space did not affect feed consumption rate ($P > 0.10$) of the pigs. These results suggest that adjunctive behaviors such as standing and drinking may be indicators of slow growth. Providing more feeder space may benefit SG pigs and improve welfare of these pigs due to decreased standing time and increased lying time.
Key words: behavior, eating rate, pigs, slow growth

INTRODUCTION

In all-in-all-out production systems, pigs that cannot reach the desired market BW by a certain age are usually sold at much lower value than their contemporaries. Theses pigs are often referred to as slow growing pigs. While slow growing pigs cause economic losses for pork producers, they also raise animal welfare concerns, especially in competitive conditions. For instance, Krauss and Hoy (2011) reported that slow growing pigs were denied more often from the prime rest areas compared with heavy pigs. Moreover, slow growing pigs are often displaced by heavy pigs from the feeder when feeder space is restricted (Gonyou and Lou, 2000), resulting in more disturbed meals during the peak feeding hours compared with heavy BW contemporaries in the pen (Averós et al., 2014). Consequently, slow growing pigs spend more time eating during the nighttime hours when the competition at the feeder is low (Young and Lawrence, 1994; Walker, 1991; Nielsen and Lawrence, 1993).

One strategy to alleviate competition at the feeder is to provide ample feeder space to pigs in a pen. Feeder space allowance determines pigs' feeding behavior (Averós

et al., 2014). For instance, when pigs in a pen are fed together and have limited access to the feeder, they increase their feeding rate and reduce the duration of visits to the feeder (Brumm and Gonyou, 2001). However, since slow growing pigs are less competitive at the feeder compared with their heavier counterparts in the pen, they may not be able to use the same behavior as heavy pigs to cope with the competition. As a result, slow growing pigs may have inadequate nutrient intake, and consequently, this may further exaggerate the growth difference between different pig growth rate categories.

To understand slow growth and its welfare implications, we need to examine the behavior of individual pigs within a group to identify differences between slow growing pigs and their heavier contemporaries. Therefore, the objectives of this study were 1) to identify the behaviors that may contribute to slow growth in pigs, 2) to assess the effect of feeder space allowance during the nursery period on behavior of slow growing pigs, and 3) to evaluate the welfare of slow growing pigs using behavioral indicators.

MATERIALS AND METHODS

The protocol of this study was reviewed and approved by the University of Minnesota Institutional Animal Care and Use Committee (Protocol No. 1302-30358A).

Animals, Housing and Management

This study was conducted at the swine unit of the University of Minnesota's West Central Research and Outreach Center in Morris, MN. The nursery facility of the swine unit had two identical rooms and each room had 32 pens (2.4 m × 1.2 m). Each pen accommodated 8 pigs and was equipped with a 5-space dry feeder (Hog Slat Inc.,

Blooming Prairie, MN) and a cup drinker located on slotted plastic flooring. Floor space allowance was 0.34 m^2/pig, excluding the space occupied by the feeder. Room temperature was controlled by exhaust fans and heaters to provide environmental conditions within the thermoneutral zone for nursery pigs. Light period was 8 h beginning at 0730 h, and an emergency light was on during the dark period beginning at 1530 h. Each room had windows that provided natural light during daylight hours.

All pigs received diets that were formulated to meet or exceed their nutritional requirements based on the NRC (2012) recommendations. Pigs were observed once daily to ensure that they had free access to feed and water and were in good health.

Experimental Design

This study consisted of 2 trials. The first trial was conducted between March and September 2013, and the second trial was conducted between June and December 2013. Each trial consisted of pigs that were born to 30 to 35 sows within one week. To evaluate whether ample feeder space could alleviate competition at the feeder and improve performance of slow growing pigs at an early age, 2 feeder space treatments were imposed during the nursery period: 2-space feeder per pen (control) vs. 5–space feeder per pen (ample). The 2-space feeder was achieved by covering 3 spaces of the 5-space feeder. The area of each feeding space measured 15 cm × 15 cm. With 8 pigs in each pen, the 2-space feeder accommodated 4 pigs/feeder space and the 5-space feeder accommodated 1.6 pigs/feeder space. During each trial, feeder openings were set at the the same level so that feeder pan coverage (the percentage of feeder trough covered by feed; Simth et al., 2004) was similar cross pens.

Pigs were sorted by weight and sex at weaning at 4-wk of age. Within each sex and weight category, pigs were randomly allocated to pens to achieve an equal number of barrows and gilts in each pen, with similar mean weight and variation (coefficient of variation) within a pen between the 2 feeder space treatments. Pigs remained in their designated pens for 5 wk until they were 9 wk of age. Then, an equal number of pigs from each feeder space treatment were moved to a grower-finisher hoop barn and remained there until they reached desired market weight. Based on their differences in growth rate, pigs in each trial were marketed twice, approximately at 150 d and 170 d of age when they reached about 115 kg. For any pigs that were removed from the study due to poor health, the age of the pig and reason for removal were recorded. Mortality and treatment were recorded throughout the entire study.

Data Collection

Behavioral time budget. In each trial, 6 pens of the 5-space feeder treatment and 6 pens of the 2-space feeder treatment were randomly selected for behavioral data collection during the nursery period. Pens for video-recording were evenly distributed between the two rooms, resulting in 3 pens of 5-space feeder treatment and 3 pens of 2-space feeder treatment being selected from each room.

Behavioral activities of pigs were video-recorded using Hi-Res Bullet Cameras (Hi-Res Bullet Cams 2505, Sony, Taiwan) at the speed of 12 frames/s. All cameras were connected to a computer equipped with a time-lapse DVR device and video-recording software (Geo Vision Multicam Digital Surveillance System V8.2; USA Vision Systems Inc., Irvine, CA). Video-recording took place for 4-d immediately after weaning, and

again at 21-d for 24 h after moving into the nursery. Before video-recording began, and then every 24 h during recording, all pigs in the video-recording pens were marked using livestock marking crayons with different patterns on their backs for individual identification under the camera.

The video-recordings were viewed using the scan sampling method (Martin and Bateson, 2007) to estimate time budget of behaviors of interest for each individual pig. Behaviors of interest included eating, drinking, standing/walking, lying, fighting, belly nosing, and feeder replacement. Since the incidence of belly nosing and feeder replacement was very low (<1%), these two behaviors were removed from data analysis. Fighting behavior was defined as a pig's aggression toward another pig involving pressing, knocking, and biting (Bornett et al., 2000). Eating was defined as pig's head in the feeder for more than 5 seconds consuming feed. Drinking was defined as pig's head in the cup-drinker for more than 2 seconds. Standing or walking was defined as pigs standing up on four legs and remaining still or moving. Lying was defined as pigs recumbent on its belly or side on the floor or pigs sitting on fore-legs and hind quarters on the floor (Morrison et al., 2003). These behaviors were mutually exclusive.

Video-recordings were scanned at a fixed interval of 5 min, resulting in 288 scan samples for each pig in a 24 h period. However, due to the disturbance to pigs by the researchers marking pigs for individual identification, and farm staff conducting routine daily animal health check, one hour scan samples (12 scans) were discarded afterwards, and 276 scan samples for each 24 h were used in data analysis. At each scan, the observers recorded the behavior that each pig in a pen was performing. Specifically, for

each sampling point, a record was made of whether or not a given behavior occurred. A score was then calculated and expressed as the proportion of all sampling points on which the behavior occurred. For example, if a behavior occurred on 40 out of 288 sampling points for the 24 h at 5-min intervals, the score would be 40/288 = 0.138, resulting in the behavioral time budget of 13.8% (Martin and Bateson, 2007).

Since two observers were trained and performed data collection from the video-recordings, variability between-observers was estimated to evaluate inter-observer errors. To do this, the two observers viewed the same 24 h video-recording selected randomly, and scan-sampled all behaviors of interest. The maximal inter-observer discrepancy was less than 5%. As a result, the data were considered consistent between the observers, and the observer factor was not included in further data analysis.

Feed consumption rate. Eating rate or feed consumption rate was assessed to investigate the effect of feeder space treatment on eating behavior of pigs, and whether pigs of different growth rate categories ate at different rates. For the two trials, a total of 96 focal pigs were selected at 9 wk of age in the nursery barn. In each trial, 4 focal pigs from each of 12 pens selected for video-recording (6 pens of 2-space feeder treatment and 6 pens of 5-space feeder treatment) were selected. In order to include both slow and fast growing pigs, the 2 heaviest and 2 lightest BW pigs were identified as focal pigs from each pen, with one barrow and one gilt in each category.

To standardize the satiation status of the pigs on the test day, light was turned on at 0630 h and all pigs were allowed to eat until 0730 h. Then, focal pigs from the same pen were moved to a holding pen in the same room. The holding pens were identical to

their home pens and a cup drinker as well as a 5-space feeder was provided in each pen. Focal pigs had access to water at all times, however, there was no feed in the feeder for 5 h in the holding pens. A feed bag containing 100 (± 7) g of the same feed provided in their home pens was prepared for each pig. During the tests, each pig was introduced into an empty test pen (same as holding pens) and the pre-weighed feed was placed in the feeder. The pig was allowed to eat for about 3 min. As soon as the pig started eating, an observer recorded total duration of eating for the pig with a stop watch. Eating was considered to start when the pig had its head in the feeder consuming feed. When the pig's head was out of the feeder and it stopped chewing, the eating bout was considered to end. A test for each individual pig often consisted of several eating bouts to achieve the accumulated total duration of eating up to 2 to 3 min. After the test, each pig was moved back to its home pen, and feed remaining in the feeder of the test pen was vacuumed and weighed. Eating rate for each pig was calculated based on the amount of feed consumed and the time the pig spent eating.

Statistical Analysis

Data of behavioral time budget and feed consumption rate were analyzed using the Mixed Procedure of SAS (Version 9.3, SAS Institute, Cary, NC), where individual pig served as the experimental unit. The model included feeder space treatment (2 vs. 5 feeder spaces), pig growth rate category (SG vs. FG), and their interaction as fixed effects. Room and trial were used as random effects. Behavioral time budget data over the 5-d of the recording period were summarized for each day. Then interactions of observation day by feeder space treatment or pig growth rate category were tested. Since

no significant interaction was detected, effect of observation day on time budget for each behavior was tested separately from the effect of feeder space treatment and pig growth rate category. All differences between means were tested by PDIFF option with the Tukey adjustment. Significant differences were identified at $P < 0.05$ and trends at $P < 0.10$.

The Logistic Procedure of SAS was used to evaluate the contribution of risk factors to the likelihood of pigs expressing eating, lying and standing behavior. Risk factors included feeder space treatment, pig growth rate category and days in the nursery. Since all variables in the model were categorical, odd ratios and 95% confidence intervals were used to evaluate each risk factor.

RESULTS

Over the 5-d of the recording period, pigs from 5-space feeder treatment spent more time eating ($P = 0.05$; Table 1) and less time standing ($P = 0.02$) than pigs from 2-space feeder treatment. Feeder treatment did not affect other behaviors measured ($P > 0.22$). Compared to FG pigs, SG pigs spent more time drinking ($P < 0.001$). No differences in eating, lying, standing, and fighting behavior were observed between the pig growth rate categories ($P > 0.10$). However, there was an interaction of feeder space treatment and pig growth category on standing ($P = 0.01$), with SG pigs from 5-space feeder treatment spending less time standing compared with SG pigs from 2-space feeder treatment. In addition, feeder space treatment and pig growth rate category tended to interact on lying behavior ($P = 0.08$), with SG pigs from 5-space feeder treatment tending to spend more time lying than SG pigs from 2-space feeder treatment.

Pigs increased eating time gradually from d 1 to d 4 (from 2.2% to 4.8%, SE = 0.2; $P < 0.05$; Table 2) after weaning in the nursery facility. On d 21 after entering the nursery rooms, pigs spent more time eating ($P < 0.05$) than any other day of the recording period. Likewise, pigs increased lying time gradually from 78.9% on d 1 to 87.9% on d 4 (SE = 0.6; $P < 0.05$), and then decreased to 82.4% on d 21. In contrast to time spent eating and lying, time spent standing, fighting and drinking decreased gradually from d 1 to d 4 ($P < 0.05$), respectively. There was no difference in pigs standing, drinking, or fighting between d 21 and d 3. On d 21, there was minimal incidence of fighting observed (0.9%, 0.6%, 0.3%, 0.2%, and 0.1% at d 1, 2, 3, 4 and 21, respectively).

The diurnal pattern of eating behavior on d 21 is presented in Fig. 1. It appears that SG pigs delayed their peak eating time compared with FG pigs. The pattern of lying behavior on d 21 is presented in Fig. 2. Overall time budget for lying was not different between SG and FG pigs, except that SG pigs appeared to spend more time lying from 1100 h to 1300 h, which is when they spent less time eating compared with FG pigs.

The logistic regression analysis revealed that pigs were less likely to eat on d 1, d 2, d 3 and d 4 compared with d 21 (OR = 0.18, 0.35, 0.43, 0.47, respectively). However, no differences were observed in eating behavior between FG and SG pigs (OR = 1.06, CI = 1.01 to 1.11) or between the two feeder treatments (OR = 1.02, CI = 0.99 to 1.06). Likewise, the odd ratios for lying behavior were both close to 1 for 5-space feeder vs. 2-space feeder (OR = 1.01, CI = 0.99 to 1.04) and for SG vs. FG (OR = 1.02, CI = 0.99 to 1.04), indicating that neither feeder treatment nor pig growth rate category affected lying behavior. Pigs were less likely to lie on d 1 compared with d 21 (OR = 0.84, CI = 0.81 to

0.86), but more likely to lie on d 4 compared with d 21 (OR = 1.59, CI = 1.53 to 1.64). In contrast, pigs were more likely to stand on d 1 compared with d 21 (OR = 2.46, CI = 2.36 to 2.56), and less likely to stand on d 4 compared with d 21 (OR = 0.85, CI = 0.82 to 0.90).

Feeder space treatment did not affect eating rate (P = 0.37; Table 4). In addition, eating rate did not differ between FG and SG pigs (*P* = 0.19). There was no interaction of feeder space treatment and pig category on eating rate (*P* = 0.16).

DISCUSSION

Pigs prefer to eat simultaneously with their contemporaries (Hsia and Wood-Gush, 1984; Nielsen et al. 1996). However, during feeding peak when feeder spaces are all occupied, some pigs, especially small pigs, wait until others finish feeding (Brouns and Edwards, 1994). In the current study, we hypothesized that pigs in the 2-space feeder treatment may have limited access to the feeders, and consequently, may have to compete for feed at the feeder. Therefore, pigs in the 2-space feeder treatment may use different feeding behaviors to achieve the same level of feed intake as pigs in 5-space feeder treatment. A previous study (Botermans and Svendsen, 2000) demonstrated that restricted access to the feeder resulted in altered feeding patterns in pigs. However, this changed feeding pattern may be at the cost of animal well-being. In the present study, we found that pigs from the 2-space feeder treatment spent more time standing compared with pigs from 5-space feeder treatment. In addition, SG pigs from the 2-space feeder treatment spent more time standing than SG pigs from 5-space feeder treatment, and there was no difference in standing behavior of FG pigs between the two feeder space treatments.

Furthermore, SG pigs were also found to spend more time drinking compared with FG pigs. These differences may indicate that SG pigs were coping with increased competition at the feeder with a high occurrence of adjunctive behaviors, such as walking, standing or queuing, and water drinking. An adjunctive behavior was defined by psychologists to be the extra, concurrent behavior when a certain schedule was induced (Falk, 1971). For instance, in the experiment by psychologist John Falk, laboratory rats were fed pellets and were obliged to wait one minute before another press of the lever to receive pellets. Under such conditions, the rats developed the habit of drinking water during these intervals (Falk, 1971). Pregnant sows are usually restrictively fed and they remain hungry for almost the entire day. If a water dispenser is available, sows will drink 2 to 3 times their normal daily intake. In this case, much of the sows' water intake appeared to be adjunctive drinking that was not related to thirst (Robert et al., 1993). Studies have shown that under such circumstance, pigs exhibit these behavior as means to reduce their anxiety or dissipate tension (Dantzer and Mormede, 1981; Dantzer and Mormede, 1983).

Due to the circadian rhythm of pigs, the restriction on feeder access may not only affect their competition for feed, but also their feeding schedule. Therefore, before the study, we hypothesized that SG pigs' feeding pattern would be different than that of FG pigs, because of their unwillingness to feed at night. More specifically, SG pigs may be forced to adapt themselves to the increased competition by shifting their feeding toward night time hours. During the first 4 d after weaning, eating pattern was not established and no differences in diurnal pattern of eating for both pig growth rate categories was

observed. On d 21, however, we observed that SG pigs delayed their eating peak until noon and early afternoon. During the same time period, SG pigs spent more time lying than FG pigs. The difference in lying behavior between SG and FG pigs from 1100 h to 1300 h should be examined together with the differences in eating behavior, which may be explained by social facilitation. Social facilitation is defined as an increase in the frequency of responses, when exhibited in the presence of others engaged in the same behavior (Hsia and Wood-gush, 1983). Eating is socially facilitated behavior and pigs will begin eating when others are already eating. In the current study, SG pigs had a reduced eating time budget compared with FG pigs, and this could be interpreted as SG pigs didn't start eating until FG pigs initiated eating. On the other hand, we did not observe increased eating time during the night time hours for SG pigs, and we did not find differences in time spent eating between FG and SG pigs. The reasons for lack of differences in eating behavior between FG and SG pigs might be that in the present study, pigs were defined as slow or fast growers based on their final market weight. And at the time when we observed their behavior, FG and SG pigs had similar weights (14.0 kg for FG vs. 12.9 kg for SG). Slow growing pigs were only slightly at a physical disadvantage when competing for feed with FG pigs during the recording period, and may not have been great enough to affect their total eating time. As a result, the time budget for eating behavior between FG and SG pigs were fairly similar. These results suggest that the total time budget for eating behavior during the nursery period may not be a good indicator for slow growth.

Increased eating rate in pigs is considered the result of constraint. When animals experience restricted feeding, the constraint on feeding environment could have a long-term effect on eating rate and increase the feeding rate in these animals (Nielsen, 1998). Therefore, we expected a higher feed consumption rate in pigs from the 2-feeder space treatment (e.g. restricted feeder) than from pigs from 5-feeder space treatment. However, we did not detect such differences in eating rate between two feeder space treatments. It is possible that pigs in our study may be eating at faster rate during the feed consumption rate test than the rate they normally eat in their home pens. This may have occurred because the focal pigs were restricted from feed access for 5 h in order to standardize satiety, and therefore, they may have had elevated feeding motivation. Pigs were then tested individually without constraint and competition, which potentially may have caused them to exhibit a maximum eating rate. Therefore, the high feeding motivation may have mask the effect of feeder space treatments. In fact, pigs in the current study did eat faster than pigs in other studies. For example, Quiniou et al. (1999) reported that the rate of feed intake for individually housed pigs weighing 23.2 kg was 12.2 g/min. The body sizes of FG and SG pigs in the present study were similar to those reported by Quiniou et al. (1999). On average, pigs in the current study ate at the rate of 17 to 24 g/min, which was higher than the results of Quiniou et al. (1999). In addition, we did not detect a difference in eating rate between FG and SG pigs. Pigs' eating rate is largely a reflection of body size, including the capacity of the mouth (Illius and Gordon, 1987). This may explain why no differences in eating rate between the pig growth rate categories was observed in the current study.

The logistic regression analysis showed a significant difference between d 21 and first 4-d after weaning in the likelihood of eating behavior of pigs. Pigs were more likely to eat at d 21 compared with pigs at d 1 to d 4, indicating that pigs adapted to weaning and had more frequent use of the feeders at d 21 compared to d 1 to d 4. As pigs continue to grow, feeding patterns can change. Nursery pigs have smaller meals and visit the feeder more frequently compared to grower-finisher pigs (Bigelow and Houpt, 1988; Nielsen, 1995).

In summary, no differences were observed between SG and FG pigs in eating rate. Furthermore, no differences were observed in time spent eating, lying, and fighting between SG and FG pigs, suggesting that these behaviors may not be used as indicators of slow growth. However, adjunctive behaviors, such as standing and drinking, may be good indicators for slow growing pigs under constraints. Providing more feeder space reduced time spent standing, and tended to increase time spent lying by SG pigs, indicating that SG pigs may benefit from more feeder space and have improved welfare.

Table 3-1. Effect of feeder treatment, pig category and their interaction on behavioral time budget for nursery pigs

Items	Treatment[1]		Category[2]		Treatment × Category				Pooled SEM	*P* - Value		
					2-feeder space		5-feeder space					
	2-feeder space	5-feeder space	FG	SG	FG	SG	FG	SG		Treatment	Category	Interaction
Number of pigs	87	104	152	39	67	20	85	19	-	-	-	-
Body weight, kg	13.73	13.75	13.98	12.86	14.11	12.46	13.87	13.27	2.62	-	-	-
Eating, %[3]	4.7	5.0	4.8	4.9	4.7	4.7	4.9	5.1	0.18	0.05	0.61	0.66
Lying, %[4]	84.1	84.3	84.2	84.3	84.4	83.9	84.0	84.7	0.59	0.53	0.91	0.08
Standing, %[5]	9.7	9.2	9.6	9.3	9.6[ab]	9.9[a]	9.7[ab]	8.7[c]	0.66	0.02	0.75	0.01
Fighting, %[6]	0.4	0.4	0.5	0.3	0.5	0.3	0.5	0.4	0.07	0.22	0.25	0.96
Drinking, %[7]	1.0	1.0	0.9	1.1	0.9	1.1	0.9	1.1	0.06	0.55	<.0001	0.82

[1]Two feeder space treatments were imposed during the nursery period, including 2 feeder spaces per pen vs. 5 feeder spaces per pen. The 2 feeder space treatment was achieved by covering 3 spaces of the 5-space feeder.
[2]Pigs were categorized into two categories based on adjusted weight at 170 d of age: Fast Growing (FG) were greater than 105kg, and Slow Growing (SG) were less than 105 kg. Pigs died during nursery were also defined as SG.
[3]Eating behavior was defined as pigs' head in the feeder for more than 5 seconds consuming feed.
[4]Lying or sitting behavior was defined as pigs in resting position on the floor or pigs sitting on fore-legs and hind quarter on the floor.
[5]Standing or walking behavior was defined as pigs standing or walking on four legs.
[6]Fighting behavior was defined as a pig's aggression towards another pig involving parallel pressing, head-to-head knocking and biting, or head-to-body knocking and biting.
[7]Drinking behavior was defined as pigs' head in the waterer for more than 2 seconds.

Table 3-2. Behavioral time budget change during first four consecutive days and 21st day in nursery

	Day[1]						
Items	1	2	3	4	21	Pooled SEM	*P* - value
Number of pigs	191	191	191	191	190	-	-
Eating, %[2]	2.2[d]	3.9[c]	4.4[b]	4.8[b]	9.0[a]	0.2	<.0001
Lying, %[3]	78.9[d]	85.0[b]	87.0[a]	87.9[a]	82.4[c]	0.6	<.0001
Standing, %[4]	16.6[a]	9.3[b]	7.5[c]	6.3[d]	7.6[c]	0.5	<.0001
Fighting, %[5]	0.9[a]	0.6[b]	0.3[c]	0.2[c]	0.1[c]	0.1	<.0001
Drinking, %[6]	1.4[a]	1.1[b]	0.8[c]	0.8[c]	0.9[c]	0.1	<.0001

[1]Behavior data was continuously recorded for 24 h for a total of 5 days, on the first 4 consecutive days after pigs were weaned and mixed in the nursery, and the 21st day in nursery.
[2]Eating behavior was defined as pigs' head in the feeder for more than 5 seconds consuming feed.
[3]Lying or sitting behavior was defined as pigs in resting position on the floor or pigs sitting on fore-legs and hind quarter on the floor.
[4]Standing or walking behavior was defined as pigs standing or walking on four legs.
[5]Fighting behavior was defined as a pig's aggression towards another pig involving parallel pressing, head-to-head knocking and biting, or head-to-body knocking and biting.
[6]Drinking behavior was defined as pigs' head in the waterer for more than 2 seconds.

Table 3-3. Factors associated with pigs eating, lying and drinking behavior.

Response variable[1]	**Factors**	Odds ratio	95% Confidence interval	*P*-value
Eating behavior[4]	Treatment (2- vs. 5-feeder space)[2]	1.02	0.99 to 1.06	0.20
	Category (SG vs. FG)[3]	1.06	1.01 to 1.11	0.01
	Day, d 1 vs d 21	0.18	0.17 to 0.20	<.0001
	d 2 vs d 21	0.35	0.33 to 0.37	<.0001
	d 3 vs d 21	0.43	0.40 to 0.45	<.0001
	d 4 vs d 21	0.47	0.45 to 0.49	<.0001
Lying behavior[5]	Treatment (2- vs. 5-feeder space)	1.01	0.99 to 1.04	0.20
	Category (SG vs. FG)	1.02	0.99 to 1.04	0.24
	Day, d 1 vs d 21	0.84	0.81 to 0.86	<.0001
	d 2 vs d 21	1.33	1.28 to 1.37	<.0001
	d 3 vs d 21	1.46	1.42 to 1.51	<.0001
	d 4 vs d 21	1.59	1.53 to 1.64	<.0001
Standing behavior[6]	Treatment (2- vs. 5-feeder space)	0.97	0.94 to 0.99	0.02
	Category (SG vs. FG)	0.93	0.90 to 0.96	<.0001
	Day, d 1 vs d 21	2.46	2.36 to 2.56	<.0001
	d 2 vs d 21	1.23	1.18 to 1.28	<.0001
	d 3 vs d 21	1.03	0.98 to 1.07	<.0001
	d 4 vs d 21	0.85	0.82 to 0.90	<.0001

[1]All logistic models included feeder treatment, pig category and day as main effects.
[2]Feeder treatments included uncovered feeders (Uncovered) and covered feeders (Covered). The Uncovered feeder was a standard 5-space feeder provided for 8 nursery pigs per pen. The Covered feeder was a 2-space feeder provided for 8 pigs per pen by covering 3 spaces of the 5-space feeder.

[3]Pigs were categorized into two categories based on adjusted weight at 170 d of age: Fast Growing (FG) were greater than 105kg, and Slow Growing (SG) were less than 105 kg. Pigs died during nursery were also defined as SG.
[4]Eating behavior was defined as pigs' head in the feeder for more than 5 seconds consuming feed.
[5]Lying or sitting behavior was defined as pigs in resting position on the floor or pigs sitting on fore-legs and hind quarter on the floor.
[6]Standing or walking behavior was defined as pigs standing or walking on four legs.

Table 3-4. Effect of pig category and feeder treatment on eating rate of pigs at 9 wk of age

Items	Treatment[1]		Pig category[2]		Treatment × Pig category				Pooled SEM	P-value		
					Covered		Uncovered					
	2-feeder space	5-feeder space	FG	SG	FG	SG	FG	SG		Treatment	Category	Interaction
Number of pigs[3]	46	44	76	14	34	8	39	5	-	-	-	-
Body weight, kg	22.3	22.8	23.2	19.2	23.5	17.3	23	21.7	5.32	-	-	-
Eating speed, g/min[4]	16.08	17.43	17.8	15.72	18.18	13.99	17.42	17.45	1.589	0.37	0.19	0.16

[1]Two feeder space treatments were imposed during the nursery period, including 2 feeder spaces per pen vs. 5 feeder spaces per pen. The 2 feeder space treatment was achieved by covering 3 spaces of the 5-space feeder.
[2]Pigs were categorized into two categories based on adjusted weight at 170 d of age: Fast Growing (FG) were greater than 105kg, and Slow Growing (SG) were less than 105 kg. Pigs died during nursery were also defined as SG.
[3]Focal pigs consisted of 2 heaviest and 2 lightest within a pen from 24 pens at approximately 65 d of age. 6 pigs were excluded because of lacking motive to eat.
[4]Each individual pig was provided with 100 ± 7 gram of feed. And pigs were allowed to eat for 3 min.

Figure 3-1. Eating behavior time budget at day 21 between slow growing pigs and fast growing pigs.

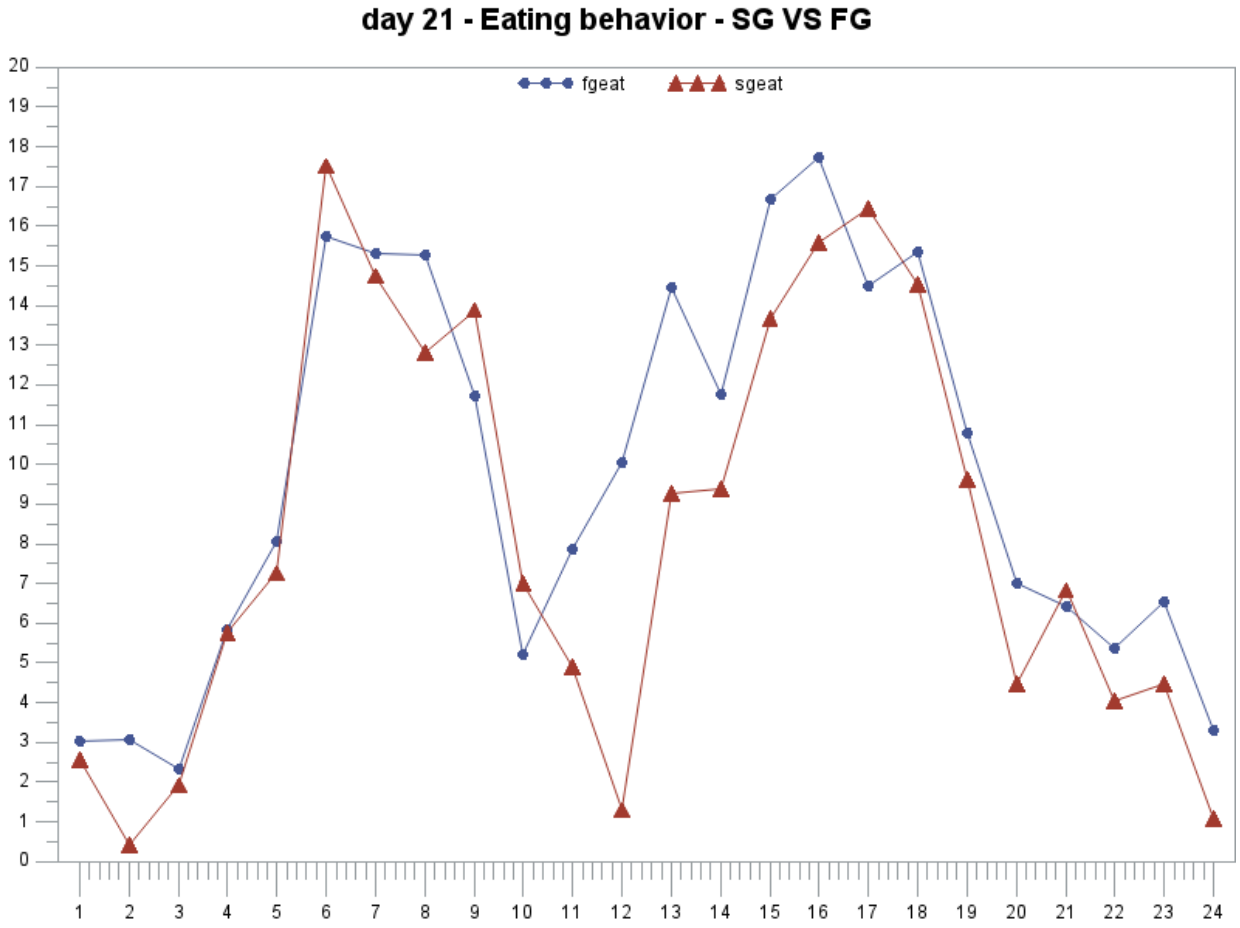
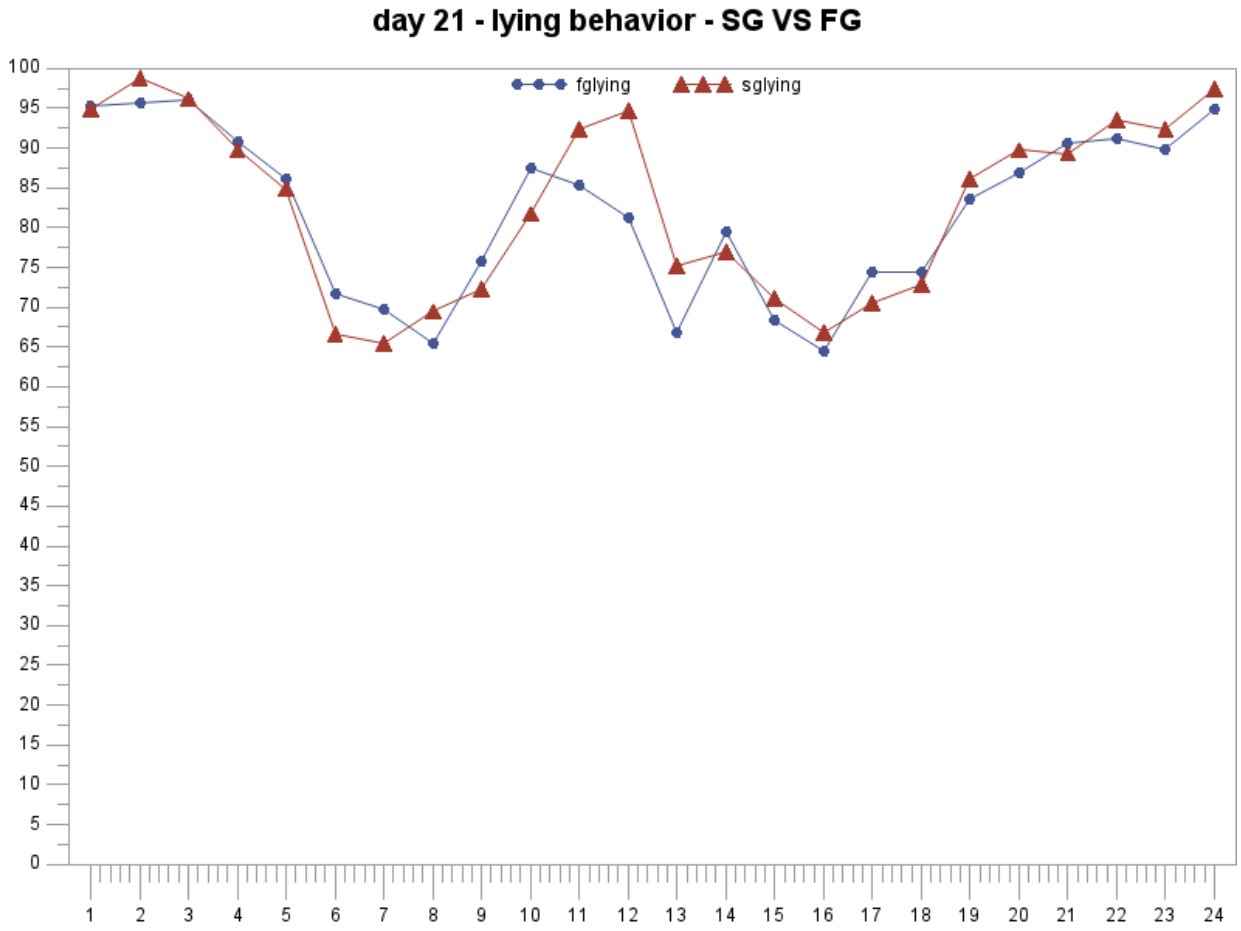


Figure 3-2. Lying behavior time budget at day 21 between slow growing pigs and fast growing pigs.



EXECUTIVE SUMMARY

Over the last few years, the prices of feed and cost of labor increased dramatically, consequently pigs had become much more costly to produce than before. In all-in-all-out production system, there were pigs that could not reach desired market weight at certain age and were often sold at much lower value than their contemporaries when marketed, causing economic losses to producers. These pigs that did not grow as efficiently as their contemporaries were often referred to as slow growing pigs. Recognizing the problem of slow growing pigs early and taking actions upon this issue are of great importance for producers to profit in modern swine industry.

It is evident that a better understanding of differences between pigs that have high growth rates and pigs that have low growth rates is needed in order to fully address this problem. In the past, performance differences between slow growing pigs and fast growing pigs were often examined and it may be beneficial now to investigate the underlying behavioral and physiological differences. It's possible that differences in these characteristics of slow growing pigs can be identified and utilized to increase growth rate.

The results of Chapter 2 provided information on performance and physiological characteristics of slow growing pigs as well as risk factors associated with slow growth. The effect of feeder space during the nursery period on performance of pigs, especially slow growing pigs, was also examined. Results showed 42 pigs were classified as slow growing pigs and accounted for approximately 10% of the group. Slow growing pigs had lower birth weight, weaning weight, and nursery exit weight compared with fast growing pigs and needed 20 extra days to reach the desired market weight of 115 kg. In terms of

carcass characteristics, slow growing pigs had less back fat and smaller loin muscle area than fast growing pigs when marketed at 21 wk of age. Providing more feeder space did not affect the performance of pigs, including slow growing pigs. We found slow growers had lower plasma concentrations of IGF-1 and insulin during the nursery period and low concentrations of leptin and insulin during the grower-finisher period, compared to average and fast growers. In addition, serum concentrations of several essential, non-essential and total AA were lower for slow growers compared with average and fast growers, potentially indicating reduced feed intake and impaired immune functions. Risk factor analysis show that sex appeared to be a contributor to slow growth, with gilts being more likely to become slow growers than barrows. Litter size and parity of the pigs' dam were not associated with slow growth. Providing ample feeder space during the nursery period tended to reduce risk of mortality.

The results of Chapter 3 demonstrated behavioral characteristics of slow growing pigs and the effect of feeder space on behaviors of pigs during the nursery period. We found no difference between slow growing and fast growing pigs in feed consumption rate, time spent eating, lying, standing, or fighting. However, we observed that slow growing pigs spent more time drinking than fast growing pigs. . Providing more feeder space decreased time spent standing and tended to increase time spent lying by slow growing pigs. In the scenario of this study, we identified drinking and standing behaviors as adjunctive behaviors, which is considered an indicator of anxiety. Our results suggest that these adjunctive behaviors may be used as indicators of slow growth. Providing more feeder space may benefit slow growing pigs and improve their welfare due to decreased

standing time and increased lying time. In conclusion, the research done in this thesis is an attempt to characterize the behavior and physiology of slow growing pigs and to evaluate the effect of providing more feeder space on slow growing pigs. Based on the information provided by this thesis, further studies could focus on utilizing swine physiological and behavioral characters to reduce the losses associated with slow growth. In production settings, providing more feeder space could benefit slow growing pigs and improve their welfare.

BIOGRAPHY

Yijie He was born in Xinjiang Province, China, and graduated from Karamay senior high school in 2008. Upon graduation, Yijie was accepted into China Agricultural University. Yijie completed his B. S. degree in Animal Science in 2012, and moved to St. Paul, Minnesota to pursue his master degree in the Department of Animal Science at the University of Minnesota, Twin Cities campus.

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