ABSTRACT

LANGDON II, JOHN MICHAEL. The Genetics of Pig Feeding Behavior. (Under the direction of Dr. Mark Knauer).

Two studies evaluated the impact of pellet quality on production efficiency and pig behavior in differing environments. Pigs (n=180) were housed in two adjacent environmental rooms, heat-stressed (HS) or thermoneutral (TN). Both environments were replicated 3 times. Average daily highs and lows for HS were 32 and 23°C and TN were 23 and 18°C. Pigs were placed in individual pens (1.5 m^2) with woven wire flooring, cup waters and open-faced feeders. Corn-soy diets were manufactured at the NCSU Feed Mill to contain 1 of 5 levels of pellet fines: 0, 15, 30, 45 or 60%. Starting at an average weight of 104.3kg±10.7, barrows and gilts were randomly assigned to treatments for 21 d. Weekly pig weights, feed consumption, behavior, respiration rates, and rectal temperatures (RT) were collected. Behavior was categorized as: drinking, eating, standing, or resting. Statistical analysis was performed using analysis of variance. Pen was experimental unit when evaluating pellet fines. Room was experimental unit when comparing HS and TN environments. Level of pellet fines not associated ($p \geq 0.35$) with ADFI or ADG in HS or TN. A 10% decrease in pellet fines numerically improved ($p=0.14$) G:F in HS by 0.007±0.005. A 10% increase in pellet fines was associated with a lower ($p<0.05$) RT for HS and TN on d 0 (-0.038°±0.018 and -0.039°C±0.019, respectively) and d 14 (-0.092°±0.021 and -0.038°C±0.016, respectively). Level of pellet fines did not impact ($p>0.05$) behavior. However, a 10% increase in pellet fines numerically increased ($p \geq 0.35$) the percentage of time eating in HS and TN by 0.3%±0.4 and 0.4%±0.5, respectively. Heat-stress had similar ($p=0.44$) ADFI (2.87 vs. 3.01kg), tended ($p=0.08$) to have lower ADG (0.95 vs. 1.07kg) and had similar

($p=0.35$) G:F (0.336 vs. 0.366) in comparison to TN. Respiration rate and RT were greater ($p<0.05$) for HS compared to TN on d 7 (95 vs. 34 and 39.5° vs. 38.8°C, respectively) and d 14 (71 vs. 30 and 39.3° vs. 38.7°C, respectively). Results are in disagreement with previous findings associating pellet quality and pig performance. Differences in experimental design, specifically housing and feeder type, may have contributed to the results.

Variance components were estimated among production and feeding behavior traits for pure-line Duroc boars (n=4,794, Smithfield Premium Genetic, Rose Hill, NC). Pigs were put on test at an average age of 82 d for a 74 d test period. Daily feed consumption was recorded using FIRE (feed intake recording equipment). Production traits collected included: average daily gain (ADG), gain to feed ratio (G:F), backfat thickness (BF), and longissimus muscle depth (MD). Feeding behavior traits include: average daily feed intake (ADFI), number of visits to the feeder per day (NVD), feed intake per visit to the feeder (FIV), occupational time at the feeder per visit (OTV), occupational time at the feeder per day (OTD), and feeding rate (FR). Variance components were estimated with AIREMLF90 using an animal model. Fixed effects contemporary group (year × season × pen) and parity were included in all models. A covariate of pig weight was used for all traits except for ADG which included off-test age as a covariate. Heritability estimates for ADG, G:F, BF, MD, ADFI, NVD, FIV, OTD, OTV, and FR were 0.34, 0.20, 0.68, 0.45, 0.36, 0.53, 0.66, 0.22, 0.88, and 0.76, respectively. Genetic correlations between G:F ratio with ADG, ADFI, NVD, and OTD were 0.42, -0.66, -0.41, and -0.45, respectively. Genetic correlations between FIV with ADG and OTV were 0.40 and 0.88 respectively. Heritability was moderate to high for most traits. Correlations between performance and feeding behavior traits were relatively low. Results suggest that selection would be possible for feeding behavior traits and ADFI, NVD, and OTD could be used to increase accuracy of selection for G:F.

The Genetics of Pig Feeding Behavior

by
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DEDICATION

To Almighty God, and to my family and loved ones: Thanks for your continuous support!

BIOGRAPHY

My name is John Michael Langdon II, and I am a native of North Carolina. I was born in Raleigh, NC on June 30, 1989. My parents are John and Eileen Langdon of Benson, NC. I was raised on our home farm of grow-finish hogs under contract with Murphy-Brown along with Simmental and Red Angus cattle, hay, and corn. I was raised to work hard and smart, to attend church, and encouraged to live a life that points to Christ as much as is humanly possible. After attending South Johnston high school, I began my collegiate career at Johnston Community College in August of 2007, where I spent two years. I continued my education at North Carolina State University (NCSU) in August of 2009. I graduated from NCSU with a Bachelor of Science in Agricultural and Environmental Technology in December of 2012 with a minor in Agricultural Business Management. In January of 2013, I began graduate school at NCSU, working with Dr. Mark Knauer.

ACKNOWLEDGMENTS

I would like to sincerely thank Dr. Knauer for allowing me the opportunity to pursue a masters of science at North Carolina State University under his guidance. I have learned a lot about animal breeding and genetics, time management, and communication by his direction. I am grateful for the great opportunities of travelling to Des Moines, Iowa for the Midwest Animal Science meetings and to Lincoln, Nebraska for NSIF as they were both valuable educational and social experiences for myself. I would also like to thank Dr. Cassady for helping me understand essential fundamentals of animal breeding and genetics as I transitioned from the agricultural engineering department (where I received my bachelors degree) to the animal science department for my masters. Thanks are also in order to Dr. van Heugten, Dr. Stark, Dr. Fahrenholtz, and all of the feed mill staff involved in formulating and manufacturing the feed for my pellet quality project. I would also like to thank Dr. Kent Gray and Shihui Jiao (Rita) for helping me compile the data for my variance components paper.

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Finally, I thank Almighty God for providing me with strength and endurance to persevere and to achieve my goals. Thanks are definitely in order to my family and loved ones for their love and support throughout my whole schooling career. I thank my parents for encouraging me to pursue opportunities for higher education. I am grateful to my parents for raising me to work hard and smart at the same time, as well as teaching me to do the right things the right way for the right reasons in every situation in life.

TABLE OF CONTENTS

LIST OF TABLES

CHAPTER 1: **Literature Review**

Introduction

It is of interest in the swine industry to identify the most efficient production methods to maximize pig producer profit. Recording feed intake behavior is pertinent to the swine industry as feeding behavior traits may increase accuracy of selection for production traits such as growth and feed conversion. Few feeding behavior studies have been completed in the U.S., however there have been a number of feeding behavior studies conducted in other countries.

Maximizing production efficiency and improving the genetics of pigs is the goal of the modern swine geneticist. Feed is a major cost of pig production, and improved conversion of feed into saleable product is one approach to increasing profitability. An assessment of opportunities to genetically improve feed conversion by selection requires estimates of heritability of feed intake as well as genetic correlations between feed intake and other traits of economic importance. Correlated responses to selection for economically important traits help provide additional accuracy to those economically important traits that are currently under selection.

The genetics of pig feeding behavior

Heritability estimates for feeding behavior traits

Considering the importance of feed cost in relation to producer profitability, relatively few studies have investigated the genetics of pig feeding behavior. While variance component estimates for average daily feed intake are common, estimates for other pig feeding behavior traits are infrequent. Feeding behavior traits feeding rate (FR), feed intake per visit to the feeder (FIV), number of visits to the feeder per day (NVD), occupational time per visit (OTV), and occupational time per day at the feeder (OTD) tend to yield moderate to high estimates of heritability (de Haer and de Vries, 1993; von Felde et al. 1996; Labroue et al. 1997; Schulze et al. 2003; Cammack et al. 2005). Heritability estimates from these studies are listed in Table 1.1.

Average daily feed intake (ADFI) is an important behavior trait to record because it is essential to have for computing feed efficiency as well as behavior traits such as feed intake per visit to the feeder and feeding rate. Rothschild and Ruvinsky (2010) reported heritability estimates for ADFI across 14 studies. Heritability ranged from 0.13 to 0.62 with an average of 0.29. These results suggest that selection for ADFI would be successful. The same authors reported a heritability estimate for residual feed intake (RFI) of 0.24 across four studies. James (1986) argues that regardless of the fact that individual feed intake is expensive to record, ADFI for individual animals should be incorporated into the selection goal even though it may not be a factor in the selection index.

Labroue et al. (1997) estimated variance components for pig feeding behavior traits on group-housed Large White and French Landrace grow-finish pigs. Heritability estimates in Large White and Landrace for ADFI, NVD, FIV, OTD, OTV, and FR were 0.42, 0.43, 0.53, 0.36, 0.45, and 0.49, respectively, and 0.42, 0.42, 0.49, 0.44, 0.54, and 0.50, respectively. Similar results were reported by Schulze et al. (2003). The authors estimated variance components for feeding behavior traits on group-housed boars utilizing electronic feeders. Heritability estimates for ADFI, NVD, FIV, OTD, OTV, and FR were 0.39, 0.34, 0.44, 0.36, 0.44, and 0.41, respectively. Heritability estimates for feeding behavior traits were also determined by de Haer and de Vries, (1993) on group-housed pigs. Average daily feed intake, NVD, FIV, OTD, OTV, and FR had heritability estimates of 0.16, 0.38, 0.35, 0.24, 0.27, and 0.29, respectively. McSweeny et al. (2003) estimated variance components on group-housed pigs using electronic feeders to record feed intake. Heritability estimates for feeding behavior traits ADFI, NVD, FIV, OTD, and OTV were 0.29, 0.29, 0.42, 0.31, and 0.29, respectively. Hall et al. (1999) reported estimates of heritability for feeding behavior traits ADFI, NVD, and FIV of 0.21, 0.34, and 0.27, respectively. Furthermore, von Felde et al. (1996) reported heritability estimates for feeding behavior traits on group-housed Landrace and Large White boars. ADFI, NVD, FIV, OTD, OTV, and FR were 0.22, 0.43, 0.51, 0.43, 0.42, and 0.44, respectively. In sheep, Cammack et al. (2005) reported genetic parameters for feeding behavior in composite ram lambs (1⁄2 Columbia, 1⁄4 Hampshire, 1⁄4 Suffolk). Feeding behavioral traits FIV, OTD, NVD, and RFI had heritability estimates of 0.33, 0.29, 0.36, and 0.11, respectively. Results from these studies suggest that feeding behavior traits are moderate to highly heritable. Therefore, selection for these traits would be successful.

Genetic correlations among production and feeding behavior traits

There have been multiple studies conducted examining the genetic associations between pig growth performance and feed intake behavior (von Felde et al. 1996; Labroue et al. 1997; Hall et al. 1999; Schulze et al. 2003; McSweeny et al. 2003; Young et al. 2012). Genetic correlations are listed in Table 1.2.

Von Felde et al. (1996) reported genetic correlation estimates between average daily feed intake with feed conversion ratio, residual feed intake, average daily gain, and backfat of 0.13, 0.97, 0.68 and 0.45, respectively. The authors further stated that the number of visits to the feeder decreased as pigs aged while occupational time per day at the feeder stayed constant. Genetic correlations between performance and feeding behavior traits were generally low. Yet, the feeding behavior trait occupational time per day at the feeder had moderate genetic correlations with average daily feed intake (0.44) and average daily gain (0.32).

Labroue et al. (1997) reported high genetic correlations between average daily gain and average daily feed intake of 0.87 and 0.81 in the Large White and French Landrace breeds, respectively. However, the genetic correlation between average daily feed intake and ultrasonic backfat thickness was 0.35 for the Large White breed and 0.62 for the French Landrace. Average daily feed intake was nearly genetically independent of feed conversion ratio with low genetic correlations in both the Large White and the French Landrace breeds of 0.11 and -0.06, respectively. Genetic correlations for the Large White and French Landrace breeds between average daily gain with feed intake per visit to the feeder were 0.49 and 0.29, respectively, and with feeding rate were 0.48 and 0.29, respectively. Feed intake per visit to the feeder was nearly genetically independent of feed conversion ratio with genetic correlation of 0.05 and 0.10 for the Large White and French Landrace breeds, respectively.

Hall et al. (1999) reported moderate genetic correlations between feeding behavior traits and growth performance traits for pigs fed using electronic feeders. Genetic correlation between feed intake per visit to the feeder, number of visits to the feeder per day, and occupational time per visit to the feeder with average daily gain were 0.49, -0.29, and 0.33, respectively. Genetic correlation between feed intake per visit to the feeder, number of visits to the feeder per day, and occupational time per visit to the feeder with backfat were 0.35, -0.15, and 0.17, respectively. Genetic correlations between feed intake per visit to the feeder, number of visits to the feeder per day, and occupational time per visit to the feeder with feed conversion ratio were -0.12, 0.31, and -0.27, respectively.

Schulze et al. (2003) estimated variance components for feeding behavior and growth performance traits on group-housed pigs utilizing electronic feeders. Results from this study showed that number of visits to the feeder per day was genetically independent of average daily feed intake, backfat, average daily gain, and feed conversion ratio with genetic correlations of 0.02, 0.05, 0.01, and 0.04, respectively. However, moderate genetic correlations were found between occupational time per day at the feeder with average daily gain and average daily feed intake of 0.31 and 0.41, respectively.

Young et al. (2012) estimated genetic correlations on Yorkshire pigs. Average daily feed intake had high genetic correlations with residual feed intake, average daily gain, and backfat of 0.65, 0.77, and 0.52, respectively. The authors reported moderate genetic correlations between occupational time at the feeder per day with residual feed intake, average daily gain, and backfat (0.39, 0.32, and 0.30, respectively) and between feed intake per visit with average daily feed intake and average daily gain (0.35 and 0.39, respectively). Feeding rate was genetically independent of back fat (0.01) and residual feed intake (-0.04).

However, feeding rate and occupational time at the feeder per day were similar traits with a genetic correlation of -0.89.

In sheep Cammack et al. (2005) reported genetic correlations were positive between all traits, except for residual feed intake and average daily gain. Genetic correlations between average daily feed intake with average daily gain and residual feed intake were high and moderately high at 0.80 and 0.61, respectively. The genetic correlation between occupational time per day at the feeder and number of visits to the feeder per day was moderate (0.55). Genetic correlations between all other traits were low (-0.03 to 0.31). However, genetic correlations between feeding behavior traits were greater than correlations between feeding behavior traits with average daily feed intake or average daily gain. Based on the results of these studies, selection for average daily gain or average daily feed intake would be expected to cause some changes in feeding behavior.

Associations between residual feed intake with feeding behavior traits

Selection feed for residual feed intake has been reported to impact feeding behavior. Dekkers et al. (2014) evaluated the effect of selection for decreased residual feed intake on feeding behavior traits. Residual correlations between residual feed intake with average daily feed intake, occupational time per at the feeder per day, number of visits to the feeder per day, feed intake per visit to the feeder, occupational time per visit to the feeder, and feeding rate were 0.75, 0.01, 0.13, -0.13, -0.11, and -0.03, respectively. Compared to the control group, pigs selected for reduced residual feed intake ate less feed and spent less time at the feeder per day. Pigs that were selected for reduced residual feed intake had fewer daily visits to the feeder and ate at a faster rate compared to the control group. Similarly, de Haer et al. (1993) reported phenotypic correlations between residual feed intake with occupational time at the feeder per day, occupational time per visit to the feeder, number of visits to the feeder per day, feed intake per visit to the feeder, and feeding rate of 0.64, -0.15, 0.51, -0.20, and -0.04, respectively. Pigs with reduced residual feed intake ate fewer meals and had a lower daily feeder occupation time. Pigs with reduced residual feed intake occupied less time at the feeder per day. Von Felde et al. (1996) reported a genetic correlation between residual feed intake and average daily gain of 0.97. In sheep, Cammack et al. (2005) reported a genetic correlation between average daily feed intake and residual feed intake of 0.61. In growing beef heifers, Kelly et al. (2009) reported genetic correlations between residual feed intake with feeding rate and number of visits to the feeder per day of 0.26 and 0.45, respectively. Results from these studies suggest that reduced residual feed intake is associated with decreased occupational time at the feeder per day and greater average daily feed intake feed intake, though further research should be conducted to confirm these results.

Environmental factors associated with pig feeding behavior

Heat stress

Environmental stressors impair production efficiencies. One such stressor is high ambient temperature. High ambient temperature, which is associated with increased body temperature and respiration rate, reduces feed intake and growth rate (Aberle et al., 1974; Hyun et al., 1998). The influence of heat stress on feed intake and weight gain in growing pigs is well documented (McGlone et al., 1985; Feddes et al., 1989; McGlone et al., 1994; Hyun et al., 1998).

Hyun et al. (1998) investigated the impact of multiple concurrent environmental stressors on young Yorkshire x Hampshire and purebred Duroc grow-finish pigs (n=256), each weighing approximately 35 kg. There were eight possible treatment combinations that pigs would be exposed to for a four-week experiment (2 x 2 x 2 factorial). The combinations consisted of ambient temperature (continuous thermoneutral of 24˚C or cycling temperatures of 28 to 34˚C), stocking density (0.56 or 0.25 m^2 floor space per pig), and social grouping (stationary or regrouped at the start of week one and three). Stress from exposure to the greater temperature, greater stocking density, and regrouping diminished average daily gain by 12, 16, and 10%, respectively and average daily feed intake decreased by 7, 6, and 5%, respectively. Based on the growth rate of pigs exposed to either of the single stressors (high cycling temperature, restricted space allowance, or regrouping), average daily feed intake, average daily gain, and feed efficiency were reduced by 16, 10, and 11%, respectively. For pigs exposed to all three stressors at the same time, average daily gain was reduced by 31%. The additivity of stressors was further validated upon investigation of the influence of stressor sequence or the quantity of stressors executed concurrently. As stressors were applied sequentially from no stressors up to three stressors, average daily gain, average daily feed intake, and feed efficiency decreased in a linear fashion. This study suggests that several simultaneous stressors impact pig growth in an additive manner and shows that prevention or elimination of a particular stressor could be beneficial regardless of additional irrepressible stressors that may be present.

Feddes et al. 1989 investigated the effects of heat stress and cycling temperatures on feed consumption. Two environmental chambers were utilized in this study. One chamber had cycling temperatures ranging from 26 to 40˚C, and the other environmental room was kept at a constant temperature of 33˚C. Four pigs with one feeder were housed in each chamber. Feed intake mainly occurred during the lowest temperature phase of the cycle. The period of greatest feed consumption happened early morning and late evening compared to pigs kept in the setting where temperature was held constant. This study suggests that pigs under heat stress refrain from eating. However, as temperature decreases pigs begin to consume more feed.

Pellet quality

Pellet quality plays a large role in determining how much feed animals will consume. According to Stark (2009), pellet durability index (PDI) is a fairly reliable test for determining the pellet quality of a feed sample. In this process whole pellets are placed into a Sprout Bauer Roto-Shaker™ and tumbled for 10 minutes. Then the tumbled pellets are screened, weighed, and the percent of whole pellets remaining is calculated to determine the PDI or essentially the pellet quality of the feed sample. Most commonly, pellet quality is expressed as percent pellets. In pigs (Stark, 1994) and chickens (McKinney and Teeter, 2003), a greater percentage of pellets in the feed improved average daily gain and feed efficiency. Greenwood et al. (2004) reported no differences in feed conversion in diets containing 20-60% fines. It is constantly a balancing act between feed mill production efficiency and producing good quality pelleted feed.

McKinney and Teeter (2003) quantified the effective caloric value attributable to pellet quality. Average daily gain and feed conversion ratio were significantly enhanced by pelleting and were positively correlated with pellet quality. However, feed intake was not affected by pellet quality. Results suggest pelleting contributed 187 kcal per kg of diet at 100% pellet quality and that the effective caloric value declined in a curvilinear fashion as pellet quality worsened. Birds were observed eating less and resting more as pellet quality increased, suggesting that effective caloric value of pelleting is mediated by energy expenditure for activity. Similar results were found by Skinner et al. (2005) where two trials were conducted to confirm the relationships among effective caloric value of the diet, net energy for gain (NEg), body weight, feed conversion ratio, and broiler behavior. Pelleting increased effective caloric value and total NEg while decreasing eating and increasing resting behavior. Results showed significant phenotypic correlations among resting, NEg, and effective caloric value. Results from these studies reveal that varying the level of pellet fines in feed causes behavioral differences in chickens.

Group size

Many studies have been conducted examining the effects of group size on growth performance and feeding behavior in grow-finish pigs. According to Nielson et al. (1995), Wolter et al. (2001), and Hyun and Ellis (2001), growth performance and behavior was not affected by group size. Floor space per pig was held constant in each study at 1.06, 0.68, and 0.90 m^2 per pig, respectively. Conversely, Gonyou et al. (1998) reported a reduction in average daily gain as group size increased (groups of 3, 5, 6, 7, 10, and 15 pigs had average daily gain estimates of 0.899, 0.851, 0.868, 0.872, 0.857, and 0.821 kg, respectively). Likewise, there was a decrease in average daily feed intake as group size increased (groups of 3, 5, 6, 7, 10, and 15 pigs had average daily feed intakes of 2.49, 2.34, 2.32, 2.28, 2.28, and 2.21 kg, respectively). However, groups containing 7 and 10 pigs had the greatest gain to feed ratios (0.383 and 0.378, respectively). Group sizes of 3 and 5 pigs had the lowest gain to feed ratios (0.362 and 0.364, respectively). Although many previous studies reveal that group size has no sizable impact on pig growth performance or feeding behavior, results suggest that further research should be conducted to confirm the effects of group size in grow-finish pigs on growth performance and feeding behavior.

Feeder space allowance

Studies have been conducted examining the effects of varying feeder space on pig performance and feeding behavior. Nielson et al. (1996) compared feeding behavior and growth performance of grow-finish pigs separated into groups of 10 pigs per pen fed with either a single-compartment computerized feeder (66 cm linear feeding space) or a four-compartment feeding trough (152 cm). Pigs fed with the four-compartment feeder visited the feeder substantially more often, spent less time per visit, and consumed less feed per visit compared to pigs on the single-compartment feeder. There were no significant differences between feeder spaces in feeding rate or occupational time at the feeder per day. No differences were detected in growth performance traits of average daily gain, average daily feed intake, or feed efficiency with changes in feeding behavior. Similarly, Gonyou et al. (2000) reported that the quantity of feeder space had no effect on the production performance of pigs when placed 12 per pen. Pigs on single-compartment feeders (38 cm linear feeder space) occupied less time at the feeder than pigs fed from double-compartment feeders (56 cm). Feeding rate was not affected by feeding space. As suggested by these studies, feeder space does not affect growth performance in pigs, however, there appears to be differences in occupation time at the feeder comparing single compartment and multi-compartment feeders. Further research should be conducted to confirm associations between eating time and feeder space allowance.

Few studies have been conducted examining pig feeding behavior and performance at different feeder adjustments. Nemechek et al. (2013) reported interesting results for production performance from varied feeder adjustment. Feed efficiency increased for pigs fed from narrow (1.27 cm gap width) adjusted feeders compared to the wide (2.54 cm gap width) adjustment. Average daily gain did not differ between pigs fed from the two feeder adjustments, but average daily feed intake decreased at the narrow gap. This suggests reducing feeder gap width reduced feed wastage and improved feed efficiency. In nursery pigs, Smith et al. (2004) reported that optimum feeder gap width (reported to be independent of feed consistency) ranged from 1.79 to 2.48 cm for greatest performance in pig growth and feed efficiency, which would equate to 56 and 26% of the feeder with no feed, respectively. Results from these studies suggest that feeder gaps between 1.27 and 1.79 cm could improve feed efficiency, optimize growth and reduce feed wastage.

Few studies have examined the impact of feeder type on pig feeding behavior and growth performance. Hyun et al. (1998) reported no differences in pig growth performance between pigs eating from conventional single compartment feeders and pigs consuming feed from electronic feed intake recording equipment (FIRE) feeders. However, Hyun and Ellis (2001) reported that pigs fed from the FIRE feeder had similar average daily gain, reduced average daily feed intake, and greater gain to feed ratios in comparison to pigs fed from the conventional feeders. Results show that pig growth performance may or may not be affected by feeder type.

Stocking density

There have been various studies examining the effects of stocking density on growth performance and feeding behavior in grow-finish pigs. Hyun et al. (1998) conducted a study examining the effects of stocking density on grow-finish pigs. Space allowances were 0.56 or 0.25 m^2 per pig. Pigs housed at 0.25 m^2 had depressed growth rate and feed efficiency (15.7 and 10.0%, respectively). Pigs with the 0.25 m^2 floor space had fewer visits to the feeder per day (11.2 vs. 15.7 visits), greater occupational time per visit to the feeder (12.5 vs. 8.9 min.) and greater feed intake per visit to the feeder (0.196 vs. 0.146 kg) than pigs with greater floor space. This study showed that greater stocking density depressed growth rates and altered feeding behavior. Similarly, Spicer et al. (1987) found differences in performance and behavior due to varying stocking density. Pigs were placed in groups of one, two, or four at stocking densities of 1.44, 0.72, and 0.35 m^2 per pig, respectively. In this study, average daily gain and average daily feed intake were reduced when pigs were placed at a stocking density of 0.35 m^2 per pig. Stocking density did not affect feed efficiency. The proportion of time that pigs were resting, standing/moving, or sitting did not vary among stocking densities. Pigs stocked at 0.72 m^2 occupied the feeder more (16.3%) than those stocked at

1.44 and 0.35 m^2 (15.2 and 15.3%, respectively). In agreement, Gonyou et al. (1998) found that increasing stocking density decreased pig production performance. Average daily gain and average daily feed intake of pigs at the greatest stocking density were lower compared to pigs at the reduced stocking densities (0.875 and 0.877 kg, respectively, and 2.35 and 2.36 kg, respectively, at 0.039 and 0.048 m^2 per pig floor space × $BW^{0.667}$). Feed efficiency showed no differences among floor spaces. Randolph et al. (1981) similarly reported increased growth with increased floor space per pig. Pigs placed in four different floor spacing allotments of 0.33, 0.66, 0.82, and 1.64 m^2 had average daily gain estimates of 0.600, 0.644, 0.687, and 0.717 kg, respectively. The authors further reported a numerical increase in gain to feed ratio for the 0.66 m^2 floor space when compared to the 0.33m^2 (0.41 and 0.42, respectively). Collectively, results suggest that increasing stocking density or decreasing floor space per pig will suppress growth in pigs and may reduce feed efficiency, visits to the feeder, and feed intake per visit.

Table 1.1 Heritability estimates for pig feeding behavior and performance traits

Trait	Heritability estimates	Range	Average
Average daily gain	0.43[2], 0.36[7], 0.29[8]	0.29-0.43	0.36
Feed conversion ratio	0.19[2], 0.19[3], 0.20[4], 0.28[7]	0.19-0.28	0.22
Backfat	0.54[2], 0.50[7], 0.49[8]	0.49-0.54	0.51
Average daily feed intake	0.16[1], 0.22[2], 0.42[3], 0.42[4], 0.21[5], 0.29[6], 0.39[7], 0.29[8]	0.16-0.42	0.30
Occupation time per day	0.24[1], 0.43[2], 0.36[3], 0.44[4], 0.31[6], 0.46[7]	0.24-0.46	0.37
Feeding rate	0.29[1], 0.44[2], 0.49[3], 0.50[4], 0.41[7]	0.29-0.50	0.43
Feed intake per visit	0.47[1], 0.51[2], 0.53[3], 0.49[4], 0.27[5], 0.42[6], 0.44[7]	0.27-0.53	0.45
Occupation time per visit	0.27[1], 0.42[2], 0.45[3], 0.54[4], 0.43[6], 0.44[7]	0.27-0.54	0.43
No. of visits per day	0.38[1], 0.43[2], 0.43[3], 0.42[4], 0.34[5], 0.29[6], 0.34[7]	0.29-0.43	0.38

[1]de Haer and de Vries, (1993b)
[2]von Felde et al. (1996)
[3]Labroue et al. (1997)-Large White
[4]Labroue et al. (1997)-French Landrace
[5]Hall et al. (1999)
[6]McSweeny et al. (2003)
[7]Schulze et al. (2003)
[8]Rothschild and Ruvinsky, (2010)

Table 1.2 Genetic correlations between pig feeding behavior traits and performance traits.

Trait combinations	Estimates	Range	Avg.
ADFI/ADG	0.68[1], 0.87[2], 0.81[3], 0.78[5], 0.77[7]	0.68-0.87	0.78
ADFI/FCR	0.13[1], 0.11[2], -0.06[3], 0.01[5]	-0.06-0.13	0.05
ADFI/BF	-0.22[1], 0.35[2], 0.62[3], 0.45[5], 0.52[7]	-0.22-0.62	0.34
ADFI/RFI	0.41[1], 0.65[7]	0.41-0.65	0.53
NVD/ADG	0.04[1], -0.19[2], -0.03[3], -0.29[4], -0.22[5], 0.01[6], -0.19[7]	-0.29-0.04	-0.12
NVD/FCR	0.11[1], 0.03[2], -0.19[3], 0.31[4], -0.12[5], 0.04[6]	-0.19-0.31	0.03
NVD/BF	0.06[1], -0.10[2], -0.15[3], -0.15[4], 0.00[5], 0.05[6], -0.16[7]	-0.16-0.06	-0.06
NVD/RFI	0.17[1], 0.15[7]	0.15-0.17	0.16
OTD/ADG	0.32[1], 0.02[2], 0.19[3], 0.33[4], 0.69[5], 0.31[6], 0.13[7]	0.02-0.69	0.28
OTD/FCR	0.12[1], 0.16[2], 0.16[3], -0.27[4], 0.12[5], 0.18[6]	-0.27-0.18	0.08
OTD/BF	0.15[1], 0.07[2], 0.09[3], 0.17[4], 0.39[5], 0.18[6], 0.30[7]	0.07-0.39	0.19
OTD/RFI	0.44[1], 0.39[7]	0.39-0.44	0.42
OTV/ADG	0.07[1], 0.23[2], 0.16[3], 0.51[5], 0.04[6], 0.20[7]	0.04-0.51	0.20
OTV/FCR	-0.02[1], 0.09[2], 0.24[3], 0.05[5], -0.01[6]	-0.02-0.24	0.07
OTV/BF	-0.05[1], 0.13[2], 0.12[3], 0.00[5], -0.02[6], 0.32[7]	-0.05-0.32	0.08
OTV/RFI	-0.01[1], 0.07[7]	-0.01-0.07	0.03
FIV/ADG	0.20[1], 0.49[2], 0.29[3], 0.49[4], 0.52[5], 0.15[6], 0.39[7]	0.15-0.52	0.36
FIV/FCR	0.01[1], 0.05[2], 0.10[3], -0.12[4], 0.04[5], 0.05[6]	-0.12-0.10	0.02
FIV/BF	0.07[1], 0.18[2], 0.31[3], 0.35[4], 0.01[5], 0.09[6], 0.26[7]	0.01-0.35	0.18
FIV/RFI	0.13[1], -0.07[7]	-0.07-0.13	0.03
FR/ADG	0.27[1], 0.48[2], 0.29[3], 0.14[6], 0.17[7]	0.14-0.48	0.27
FR/FCR	0.03[1], -0.03[2], -0.21[3], 0.10[6]	-0.21-0.10	-0.03
FR/BF	0.19[1], 0.11[2], 0.25[3], 0.16[6], 0.01[7]	0.01-0.25	0.14
FR/RFI	0.25[1], -0.04[7]	-0.04-0.25	0.11

References:	Feeding Behavior Traits:	Performance Traits:
[1]von Felde et al. (1996)	ADFI - Average daily feed intake	ADG - Average daily gain
[2]Labroue et al. (1997)-Large White	NVD - No. of visits per day	FCR - Feed conversion ratio
[3]Labroue et al. (1997)-French Landrace	OTD - Occupational time per day	BF - Backfat
[4]Hall et al. (1999)	OTV - Occupational time per visit	RFI - Residual feed intake
[5]McSweeny et al. (2003)	FIV - Feed intake per visit	
[6]Schulze et al. (2003)	FR - Feeding rate	
[7]Young et al. (2012)		

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CHAPTER 2: **The impact of pellet quality on production efficiency and pig behavior in different environments**

ABSTRACT

Two studies evaluated the impact of pellet quality on production efficiency and pig behavior in differing environments. Pigs (n=180) were housed in one of two adjacent environmental rooms, heat-stressed (HS) or thermoneutral (TN). Both the HS and TN environments were replicated 3 times. Average daily highs and lows for HS were 32° and 23°C and for TN were 23° and 18°C. Pigs were housed individually in pens (1.5m^2 per pig) with woven wire flooring, cup waters and open-faced feeders. Corn-soy diets were manufactured at the NCSU Feed Mill to contain 1 of 5 levels of pellet fines; 0, 15, 30, 45 or 60%. Different levels of pellet fines were created by separating the pellets from the fines and then adding the fines back to the pellets at the desired ratio. At an average weight of 103.9±5.4 kg, barrows and gilts were randomly assigned to treatments for 21 d. Weekly pig weights, feed consumption, pig behavior, respiration rate (breaths per min) and rectal temperature (RT) were collected. Pig behavior was categorized as drinking, eating, standing or resting. Statistical analysis was performed using analysis of variance. Pen was the experimental unit when evaluating pellet fines and room was the experimental unit when comparing HS and TN environments. Level of pellet fines was not associated ($p \geq 0.35$) with ADFI or ADG in either HS or TN. A 10% decrease in pellet fines numerically improved ($p=0.14$) G:F in HS by 0.007±0.005. A 10% increase in pellet fines was associated with lower ($p<0.05$) RT for both HS and TN on d 0 (-0.038°±0.018 and -0.039°C±0.019, respectively) and d 14 (-0.092°±0.021 and -0.038°C±0.016, respectively). Level of pellet fines did not impact ($p>0.05$) behavior. However, a 10% increase in pellet fines numerically

increased ($p \geq 0.35$) the percentage of time observed eating in HS and TN by 0.3±0.4 and 0.4%±0.5, respectively. Heat-stress had similar ($p=0.44$) ADFI (2.87 vs. 3.01kg), tended ($p=0.08$) to have lower ADG (0.95 vs. 1.07kg) and had similar ($p=0.35$) G:F (0.336 vs. 0.366) in comparison to TN. Respiration rate and RT were greater ($p<0.05$) for HS in comparison to TN on d 7 (95 vs. 34 bpm and 39.5° vs. 38.8°C, respectively) and d 14 (71 vs. 30 bpm and 39.3° vs. 38.7°C, respectively). Results are in disagreement with previous findings associating pellet quality and pig performance. Differences in experimental design, specifically housing and feeder type, may have contributed to the results.

INTRODUCTION

It is of interest in the swine industry to identify the most efficient production methods to maximize pig producer profit. Pelleting is a feed processing technology commonly used in the swine industry as it improves growth rate and feed conversion (Stark 1994). Numerous reports have evaluated the relationship between diet and productivity in pigs. Yet few studies have examined the association between pellet quality and production efficiency. Pellet quality, commonly defined as pellet durability or the level of fines present in the diet, impact production efficiency. Stark (1994) and Schell and van Heugten (1998) reported feed efficiency improved in grow-finish pigs as the level of fines in the diet decreased. Similarly in chickens, a lower level of pellet fines was associated with an improvement in feed conversion (McKinney and Teeter 2004; Greenwood et al. 2004).

However, further studies are needed to identify an acceptable level of pellet fines in relation to growth performance and feed conversion.

Environmental stressors impair production efficiencies. High ambient temperature, which is associated with increased body temperature and respiration rate reduces feed intake and growth rate (Aberle et al., 1974; Hyun et al., 1998). Hence, pelleting is a possible management approach to reduce the impact of environmental stressors on production efficiency. Therefore, the objective of this project was to evaluate the impact of pellet quality on production efficiency and pig behavior in both heat stressed and thermoneutral environments.

MATERIALS AND METHODS

Feed Manufacturing

Feed was processed at the North Carolina State University Feed Mill Education Unit (Raleigh, NC). Corn-soy diets (Table 2.1) were fed that met or exceeded NRC recommendations (NRC, 2012). Diets were mixed using a Hayes & Stolz (Fort Worth, TX) model TRDB126-0604 2-ton counterpoise mixer. A Bliss (Ponca City, OK) model 60-130 pellet mill equipped with a 3.97mm (5/32") by 31.75mm (1 ¼") pellet die was used to pellet diets. Pellets were screened to remove fines using a Sprout Bauer (Muncy, PA) model 3 5/7 Roto-Shaker™ pellet screener. In order to meet the demand for total fines, a portion of the pellets were ground using crumble rolls. The ground pellets were passed over the pellet screener to obtain the fines. Equal amounts of "regular" and "manufactured" fines were then mixed with the pellets in a 2-ton mixer to reach the desired level of pellet fines.

Experiment 1—Heat-Stressed Environment

Pigs (n=90) were housed at a producer research farm near Harrells, NC. Genetics were provided by Smithfield Premium Genetics (Rose Hill, NC) and consisted of Duroc sires mated to Landrace × Large White females. Pigs were individually penned in each of three replicates. Each replicated consisted of 15 gilts and 15 barrows. Pens were 1.5m^2 and had woven wire flooring. Water was provided ad libitum by a nipple-water contained within a bowl (Hog Slat, Newton Grove, NC). Pigs were hand fed to appetite twice daily in open-faced feeders (Hog Slat, Newton Grove, NC). After a seven-day acclimation period, pigs were randomly assigned within sex to one of five dietary treatments; 0%, 15%, 30%, 45%, and 60% pellet fines. Dietary treatments were fed for 21 days. Starting on the first day of dietary treatments, room temperature was increased, using automatic controllers to mimic a heat-stressed environment. Average daily high and low temperatures were 32° and 23°C, respectively. Weekly pig weights, pen feed consumption, rectal temperature and respiration rate were collected. Rectal temperatures were taken with a digital rectal thermometer while pigs were eating. Respiration rate was measure by counting the number of breaths in a 15 second time period and then multiplied by four for breaths per minute. Weekly pig feeding behavior was observed and recorded immediately following feeding once in the morning and again in the afternoon. Behavior was recorded every five minutes for 45 minutes by the same person each time. Pig behavior was classified into one of the following categories: drinking, eating, standing, or resting.

Experiment 2—Thermoneutral Environment

Experiment 2 was conducted simultaneously with experiment 1 in an adjacent room. Procedures for experiment 2 were exactly the same as in experiment 1 except for the room temperature. Average daily high and low temperatures were 23° and 18°C, respectively.

Statistical Analysis

Data were analyzed using PROC MIXED in SAS (SAS Institute, Inc. Cary, North Carolina). The PROC MIXED procedure is an analysis of variance (ANOVA) that compares means using an F test. A value of $P<0.05$ was considered statistically significant in all tests. For comparisons within environment, all models included dietary treatment, sex, and replicate as fixed effects. For comparisons across environments, all models included room as a fixed effect.

RESULTS

Summary statistics for production, behavior and vital signs from experiment 1 and experiment 2 are shown in Table 2.2. Estimates between production, behavior and vital signs with sex and pellet quality are shown for the HS environment in Table 2.3 and TN environment in Table 2.4.

Production traits were not associated ($p>0.05$) with sex or pellet quality in either the HS or TN environments. However, a 10% decrease in pellet fines numerically ($p=0.14$) improved G:F in HS by 0.007.

Pig behavior was generally not associated with sex or pellet quality. However, barrows spent 1.9% less ($p<0.05$) time standing in comparison to gilts in the TN environment. Barrows spent numerically more time resting in both the HS (2.0%, $p=0.26$) and TN (2.7%, $p=0.24$) environments when compared to gilts. As pellet quality improved, there appeared to be a decrease in eating and an increase in resting in both HS and TN environments. For both HS and TN, a 10% decrease in pellet fines numerically decreased eating (0.3 and 0.4%, respectively) and increased resting (0.2 and 0.6%, respectively).

For vital signs, there generally appeared to be no associations between respiration rate with pellet quality and significant relationships between rectal temperature and pellet quality. A 10% decrease in pellet fines was associated ($p<0.05$) with increased rectal temperature at d 0, d 7, and d 14 (0.04, 0.06 and 0.09°C, respectively) for HS and d 0 and d 14 (0.04 and 0.04°C, respectively) for TN. Rectal temperature and respiration rate showed a phenotypic correlation of 0.32.

Pigs in the HS environment generally had poorer production and elevated vital signs in comparison to the TN environment. Pigs from HS had numerically lower ($p=0.44$) ADFI (2.87 vs. 3.01kg), tended ($p=0.08$) to have lower ADG (0.95 vs. 1.07kg) and had numerically reduced ($p=0.35$) G:F (0.336 vs. 0.366) in comparison to the TN environment. Respiration rate and rectal temperature were greater ($p<0.05$) for HS in comparison to TN on d 7 (95 vs. 34 bpm and 39.5° vs. 38.8°C, respectively) and d 14 (71 vs. 30 bpm and 39.3° vs. 38.7°C, respectively).

DISCUSSION

In the present study no significant associations were found between pellet quality, as defined by percentage of pellet fines, and growth performance. In agreement, Hanrahan (1984), Stark (1994) and Nemechek et al. (2013) reported pellet quality did not impact growth rate of finishing pigs. However in chickens, McKinney and Teeter (2003), Greenwood et al. (2004), and Proudfoot et al. (1978) reported that decreased fines significantly improved average daily gain. Collectively, these results suggest pellet quality does not impact growth rate in pigs but may in other species.

In the current study pellet quality did not impact feed conversion. In agreement, Hanrahan (1984) reported pellet quality did not impact feed conversion of finishing pigs. However, Stark (1994), Schell and van Heugten (1998), and Nemechek (2013) reported feed conversion improved as pellet quality improved in finishing pigs. Stark (1994) reported diets containing 0, 20, 40, and 60% fines had gain to feed ratios of 0.380, 0.360, 0.360, and 0.350, respectively. Similarly, Schell and van Heugten (1998) reported pigs fed diets containing 3, 12, 23, and 37% fines had gain to feed ratios of 0.498, 0.481, 0.478, and 0.476, respectively. These results show small numeric increases in gain to feed ratio with improving pellet quality. Similarly in chickens, McKinney and Teeter (2003) and Greenwood et al. (2004) found that feed conversion was improved by increased pellet quality. Perhaps feeder adjustments partially explain differences between studies. Nemechek et al. (2013) reported an interaction between pellet quality and feeder adjustment. The authors reported pigs that were fed diets containing 0 and 50% fines at a reduced feeder gap width had G:F of 0.392 and 0.374, respectively and G:F of 0.387 and 0.354, respectively when fed from a wider feeder gap. This shows feed conversion was similar at either feeder gap when pigs were fed good quality pellets but much poorer for poor quality pellets at the wide feeder gap.

In the current study, as pellet quality improved there appeared to be a decrease in eating frequency and an increase in resting behavior. In agreement, Jensen et al. (1962) and Skinner et al. (2005) reported modifications in the eating behavior patterns of chickens as the level of fines increased. The authors found chickens ate more often and rested less when fed lower quality pellets when compared to higher quality pellets. Together these results suggest high quality pellets reduce energy expenditure from activity.

In the present study, a lower level of pellet fines was associated with greater rectal temperature. The underlying biological reason for this association is unclear. Perhaps the lower level of fines produced more heat during digestion causing a rise in rectal temperature. Further investigation must be done in order to better understand why rectal temperature increases with increased pellet quality.

In the heat stress environment respiration rate and rectal temperature increased from d 0 to d 7 and stabilized by d 14. The pattern of rectal temperature changes suggests that pigs adapted to the heat stress environment over time. This is in agreement with Patience et al. (2005) in pigs and Bernabucci et al. (1999) in cattle who reported rapid peaks in rectal temperature at the onset of heat stress followed by gradual decreases in rectal temperature over time as animals adapted to heat stress conditions. Similarly, Black et al. (1993), Brown-Brandl et al. (1998), and Patience et al. (2005) reported that heat stress increases respiration rate in pigs. Patience et al. (2005) confirmed the pattern of changes in vital signs observed in the present study. In the current study, respiration rate and rectal temperature decreased simultaneously and were moderately correlated, consistent with findings of Black et al. (1993) and Patience et al. (2005).

Barrows appeared to have a greater rectal temperature than the gilts in both the heat stress and thermoneutral environments. In contrast, Hamilton et al. (2004) reported no differences in rectal temperature between sexes of pigs under a heat stress environment. Nonetheless, the biological relationship between sex and rectal temperature under heat stress is unclear. Further investigation into this subject would be necessary to confirm the findings of the present research.

CONCLUSION

The present study reports pellet quality did not impact growth performance. As pellet quality improved, there appeared to be a decrease in eating frequency and an increase in resting behavior. The present study reported a lower level of pellet fines was associated with greater rectal temperature and respiration rate. Further research must be conducted to investigate the underlying biology behind the effects of pellet quality on vital signs and to confirm an association between pellet quality and vital signs in pigs.

Table 2.1 Diet formulation used in experiment 1 and 2.

Ingredient	% of diet
Corn US #2	76.43
Soybean meal	14.90
Poultry fat	6.50
Limestone	0.43
Defluorinated Phosphate	1.07
Lysine	0.23
Threonine	0.05
Salt	0.29
Trace mineral premix	0.05
Vitamin premix	0.02
Selenium premix	0.025
Virginiamycin	0.0125

Table 2.2 Summary statistics for pig production, behavior and vital signs from experiment 1 and experiment 2.

	Experiment 1 (heat stress)			Experiment 2 (thermoneutral)		
Trait†	No.	Mean	SD	No.	Mean	SD
Production						
IBW, kg	90	104.3	10.7	90	103.4	12.9
ADFI, kg	90	2.87	0.44	90	3.01	0.50
ADG, kg	90	0.95	0.25	90	1.07	0.30
G:F	90	0.336	0.098	90	0.366	0.121
Behavior						
Drinking, %	90	1.7	1.9	90	1.5	2.5
Eating, %	90	11.6	7.9	90	21.8	9.2
Standing, %	90	1.2	1.8	90	3.3	3.9
Resting, %	90	85.6	8.6	90	73.5	10.8
Respiration rate						
Day 0, bpm	90	43	16	90	36	8
Day 7, bpm	90	95	25	90	34	16
Day 14, bpm	90	71	23	90	30	10
Rectal temperature						
Day 0, ˚C	90	39.2	0.5	90	39.0	0.4
Day 7, ˚C	90	39.5	0.5	90	38.8	0.5
Day 14, ˚C	90	39.3	0.5	90	38.7	0.3

†IBW = initial body weight, ADFI = average daily feed intake, ADG = average daily gain, G:F = gain to feed ratio, bpm = breaths per minute.

Table 2.3 Regression estimates between pig production, behavior and vital signs with sex and pellet quality in a heat stressed environment.

	Sex			Level of Fines[¥]		
Trait†	Estimate‡	SE	P-Value	Estimate	SE	P-Value
Production						
ADFI, kg	0.03	0.089	0.71	0.01	0.021	0.57
ADG, kg	0.00	0.051	0.99	-0.01	0.012	0.35
G:F	-0.001	0.0197	0.96	-0.007	0.0050	0.14
Behavior						
Drinking, %	-0.6	0.38	0.11	-0.1	0.09	0.51
Eating, %	-0.8	1.6	0.60	0.3	0.38	0.41
Standing, %	-0.5	0.39	0.21	0.0	0.09	0.93
Resting, %	2.0	1.74	0.26	-0.2	0.41	0.58
Respiration rate						
Day 0, bpm	4.0	2.87	0.17	-0.6	0.07	0.41
Day 7, bpm	-0.7	5.13	0.90	0.6	0.12	0.65
Day 14, bpm	1.7	4.24	0.70	-2.3	0.10	0.03
Rectal temperature						
Day 0, ˚C	0.14	0.077	0.07	-0.004	0.0018	0.04
Day 7, ˚C	0.23	0.091	0.01	-0.006	0.0021	0.01
Day 14, ˚C	0.10	0.090	0.29	-0.009	0.0021	0.01

†ADFI = average daily feed intake, ADG = average daily gain, G:F = gain to feed ratio, bpm = breaths per minute ‡the estimates for sex represents the difference between barrow and gilt performance, (i.e. barrows spent 2.0% more time resting than gilts), [¥]represent a 10% change in level of fines.

Table 2.4 Regression estimates between pig production, behavior and vital signs with sex and pellet quality in a thermoneutral environment.

	Sex			Level of Fines[¥]		
Trait†	Estimate‡	SE	P-Value	Estimate	SE	P-Value
Production						
ADFI, kg	0.03	0.103	0.75	-0.01	0.024	0.71
ADG, kg	-0.00	0.063	0.97	0.00	0.015	0.85
F:G	-0.014	0.0251	0.58	0.003	0.0060	0.58
Behavior						
Drinking, %	-0.5	0.51	0.31	0.1	0.12	0.63
Eating, %	-0.4	1.96	0.86	0.4	0.46	0.36
Standing, %	-1.9	0.80	0.02	0.1	0.19	0.61
Resting, %	2.7	2.25	0.24	-0.6	0.53	0.28
Respiration rate						
Day 0, bpm	-0.2	1.66	0.88	0.3	0.39	0.51
Day 7, bpm	4.9	2.76	0.08	-0.8	0.65	0.25
Day 14, bpm	-0.3	2.01	0.87	-0.6	0.47	0.22
Rectal temperature						
Day 0, ˚C	0.09	0.079	0.24	-0.004	0.0019	0.04
Day 7, ˚C	0.07	0.095	0.46	-0.002	0.0022	0.43
Day 14, ˚C	0.17	0.067	0.01	-0.004	0.0016	0.02

†ADFI = average daily feed intake, ADG = average daily gain, G:F = gain to feed ratio, bpm = breaths per minute ‡the estimates for sex represents the difference between barrow and gilt performance, (i.e. barrows spent 2.7% more time resting than gilts), [¥]represent a 10% change in level of fines.

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CHAPTER 3: **Estimates of variance components for swine feeding behavior traits**

ABSTRACT

Variance components were estimated among production and feeding behavior traits for pure-line Duroc boars (n=4,794 Smithfield Premium Genetic, Rose Hill, NC). Pigs were put on test at 82 d of age for an average of 74 d. Daily feed consumption was recorded using electronic feed intake recording equipment. Production traits collected included: average daily gain (ADG), gain to feed ration ratio (G:F), backfat (BF), and longissimus muscle depth (MD). Feeding behavior traits included: average daily feed intake (ADFI), number of visits to the feeder per day (NVD), feed intake per visit to the feeder (FIV), occupational time at the feeder per visit (OTV), occupational time at the feeder per day (OTD), and feeding rate (FR). Variance components were estimated with AIREMLF90 using an animal model. Fixed effects of contemporary group (year × season × pen) and parity were included in all models. A covariate of pig weight was used for all traits except for ADG which included off-test age as a covariate. Heritability estimates for ADG, G:F, BF, MD, ADFI, NVD, FIV, OTD, OTV, and FR were 0.34, 0.20, 0.68, 0.45, 0.36, 0.53, 0.66, 0.22, 0.88, and 0.76, respectively. Genetic correlations between G:F with ADG, ADFI, NVD, and OTD were 0.42, -0.66, -0.41, and -0.45, respectively. Genetic correlations between FIV with ADG and OTV were 0.40 and 0.88 respectively. Correlations between performance and feeding behavior traits were generally low. Results suggest that selection would be possible for feeding behavior traits and ADFI, NVD, and OTD could be used to increase accuracy of selection for G:F.

INTRODUCTION

Maximizing production efficiency and improving the genetics of pigs is the goal of the modern swine geneticist. Feed is a major cost of pig production, and improved conversion of feed into saleable product is one approach to increasing profitability. An assessment of opportunities to genetically improve feed conversion by selection requires estimates of heritability of feed intake as well as genetic correlations between feed intake and other traits of economic importance. Correlated responses to selection for economically important traits help provide additional accuracy to traits of economic importance under selection.

Feeding behavior traits have been reported to be moderate to highly heritable (von Felde et al. 1996, Labroue et al. 1997, Cammack et al. 2005). However, von Felde et al. (1996) reported that genetic correlations between performance and feeding behavior traits were generally low. Variance component estimation for feeding behavior traits has occurred in several countries, but not in the U.S. Although feed intake by individual pigs is expensive to record, it has been argued by James (1986) that feed intake should be included in the selection objective even if it is not a component of the selection index. Therefore, the objective of this study was to estimate variance components among feeding behavior traits in a U.S. nucleus population.

MATERIALS AND METHODS

Data was collected from a Duroc nucleus (Smithfield Premium Genetics, Rose Hill, NC) from 2009 to 2012. Boars (n=4,794) were raised on slatted flooring, in a mechanically ventilated building with ad libitum access to feed and water. Pigs were fed a pelleted corn-soy diet that met or exceeded nutrient requirements (NRC, 2012). Starting at an average age of 82 d, individual feed intake and body weight were measured using the FIRE (Feed Intake Recording Equipment, Osborne Industries, Inc., Osborne, KS, USA) system. Gain to feed ratio (G:F) was computed as the ratio between ADG and average daily feed intake (ADFI). At 115 kg of weight, ultrasound backfat thickness (BF) and longissimus muscle depth (MD) were collected and ADG was computed for each individual. Ultrasound measurements were captured from a longitudinal measurement across the last three ribs using an Aloka 500 (Corometrics Medical Systems, Wallingford, CT) B-mode ultrasound machine. Average daily feed intake and number of visits to the feeder per day (NVD) were recorded by the FIRE system. Feed intake per visit to the feeder (FIV) was calculated by dividing ADFI by NVD. Occupational time at the feeder per day (OTD) was recorded by the FIRE system. Occupational time per visit (OTV) was computed by dividing OTD by NVD. Feeding rate (FR) was determined by the ratio of FIV to OTV.

Statistical Analysis

Fixed effects were tested for all traits and model selection was completed using PROC GLM in SAS (SAS Institute, Cary, NC). Fixed effects tested included contemporary group, off-test-weight, and off-test-age. Contemporary group was defined as year × season × pen. All models contained the covariate of weight at end of the FIRE testing except for average daily gain, which used off test age as a covariate. Variance components were estimated using AIREMLF90 using an animal model. All heritability estimates were taken from the single trait analysis.

RESULTS AND DISCUSSION

Growth performance traits

Descriptive statistics and variance component estimates for production and feeding behavior traits from 4,794 Duroc boars are shown in Table 1. Heritability estimates of growth performance traits ranged from 0.20 to 0.68. The heritability estimate for average daily gain (0.34) was lower than those reported by de Haer and de Vries (1993) and Labroue et al. (1997) (0.49 and 0.42, respectively), and slightly greater than that reported by Rothschild and Ruvinsky (2010) (0.29). In the current study, heritability of G:F (0.20) was greater than that reported by Cameron et al. (1988) (0.12) and similar to that of Cameron and Curran (1994) (0.19). In contrast, Smith et al. (1962) reported a greater estimate of heritability for gain to feed ratio (0.58). In the present study, the heritability estimate for backfat thickness (0.68) was similar to Smith et al. (1962) and Cai et al. (2008) who reported heritability estimates of 0.66 and 0.68, respectively. Rothschild and Ruvinsky (2010) reported slightly lower heritability for backfat of (0.49). In the present study, longissimus muscle depth had a heritability of 0.45, less than that reported by Y. Miar et al. (2014) (0.63).

In the present study, genetic correlations between performance traits ranged from -0.12 to 0.48. The genetic correlation between ADG and G:F (0.42) was similar to that reported by McPhee et al. (1979) (0.34). Average daily gain and backfat thickness were moderately correlated (0.48) in the current study. Similarly, McPhee et al. (1979) reported a slightly greater genetic correlation between ADG and backfat (0.55), while Robison and Berruecos (1973) reported a marginally lower estimate (0.37).

Feeding behavior traits

In the present study, heritability estimates for feeding behavior traits ranged from 0.22 to 0.88. The heritability estimate for average daily feed intake (0.36) was similar to that reported by Smith et al. (1962) (0.34). Rothschild and Ruvinsky (2010) reported a lower estimate of heritability for ADFI (0.29), whereas Mrode and Kennedy (1993) reported a greater estimate (0.45) compared to the present study. In the present study, the heritability estimate for feeding rate (0.76) was greater than that reported by von Felde et al. (1996) and similar to Hyun et al. (1997) (0.44 and 0.71, respectively). The heritability estimate for feed intake per visit in the present study was 0.66, similar to findings from Hyun et al. (1997) and greater than estimates by von Felde et al. (1996) and Cammack et al. (2005) (0.60, 0.51, and 0.33, respectively). Heritability for occupational time per visit to the feeder was 0.88 in the current study, which is greater than findings by Labroue et al. (1997) and von Felde at al. (1996) (0.54 and 0.42, respectively). In the present study, the heritability estimate for occupational time at the feeder per day was 0.22, comparable to that by Cammack et al. (2005) and Nkrumah et al. (2014), and less than the estimate by von Felde et al. (1996) (0.29, 0.28, and 0.43, respectively). The heritability estimate for number of visits to the feeder per day was 0.53 in the present study, which is greater than findings by Cammack et al. (2005), Nkrumah et al (2014), and von Felde et al. (1996) (0.36, 0.38, and 0.43, respectively). Results from the current study suggest that selection for feeding behavior traits is possible.

Genetic and environmental correlations between growth performance and feeding behavior traits are shown in Table 2. The genetic correlation between feed intake per visit to the feeder and occupational time at the feeder per visit was 0.88, which is in agreement with Labroue et al. (1997) who reported an estimate of 0.87. This indicates that feed intake per visit to the feeder and occupational time per visit to the feeder are similar traits. In the current study, the genetic correlation between feed intake per visit and number of visits to the feeder per day was -0.92, consistent with Labroue et al. (1997) who reported a genetic correlation of -0.86. This suggests that pigs who visited the feeder fewer times ate more feed per visit. In the present study, occupational time per visit to the feeder and number of visits to the feeder per day had a genetic correlation of -0.94, similar to results found by Labroue et al. (1997) (-0.80). This suggests that pigs who visited the feeder fewer times spent more time at the feeder per visit. Results suggest that feed intake per visit to the feeder and occupational time per visit to the feeder are similar traits. The current research and previous studies show that when pigs visit the feeder fewer times per day, they will spend more time per visit and eat more feed per visit to the feeder.

Genetic correlations between performance and feeding behavior traits

Genetic correlations between performance traits and feeding behavior traits ranged from to -0.66 to 0.62. Average daily feed intake and backfat thickness had a moderate correlation (0.49), which was similar to that of Cameron and Curran (1994) (0.24) and greater than results from Johnson et al. (1999) (0.51).

In the present study, genetic correlations between average daily gain with feeding behavior traits ranged from -0.11 to 0.61. Genetic correlations between average daily gain with feed intake per visit and feeding rate were 0.40 and 0.10, respectively. The genetic correlation between average daily gain and average daily feed intake (0.61) was similar to that reported by Cameron et al. (1988) who reported 0.69. Labroue et al. (1997) reported a relatively greater genetic correlation between average daily gain and average daily feed intake (0.85). The authors also reported moderate correlations between average daily gain with feed intake per visit to the feeder (0.50) and feeding rate (0.40). In the present research, the genetic correlation between average daily gain with occupational time per day at the feeder was -0.11, lower than findings of von Felde et al. (1996) reporting a moderate genetic correlation between average daily gain with occupational time per day at the feeder (0.32).

In the present study, genetic correlations between gain to feed ratio with feeding behavior traits ranged from -0.66 to 0.23. The genetic correlations between gain to feed ratio with number of visits to the feeder per day, occupational time at the feeder per day, and average daily feed intake were -0.41, -0.45, and -0.66, respectively. Multiple studies reported genetic correlations between pig feeding behavior and feed conversion ratio (feed to gain) (von Felde et al. 1996; Labroue et al. 1997; McSweeny et al. 2003). Von Felde et al. (1996) reported genetic correlations between feed conversion ratio with number of visits to the feeder per day, occupational time at the feeder per day, and average daily feed intake of 0.11, 0.12, and 0.13, respectively. Labroue et al. (1997) reported genetic correlations between feed conversion ratio with number of visits to the feeder per day, occupational time at the feeder per day, and average daily feed intake for Large White and French Landrace pigs of 0.03, 0.16, and 0.11, respectively and -0.19, 0.16, and -0.06, respectively. McSweeny et al. (2003) reported genetic correlations between feed conversion ratio with number of visits to the feeder per day, occupational time at the feeder per day, and average daily feed intake of -0.12, 0.12, and 0.01, respectively. These studies showed generally low genetic correlations between FCR with NVD, OTD, and ADFI compared to the present study. Due to moderate negative correlation between G:F with number of visits to the feeder per day, occupational time at the feeder per day, and average daily feed intake would add accuracy of selection to feed efficiency. Nevertheless, further research must be conducted to confirm the genetic correlations between gain to feed ratio with number of visits to the feeder per day, and occupational time at the feeder per day in the present study.

However, in the present study phenotypic correlations between gain to feed ratio with number of visits to the feeder per day, occupational time at the feeder per day, and average daily feed intake were -0.40, -0.51, and 0.64, respectively. Hyun et al. (1997) reported phenotypic correlations between gain to feed ratio with number of visits to the feeder per day, occupational time at the feeder per day, and average daily feed intake of 0.14, -0.24, and -0.34, respectively. Hyun et al. (2001) reported phenotypic correlations between gain to feed ratio with number of visits to the feeder per day and occupational time at the feeder per day of -0.19 and -0.23, respectively.

CONCLUSION

When attempting to reduce feed cost and improve producer profitability, gain to feed ratio would benefit from increased accuracy of selection due to moderately high negative genetic correlations with average daily feed intake, number of visits to the feeder per day, and occupational time at the feeder per day in the present study. Results from the present study reveal that genetic variation exists for pig feeding behavior traits including number of visits to the feeder per day and occupational time at the feeder per day, which may increase accuracy of selection for feed conversion.

Table 3.1 Descriptive statistics and variance component estimates for growth performance and feeding behavior traits for 4,794 Duroc boars.

	No.	Mean	σ^2_a	σ^2_p	h^2	SE
Performance traits						
Average daily gain, kg per d	4780	0.68	0.0026	0.0078	0.34	0.05
Gain to feed ratio	4593	0.32	0.0032	0.0030	0.20	0.03
Backfat thickness, cm	4764	1.02	0.0323	0.0475	0.68	0.07
Longissimus muscle depth, cm	4788	4.04	0.0980	0.2194	0.45	0.06
Feeding behavior traits						
Average daily feed intake, kg per d	4664	2.19	0.0263	0.0724	0.36	0.05
Number of visits per d	4713	6.53	0.5196	0.9800	0.53	0.06
Feed intake per visit to feeder, kg	4787	0.42	0.0188	0.0285	0.66	0.06
Occupational time at feeder per d, min.	4754	68.56	22.176	99.620	0.22	0.03
Occupational time at feeder per visit, min.	4784	12.76	10.594	12.103	0.88	0.08
Feeding rate, kg per min.	4741	0.03	0.0005	0.0007	0.76	0.07

σ^2_a = additive genetic variance, σ^2_p = phenotypic variance, h^2 = heritability

Table 3.2 Estimated genetic (above diagonal) and phenotypic (below diagonal) correlations between growth performance and behavior traits on 4,794 Duroc boars.

Trait	Average daily gain	Gain to feed ratio	Backfat thickness	Longissimus Muscle depth	Averge daily feed intake	No. visits to feeder per day	Feed intake per visit to feeder	Occupational time at feeder per day	Occuoational time at feeder per visist	Feeding rate
Average daily gain		0.42	0.48	-0.12	0.62	-0.22	0.40	-0.11	0.03	0.10
Gain to feed ratio	0.41		0.03	0.09	-0.66	-0.41	0.20	-0.45	0.18	0.23
Backfat thickness	0.41	0.04		0.16	0.49	0.14	0.18	-0.22	-0.19	0.36
Longissimus muscle depth	0.22	0.06	0.04		0.04	-0.21	0.15	-0.34	-0.18	0.09
Average daily feed intake	0.42	-0.64	0.37	0.15		0.11	0.25	0.25	-0.08	-0.77
No. visits to feeder per day	0.06	-0.40	0.09	-0.02	0.36		-0.92	-0.32	-0.94	-0.49
Feed intake per visit to feeder	0.13	0.19	0.11	0.07	0.01	-0.86		0.21	0.88	0.25
Occupational time at feeder per day	0.12	-0.51	0.02	0.03	0.57	0.43	-0.32		0.52	-0.88
Occupational time at feeder per visit	0.01	0.13	-0.09	0.00	0.12	-0.55	0.59	0.45		-0.52
Feeding rate	0.09	0.24	0.08	-0.34	-0.61	-0.77	0.26	-0.56	-0.26	

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