ABSTRACT

KNAUER, MARK THOMAS. Genetics of Gilt Estrous Behavior. (Under the direction of Dr. M. Todd See).

Studies were conducted to develop and analyze gilt estrous behavior as related to production and first parity traits. Variance components, genetic correlations, and genetic line differences were estimated for gilt estrus, puberty, growth, composition, structural conformation, and first litter sow reproductive measures. Four groups of Landrace-Large White gilts (n=1,225, GIS of NC) from 59 sires and 330 dams were utilized. Heritability (h^2) estimates for estrous traits; length of estrus, maximum strength of standing reflex with a boar, total strength of standing reflex with a boar, maximum strength of standing reflex without a boar, total strength of standing reflex without a boar, vulva redness, strength of vulva reddening and swelling (VISUAL VULVA), and vulva width were 0.21, 0.13, 0.26, 0.42, 0.42, 0.26, 0.45, and 0.58, respectively. For puberty traits; age at puberty, puberty weight, puberty backfat, and puberty longissimus muscle, h^2 estimates were 0.29, 0.39, 0.41, and 0.38, respectfully. The h^2 of whether or not a gilt farrowed a litter (STAY1) was 0.14. Age at puberty had favorable genetic associations with length of estrus, maximum strength of standing reflex with a boar, vulva redness, STAY1, and age at first farrowing (AFF) (-0.23, -0.32, 0.20, -0.27, and 0.76, respectively). Genetic correlations between length of estrus and the standing reflex traits with STAY1 (0.34 to 0.74) and AFF (-0.04 to -0.41) were positive and negative, respectively. Growth rate had unfavorable genetic correlations with length of estrus, the standing reflex traits, vulva redness, STAY1, and AFF (0.30, 0.14 to 0.34, -0.19, 0.52, and -0.25, respectfully). Backfat had unfavorable genetic associations with length of estrus, age at puberty, and first litter total number born (TNB1) (0.29, -0.26, and 0.47, respectively). Vulva redness and TNB1 had favorable phenotypic and genetic correlations (-0.14 and -0.53, respectively). For estrous traits, crossbred performance was superior to the pure-line average for length of estrus, total strength of standing reflex with a boar, vulva redness, VISUAL VULVA, and vulva width. These findings imply the use of F_1 females would increase length of estrus and improve vulva traits. The unfavorable genetic associations between production and reproduction traits further strengthen the need for a balanced selection objective. Selection for strength of standing reflex with a boar is suggested through direct or indirect selection (i.e. age at first farrowing).

Genetics of Gilt Estrous Behavior

by
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Biography

Mark Thomas Knauer was born and raised in southern Wisconsin. Growing up on a pure-line pig (Hampshire, Landrace, Yorkshire) and cattle (Angus) operation Mark acquired an interest in livestock at an early age. He exhibited pure-line Landrace animals at local, state, and national shows. Active in livestock and meats judging in 4-H and FFA Mark captured all four state championships. Mark was also active in high school sports participating in basketball, football, track, and wrestling. After attending a semester at UW Platteville, it was an interest in agriculture and wrestling that led him to Iowa State University. There he majored in agriculture education and wrestled heavyweight (although rather skinny) on the university team. Upon graduation Mark completed a M.S. in Animal Science with a focus on Animal Breeding under the direction of Dr. Ken Stalder at Iowa State. His research focused on sow longevity. Mark then faced a decision whether to continue his wrestling career at Colorado Springs, CO or pursue a Ph.D. at North Carolina State University. Choosing sunshine and warm temperatures Mark enrolled at NC State in the fall of 2006 under the direction of Dr. Todd See and Dr. Joe Cassady. Building off his research at Iowa State and trying to address swine industry needs Mark formulated a plan with Dr. See to study gilt estrous behavior. Improvement in this area would reduce labor and increase reproductive efficiency on pig farms. Upon successful completion of his dissertation Mark plans to become gainfully employed where he can make a positive impact on the livestock industry.

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Introduction

Maximizing saleable pigs per female per year at the lowest cost is the goal of a modern swine industry. Pig reproductive genetic evaluations have chosen to focus predominantly on pigs per litter (Rydhmer, 2000). In practice, however, problems also exist with other reproductive traits such as weak estrous signs or symptoms. Absent, short, or weak estrous symptoms increase the difficulty of detecting estrus and mating in herds that utilize artificial insemination.

Few studies have reported (co)variance estimates for estrous traits. Perhaps this is due to the difficulty associated with developing well defined measures of physiological and behavioral indicators of estrus. Rydhmer et al. (1994) and Gäde et al. (2006) reported genetic variation for estrous traits in gilts and sows, respectively. However, Rydhmer et al. (1994) noted “practical methods of registering estrous traits in the field must be developed before they can be included in the breeding work”.

Increasing behavioral estrus strength is expected to offer several economic benefits to producers. Strong visible estrous symptoms reduce farm labor needed for detecting estrus. Females easily identified in estrus reduce missed heat cycles thereby decreasing non-productive sow days and increasing pigs per sow per year. Good estrous symptoms reduce culls for reproductive failure which improves reproductive lifetime and reduces gilt replacement costs. Greater conception rates and fewer non-productive days reduce feed costs by decreasing the number of females needed for mating.

Elevated estrogen levels during pro-estrus are responsible for clinical estrous behavior (Andersson et al., 1984). Standing reflex is the sexual behavior upon which most matings are based (Flowers, 1998). Other visual indicators include vulva swelling, increased activity, vocalization, mucous discharge, and riding of other females.

Physiology of estrous behavior traits

Age at puberty

At puberty estradiol, luteinizing hormone, and progesterone increase (Karlbom et al., 1982). Follicle-stimulating hormone also surges at this time. A diagram of these events is depicted in Figure 1.1 (Bearden and Fuquay, 2000). After puberty, a fall in progesterone coincides with a rise in estrogen concentration. Estrogen peaks during pro-estrus and drops sharply just before the onset of standing estrus.

Progesterone and estradiol have negative correlations with age at puberty. Eliasson (1991) collected blood samples to estimate circulating plasma concentrations of progesterone every 10 days from 170 days of age to approximately 12 days after first observed estrus from Swedish Yorkshire gilts. Levels of plasma concentrations of progesterone were determined by radioimmunoassay. The authors reported a negative correlation (r = -0.15, $P < 0.01$) between age at puberty and progesterone concentration measured 10 to 14 days after the determined first estrus. Knauer and See (unpublished data) collected urine samples at puberty to ascertain estradiol levels in 125 Landrace-Large White gilts. Age at puberty and estradiol were negatively correlated (r = -0.19, $P < 0.05$). However, urine samples were only collected once a day. Perhaps increasing the frequency of estrus checks per day and urine samples would better define peak level of estrogen and the association between age at puberty and estradiol. Negative relationships between age at puberty with progesterone and estradiol may partially explain superior reproductive performance associated with early maturing gilts.

Leptin, a peptide hormone produced by adipocytes involved in appetite regulation, has also been associated with age at puberty. Kuehn et al. (2009) reported age and leptin concentration at puberty had negative ($P < 0.05$) phenotypic (-0.51) and genetic (-0.63) correlations. However, the authors note leptin concentrations from blood samples taken from a portion of these gilts at fixed ages were not phenotypically correlated with age at puberty ($P > 0.05$). Thus the correlation may have been due to a phenotypic decrease in leptin concentrations resulting from age vs. pubertal status.

Standing reflex

To identify females exhibiting a standing reflex Willemse and Boender (1966) developed the back-pressure test. During the test, hand pressure is applied to the longissimus dorsi in the presence of a boar, females that become immobilized and "push back" are determined to be in estrus. "Ear play", characterized by the ears becoming erect and/or flickering is also typical during the standing reflex.

Estradiol is the hormone primarily responsible for the standing reflex. Dial et al. (1983) studied the influence of varying doses of estradiol benzoate on occurrence and length of estrus. Prepubertal gilts were randomly treated with 0, 10, 20, 100, or 200 μg estradiol benzoate per kg of body weight. Increasing dose of estradiol benzoate tended ($P < 0.10$) to increase the proportion of prepubertal gilts in estrus. The same study reported increasing dose of estradiol benzoate administered was positively correlated ($r = 0.82$, $P < 0.01$) with length of standing estrus. This indicates estradiol is the predominant endocrine signal that determines length of standing estrus. Exogenous estrogen has also been shown to induce the standing reflex in barrows (Ford and Schanbacher, 1977). Besides pigs, length of standing estrus is also associated with estradiol in dairy cattle. Lyimo et al. (2000) reported estradiol was correlated with a composite score of length of estrus and strength ($r = 0.66$, $P < 0.05$).

The standing reflex is characterized by isometric muscle contractions from most of the pig's skeletal muscle. This process uses an immense amount of energy as most females become fatigued. Levis and Hemsworth (1995) induced estrus in 17 ovariectomized gilts by injecting 0.8 mg of estradiol benzoate on two consecutive days and measured the proportion of gilts standing after entry to the estrus check pen. The proportion of gilts showing the standing reflex at 0, 5, 10, 11, 16, and 21 minutes 123 hours after injection was 100, 94, 77, 71, 65, and 65%, respectively.

Both boar and sow stimuli are thought to elicit the standing reflex. Hughes et al. (1990) summarized the boar effect on initiating the standing reflex in gilts. Although the underlying biological mechanisms are poorly understood, a combination of visual, auditory, tactile, and olfactory stimuli are involved. The most important of these stimuli is thought to be olfactory. Female pheromones may also be involved as exposure of primiparous weaned sows to an estrus sow shortened the duration of the rebreeding period after weaning during summer months (Pearce and Pearce, 1992). However, boar vs. sow stimuli is much more effective in eliciting a standing reflex response.

Vulva swelling and coloring

Vulva swelling and coloring is associated with elevated estrogen levels (Andersson et al., 1984). Intensity of vulva symptoms peak just prior to the standing reflex and then subside, coinciding with the peak in estrogen. Andersson et al. (1984) reported duration of vulva symptoms was shorter ($P < 0.01$) at fourth vs. second pro-estrus (23.4 vs. 56.4 hours) although estradiol levels were higher ($P < 0.01$) (43.9 vs. 37.8 pmol) in six Swedish Landrace × Yorkshire gilts. Similarly, Andersson and Einarsson (1980) established reddening and swelling of the vulva during pro-estrus was longer for first and second estrus vs. third to sixth estrus in 11 gilts. Perhaps the relationship between vulva traits and estrous number is explained by a change in the estrogen receptor mechanism in the vulva tissue. Ozasa and Gould (1982) reported the presence of vulva estrogen receptors was associated with vulva swelling in chimpanzees. Thus a change in the estrogen receptor mechanism may also explain why gilts have stronger vulva symptoms than sows.

Beeson et al. (1955) reported feeding estrogens effected vulva traits. The authors fed 2.0 mg of diethylstilbestrol daily from 20 to 105 kg. In females, there was a marked increase in mammary tissue, growth of the teats, and an increase in size of the vulva. Similarly, feeding zearalenone, an estrogenic mycotoxin synthesized by different strains of Fusarium, can increase vulva reddening and swelling (McErlean, 1952). Although feeding zearalenone is detrimental to reproduction, these studies further show the importance of estrogen as related to vulva traits.

Increased activity

Female pigs increase their motor activity during estrus (Altmann, 1941) and will often seek a boar. Gilts coming into or leaving standing estrus also have a tendency to ride other pigs. Estrogen is related to activity during estrus. Ford (1983) studied the activity of ovariectomized gilts and barrows after postpubertal estrogen treatment. Animals were allowed simultaneous access to a mature boar and an ovariectomized sow. Gilts and barrows castrated within 48 hours of birth spent more time near the mature boar than the sow.

Automation of estrus detection by measuring female activity has been proposed. Blair et al. (1994) fitted transponder collars to sows after weaning and placed them in a pen. Within that pen, a boar pen was constructed. Solid wood partitions were placed between the boar and sow pens so that the only available contact between the boar and sows was immediately over the antenna of an electronic estrus detection station. A computer was utilized to monitor boar visitation by the sows. The authors concluded their system would be useful for detecting estrus and measuring age at puberty. Currently, Osborne Industries Inc. (Osborne, KS) markets the same concept in the United States, the *TEAM* electronic estrous detection system. However, the concept has yet to gain popularity here. One reason may be limited scientific cost benefit analysis has been performed on the system.

Phenotypic and genetic variation for estrous behavior traits

A summary of genetic estrous behavior studies are shown in Table 1.1. Heritability estimates range from 0.09 to 0.55.

Age at puberty has ample variation from which to make selection. Reported phenotypic standard deviations range from 20 to 30 days for age at puberty (Eliasson, 1991; Lamberson et al., 1991; Johnson et al., 1994; Rydhmer et al., 1994; Bidanel et al. (1996); Cassady et al., 2002; Kuehn et al., 2009) and 21 to 32 days for age at first mating (Hanenberg et al., 2001; Holm et al., 2005). Heritability estimates for age at puberty range from 0.20 to 0.55 (Lamberson et al., 1991; Johnson et al., 1994; Rydhmer et al., 1994; Bidanel et al. (1996); Cassady et al., 2002; Kuehn et al., 2009) and age at first mating from 0.31 to 0.32

(Hanenberg et al., 2001; Holm et al., 2005). In a review, Rydhmer et al. (2000) reported that the average literature heritability estimate for age at puberty and age at first mating was 0.30.

Selection for reduced age at puberty is possible. Lamberson et al. (1991) reported that the total response to selection for decreased age at puberty was -15.7 days ($P < 0.01$) after eight generations. Genetic line differences reported for age at puberty (Young, 1995; Young, 1998; Moeller et al., 2004) also indicate selection is feasible. Chinese breeds such as Meishan and Fengjing are known to have younger ages at puberty relative to American lines (i.e. Duroc, Yorkshire). However, incorporating Meishan or Fengjing to reduce age at puberty would be counterproductive as these breeds tend to be relatively fat and slow growing. A better option would be to reduce age at puberty in the lean, fast growing lines present in the United States.

Rydhmer et al. (1994) reported heritability estimates for estrous traits from 740 Swedish Yorkshire gilts. Estrus detection was performed twice daily from 160 to 260 days of age and blood samples were taken every 10 days to measure progesterone concentrations. Age at puberty was defined as age at first detected ovulation and was determined by combining estrus and progesterone records. This differs from most studies as normally the first observed standing reflex is used to define age at puberty. However, use of progesterone data by Rydhmer et al. (1994) allowed silent estruses (gilts that ovulate but do not exhibit the standing reflex) to be quantified. Heritability estimates not previously reported included length of pro-estrus (0.23), length of standing estrus (0.16), duration of vulva reddening and swelling (0.38), the ability to exhibit the standing reflex at puberty (0.12 to 0.29), and the ability to exhibit strong vulva reddening and swelling at puberty (0.11 to 0.24). Of the gilts that reached puberty, 87% exhibited the standing reflex and 83% had strong vulva reddening and swelling. Although very valuable information, the majority of the estrous traits measured by Rydhmer et al. (1994) are currently difficult to measure with the exception of length of estrus. Length of estrus would be relatively easy to record once a day as most nucleus farms perform daily estrus checks.

In 464 Swedish Yorkshire gilts and sows, Sterning et al. (1998) reported phenotypic and genetic variation for estrous traits. Means and standard deviations for length of pro-estrus, length of standing estrus, and length of vulva reddening and swelling were 3.8, 1.9, and 7.5 and 3.4, 0.7, and 5.0 days, respectively for gilts and 2.1, 2.0, and 6.4 and 1.6, 0.6, and 2.5 days, respectively for sows. Phenotypic correlations between gilt and sow length of pro-estrus, length of standing estrus, and length of vulva reddening and swelling were 0.08, -0.03, and 0.26, respectively. However gilt vs. sow estrous traits have been shown to have a higher repeatability (Eliasson-Selling, 1991). Sterning et al. (1998) further reported 78% of sows ovulated and exhibited the standing reflex within 10 days of weaning ($h^2 = 0.31$). Of the other 22%, 7% ovulated without showing a standing reflex, 1% exhibited the standing reflex without ovulating, and 14% neither ovulated nor showed a standing reflex.

Gäde et al. (2006) estimated variance components for estrous behavior from 9,717 German PIC Landrace × Large White composite sows in 32 farms. Estimation was conducted with a threshold animal model using a Gibbs sampling statistical procedure. The trait estrous behavior was a composite of swelling and coloring of the vulva, interest in the boar, and tolerance of the boar mounting scored 1 (clear and intense) to 5 (absent). The mean, standard deviation, and heritability for estrous behavior was 1.9, 0.7, and 0.09, respectively. Although a low heritability was realized, this study indicates selection for estrous symptoms is possible outside of experimental conditions.

Genetic line differences for length of estrus indicate selection is possible. Bazer et al. (1988) studied reproductive differences between 82 Meishan and Large White gilts. Average length of estrus was longer ($P < 0.01$) for Meishan vs. Large White females (60 vs. 49 hours). Similarly, White et al. (1993) reported a longer ($P < 0.05$) length of estrus in Meishan vs. Yorkshire gilts for first (2.7 vs. 1.9 days), second (2.6 vs. 1.9 days), and third (2.9 vs. 2.1 days) estrus. It remains unclear what the optimal length of standing estrus is. A short estrus of 12 to 24 hours is likely to increase culling in a commercial sow farm that heat checks once daily. However a long estrus may increase the difficulty of timing the insemination relative to ovulation. Further investigation examining the effects of a long length of estrus on subsequent conception rate should take place before length of estrus is incorporated into a selection scheme.

Langendijk et al. (2000) studied the amount of boar contact needed to elicit a response to the back-pressure test in 130 Yorkshire × Dutch Landrace sows. For each treatment, the protocol for estrus detection consisted of four stimulus levels. Each stimulus level was applied to all the sows before proceeding to the next stimulus level. First, sows were checked for a standing response in absence of a boar, using the back-pressure test. Second, fence-line boar contact was used but the sow was not given the back-pressure test. Third, fence-line boar contact was used in conjunction with the back-pressure test. Fourth, sows were checked for the back-pressure test after being in a pen surrounded by four boar pens. The percentage of sows exhibiting the standing reflex for the first, second, third, and fourth levels of stimulus were 41, 54, 89, and 97%, respectively. Hence, the author's demonstrated phenotypic variation for the level of stimulus needed to elicit the standing reflex. Ideally 100% of females would exhibit the standing reflex instantaneously for the back-pressure test in the absence of a boar. Then usage of boars to detect estrus would be unnecessary.

Cronin et al. (1983) developed a scoring system in response to the back-pressure test for 2,484 Australian Landrace × Large White gilts. Four score categories were created; negative (vigorous avoidance), low (stands for 10 seconds before running off), moderate (stands for 15 to 30 seconds before running off), and high (stands for greater than 30 seconds and exhibits ear play). Of the 260 gilts not mated by 35 weeks of age, 31, 49, 6, and 14% of gilts had negative, low, moderate, and high responses, respectively, to the back-pressure test. Thus, the authors demonstrated phenotypic variation for strength of standing reflex in the presence of a boar. A strong standing reflex reduces culling for reproductive failure, non-productive days, and labor needed for estrus detection. Hence strength of standing reflex may be the breeding goal for estrous traits. Strength of standing reflex may be expensive to measure in a nucleus setting. Perhaps a correlated trait, such as age at first farrowing, would be the ideal way to select for strength of standing reflex.

Production traits correlated with estrous behavior

Growth

Typically age at puberty is thought to have a negative correlation with growth rate, a lower age at puberty associated with a faster growth rate. This is supported by Eliasson et al. (1991), Rydhmer (1993), Rydhmer et al. (1994), and Bidanel et al. (1996) who reported low favorable phenotypic (-0.09 to -0.16) and genetic (-0.07 to -0.31) correlations between age at puberty and average daily gain. Holm et al. (2004) established a favorable genetic association between age at first mating and days to 100 kg (0.68). In agreement, Serenius and Stalder (2004) reported favorable phenotypic (-0.19 to -0.20) and genetic (-0.35 to -0.45) correlations between age at first farrowing and average daily gain. Perhaps associations between growth rate with age at first mating or first farrowing vs. puberty are larger in magnitude due to management practices. Often gilts are not bred until they reach a target weight which would increase the correlation between growth rate and age at first mating. Perhaps mating gilts in accordance to their estrus number is ideal in a nucleus setting while a combination of weight and estrus number best in a commercial setting.

Growth rate has no effect or an unfavorable association with vulva and standing reflex traits. Eliasson (1991) reported no differences in average daily gain between gilts that exhibited the standing reflex at puberty vs. those that did not (805 vs. 815g) or strong vs. weak vulva reddening and swelling (805 vs. 811g). Rydhmer et al. (1994) reported low phenotypic correlations between average daily gain with length of pro-estrus, length of standing estrus, ability to exhibit the standing reflex at puberty, and ability to show strong vulva reddening and swelling at puberty of -0.00, -0.02, -0.08, and -0.05, respectively. Genetic correlations between average daily gain with length of pro-estrus and the ability to show strong vulva reddening and swelling at puberty were low (0.03 and 0.19, respectively). Genetic associations between average daily gain with length of standing estrus and ability to exhibit the standing reflex at puberty were negative (-0.49 and -0.61, respectively). These unfavorable correlations further strengthen the need for a balanced selection objective.

Especially since growth rate, a key component trait in selecting for lean growth efficiency is in the selection objective of most breeding programs.

Backfat

Gilt backfat has been shown to have a negative correlation with age at puberty, a lower backfat associated with a higher age at puberty. Eliasson et al. (1991), Rydhmer (1993), and Rydhmer et al. (1994) reported unfavorable phenotypic (0.12 to 0.20) and genetic (0.20 to 0.40) associations between lean percentage and age at puberty. Similarly, Bidanel et al. (1996) established unfavorable phenotypic and genetic correlations between backfat and age at puberty (-0.11 and -0.21, respectively). Holm et al. (2004) estimated a small unfavorable genetic association between age at first mating and backfat (-0.03) in 56,932 Norwegian Landrace. In agreement, Serenius and Stalder (2004) reported low unfavorable phenotypic (-0.06) and genetic (-0.09 to -0.18) correlations between age at first farrowing and backfat at 100 kg. Perhaps these results indicate successful selection for reduced backfat during the past two decades in the United States has increased age at puberty and/or age at first farrowing. A rise would increase sow farm non-productive days.

Backfat generally has low unfavorable associations with vulva and standing reflex traits. For vulva traits Eliasson (1991) reported gilts with strong vs. weak vulva symptoms had more ($P < 0.01$) backfat (15.0 vs. 14.3 mm) and a lower ($P < 0.05$) lean percentage (58.7 vs. 59.2 %). Length of pro-estrus and length of vulva reddening and swelling were positively correlated with backfat (0.09 to 0.11) and lean percentage (-0.15). In agreement, Rydhmer et al. (1994) reported negative phenotypic and genetic associations between lean percentage with length of pro-estrus (-0.12 and -0.09, respectively) and length of vulva reddening and swelling (-0.09 and -0.17, respectively). In standing estrous traits Eliasson (1991) established backfat and lean percentage had no effect on the ability to exhibit the standing reflex at puberty or length of standing estrus (r = 0.01 and 0.00, respectively). Rydhmer et al. (1994) reported low positive genetic associations between lean percentage with length of standing estrus and the ability to exhibit the standing reflex at puberty (0.02 and 0.10, respectively).

Reproduction traits correlated with estrous behavior

Age at puberty

Age at puberty has favorable associations with other estrous behavior traits. This statement is supported by Eliasson (1991) who established negative phenotypic associations between age at puberty with length of pro-estrus, length of standing estrus, and length of vulva reddening and swelling (-0.14, -0.01, and -0.11, respectively). Similarly, Rydhmer et al. (1994) reported negative genetic correlations between age at puberty with length of standing estrus and the ability to exhibit strong reddening and swelling of the vulva (-0.12 and -0.01, respectively). However, the same study reported a low positive genetic association between age at puberty with the ability to exhibit a standing reflex at puberty (0.05). In sows, Sterning et al. (1998) established negative phenotypic and genetic correlations between age at puberty with the ability to ovulate and exhibit the standing reflex within 10 days of weaning (-0.22 and -0.50, respectively). These results indicate selection for a reduced age at puberty would indirectly improve sow estrous behavior. Thus selection for a reduced age at puberty would appear to improve estrous behavior in gilts and sows.

Standing reflex and vulva traits

Rydhmer et al. (1994) reported positive phenotypic and genetic correlations between duration of vulva reddening and swelling with length of pro-estrus (0.43 and 0.66, respectively) and length of standing estrus (0.11 and 0.22, respectively). Also, the ability to exhibit the standing reflex at puberty had a positive genetic association with the ability to exhibit strong vulva reddening and swelling at puberty (0.52). In sows, Sterning et al. (1994) established positive phenotypic correlations between length of pro-estrus with length of vulva reddening and swelling and intensity of vulva reddening and swelling (0.76 and 0.26, respectively). Length and intensity of vulva reddening and swelling also had a positive association (0.32). Length of standing estrus did not have an association ($P > 0.05$) with length or intensity of vulva reddening and swelling (-0.05 and -0.02, respectively). Both Rydhmer et al. (1994) and Sterning et al. (1994) established length of pro-estrus and length of standing estrus had a negative phenotypic correlation (-0.10 and -0.16, respectively) in gilts and sows, respectively. Perhaps these results indicate larger, redder vulvas are easier to identify coming into estrus. Larger, redder vulvas have a favorable genetic association with strength of standing reflex indicating selection for one trait would positively affect the other. Perhaps the role estrogen plays in the expression of vulva and standing reflex traits explains their favorable association. Both traits are correlated with peak estradiol levels.

Litter size

Puberty, first mating, or first farrowing ages have an unclear association with litter size. Rydhmer et al. (1993), Hanenberg et al. (2001), Serenius and Stalder (2004), Holm et al. (2005) reported genetic correlations between age at first mating or farrowing with litter size of 0.00, -0.08, 0.01 to 0.21, and 0.17, respectively. The same authors reported phenotypic correlations ranging from 0.07 to 0.12. In contrast, Young et al. (2008) established early puberty (< 185 days of age, n = 165) vs. later puberty (≥ 185 days, n = 945) gilts tended (P = 0.13) to farrow more piglets born alive (10.7 vs. 10.2) in PIC crossbred gilts. Similarly, Nelson et al. (1990) reported early puberty (148 to 205 days, n = 12) vs. late puberty (210 to 254 days, n = 13) gilts tended (P < 0.10) to farrow more live piglets (9.32 vs. 8.34) in Yorkshire-based crossbred females. However, Holder et al. (1995) reported a line selected for reduced age at puberty vs. control were not different (P > 0.05) for litter size (8.5 vs. 8.5) or ovulation rate (14.3 vs. 14.1, respectively), a component trait of litter size. Bidanel et al. (1992) established favorable phenotypic and genetic correlations between age at puberty and ovulation rate (-0.04 and -0.36, respectively). In contrast, Rosendo et al. (2007) reported differing estimates between the same traits (0.04 and 0.24, respectively).

Perhaps differing results reported relating litter size to age at puberty is explained by maturity. Gilts mated at a younger age have fewer body reserves built up for reproduction. Once these sows reach a mature skeletal size, the negative environmental effect of early mating is reduced or eliminated. This is supported by Tummaruk et al. (2001) who reported the association between age at first mating with litter size from parities 1 to 5 in Swedish Landrace and Yorkshire females. Age at first mating and litter size had a positive association in parity 1 and a negative association in parities 4 and 5.

Duration of standing estrus may have a positive association with litter size. Steverink et al. (1999) investigated the effects of reproductive traits related to duration of standing reflex in 55 Dutch commercial swine farms. The average duration of standing estrus tended (P = 0.09) to be favorably correlated with litter size within farm (r = 0.23). Within repeat-breeder sows, duration of standing estrus had a favorable ($P < 0.05$) linear association to litter size. However, duration of estrus did not affect litter size in gilts. The authors noted number of inseminations, timing of insemination, and duration of estrus were correlated and therefore confounded. Sterning (1995) studied the effects of litter size on subsequent estrous behavior. The author reported total number born, number born alive, and number of piglets at three weeks had negative ($P > 0.05$) correlations with duration of standing estrus (-0.11, -0.07, and -0.02, respectively).

Gäde et al. (2006) established a low unfavorable genetic correlation between estrous behavior and litter size (-0.05). However the study did not specify whether litter size was previous or subsequent relative to the estrous behavior measure. In contrast, Cronin et al. (1982) reported gilts that showed a high vs. moderate response to the back-pressure test on their first day of mating had a higher ($P < 0.05$) litter size (9.35 vs. 9.05). Despite differences between studies a distinct estrous period with strong symptoms is necessary for a successful mating or insemination (Rydhmer et al. (1994). Hence every female missed due to poor estrous behavior farrows zero piglets.

Interval and conception traits

Interval and conception traits (i.e. wean-to-estrus interval, wean-to-conception interval, farrowing interval, conception rate) are positively associated with age at puberty. Sterning et al. (1998) established favorable phenotypic and genetic correlations between age at puberty with weaning-to-estrus interval (0.16 and 0.45, respectively). These findings are supported by Serenius and Stalder (2004) who reported positive genetic associations between age at first farrowing with first farrowing interval (0.25 to 0.55). Several other studies report favorable genetic associations between age at puberty, first mating, or first farrowing with sow interval and conception traits (Holder et al., 1995; Hanenberg et al., 2001; Holm et al., 2005). These results clearly indicate a lower age at puberty has a favorable association with subsequent sow reproductive performance.

Reproductive lifetime

A reduced age at puberty is commonly associated with improved sow reproductive lifetime. Holder et al. (1995) reported the effect of decreasing age at puberty on reproductive lifetime in sows. Two lines from the Nebraska Gene Pool population were used: a line that had been selected for decreased age at puberty (AP) and a line in which selection had been random (RS). Gilts from AP and RS lines reached puberty at an average age of 159 and 170 days, respectively. After five parities, the percentage of sows farrowing relative to parity 1 was 58.8% for the AP line, but only 39.4% for the RS line. Moeller et al. (2004) reported results from the National Pork Producers Council Maternal Line Program, the largest reproductive lifetime study to date with standardized culling criteria. Average age at puberty for the six genetic lines Newsham, National Swine Registry, American Diamond Swine Genetics, Danbred, Dekalb-Monsanto DK44, and Dekalb-Monsanto GPK347 was 223, 222, 225, 222, 222, and 209 days, respectively. The percentage of sows completing four parities was 52, 52, 50, 48, 50, and 70%, respectively. The GPK347 females again illustrate a genetic line with a younger age at puberty having superior reproductive lifetime. These results are supported by Nelson et al. (1990), Schukken et al. (1994), Koketsu et al. (1999), Yazdi et al. (2000), and Serenius and Stalder (2004) who reported a lower age at puberty, first conception, or farrowing was associated with improved reproductive lifetime. This association can be explained by those gilts that mature early are less likely to be culled for reproductive failure, the leading cause of culling (Dagorn & Aumaitre, 1979; D'Allaire et al., 1987; Lucia et al., 2000). In contrast, Brooks and Smith (1980) and Kirkwood et al. (2000) established age at puberty had no effect of reproductive lifetime. However, these studies lowered age at puberty in a portion of the animals through environmental techniques (boar exposure and P.G. 600, respectively), a likely explanation. Reducing age at puberty by environmental methods should increase pigs per sow per day but appears to have little effect on length of productive life.

Environmental factors associated with estrous traits

Age at puberty

The effect of feeding level on age at puberty has been studied thoroughly. Many experiments have been conducted comparing ad libitum vs. restricted feeding regimes on the attainment of puberty. These studies have shown mixed results. Age at puberty for gilts fed 60 to 70 % of ad libitum vs. ad libitum was delayed (Robertson et al., 1951), advanced (Christian and Nofziger, 1952; Self et al., 1955), or did not differ (Gossett and Sorensen, 1959). However feeding gilts 50% of ad libitum increased age at puberty (Haines et al., 1955). More recent studies also show mixed results as Beltranena et al. (1991), Newton and Mahan (1993) and Klindt et al. (2001) reported restricted vs. ad libitum feeding increased or had no effect on age at puberty. Restricting feed intake to 80% of ad libitum during the finishing phase reduces feed costs while not severely inhibiting age at puberty. Given the inconsistency of published results it is concluded that environmental factors other than nutrition exert a marked effect on age at puberty.

Utilizing boar exposure to reduce age at puberty is well documented (Zimmerman et al, 1969; Brooks and Cole, 1970; Brooks and Smith, 1979). Brooks and Smith (1979) induced puberty at different ages (160 or 200 days) utilizing boar exposure in 64 Landrace crossbred gilts. Mean age at puberty for the two groups was 171 and 216 days, respectively. Clearly, boar exposure influences the onset of puberty.

Other boar factors such as age, libido, and frequency of exposure also influence age at puberty. Kirkwood and Hughes (1981) studied the influence of boar age on the attainment of puberty. Boars of three ages (two years, 11 months, and 6.5 months) were penned with gilts for 30 minutes daily. Gilts exposed to two year or 11 month vs. 6.5 month old boars were younger ($P < 0.01$) at puberty (182 vs. 206 days). Age at puberty was similar ($P > 0.05$) between gilts exposed to 6.5 month boars and those receiving no boar contact (206 and 203 days, respectively). These results indicate very young boars are ineffective in advancing puberty in gilts. Perhaps C_{19} steroid levels explain differences reported between boar ages. Booth (1975) reported C_{19} steroids concentrations, including 5-androstenediol, were relatively low at 24 months and peaked at two years of age in boars. Kirkwood and Hughes (1981) suggest boars 10 months or older be used to stimulate puberty. However libido differences between boars this age also influence age at puberty. Hughes (1994) studied the effects of boar libido on 81 Landrace × Large White gilts. Twelve boars were classified as either high or low libido based on three 15 minute mating tests at 9 to 10 months of age. High vs. low libido boars hastened ($P < 0.05$) age at puberty (180 vs. 194 days). Philip and Hughes (1995) investigated the effects of boar contact frequency on puberty attainment. Exposure started at 160 days of age and continued for 60 days. Gilts were exposed to boars once, twice, or three times daily, each treatment totaling 60 minutes in duration. Boar exposure three times daily vs. once daily reduced ($P < 0.01$) gilt pubertal age (183 vs. 196 days). Twice daily boar contact resulted in an intermediate age at puberty (190 days). Thus increasing the frequency of boar exposure appears to have an additive effect on the attainment of puberty.

Photoperiod is an environmental factor that may mediate seasonal variation in attainment of puberty in gilts (Paterson et al., 1991). Paterson et al. (1991) allocated 467 Landrace × Large White gilts to either isolation or exposure to a mature boar for 30 minutes daily. The proportion reaching puberty was lower ($P < 0.01$) for the long-day vs. the short-day group in both the isolated (0.14 vs. 0.53) and the boar-exposed gilts (0.74 vs. 0.89). However, there was no seasonal effect on the interval to puberty in either treatment. This study shows photoperiod, although confounded with temperature, may influence age at puberty. However, the study also demonstrated boar exposure virtually eliminates the effect of photoperiod on the attainment of puberty. Perhaps remaining differences between the long-day and short-day boar exposed gilts are explained by high ambient temperatures.

Flowers et al. (1989) studied the effects of high ambient temperatures on puberty attainment. Forty crossbred gilts were placed in environmentally controlled chambers at 140 days of age. After a ten day acclimation period of 20°C, gilts were randomly allocated to one of two treatments; control (15.6°C) or heat stress (33.3°C). More gilts ($P < 0.01$) reached puberty by 230 days of age under the control conditions (18/20) than the heat stress environment (4/20). These results clearly indicate constant exposure to high ambient temperatures delay puberty attainment in gilts.

The effects of P.G. 600 (400 IU of pregnant mare's serum gonadotropin and 200 IU of human chorionic gonadotropin) on inducing puberty are well documented. Britt et al. (1989) conducted ten trials involving 678 presumed prepuberal gilts (5.5 to 7.5 months old) in North Carolina, Illinois, and Missouri to evaluate the reproductive performance of gilts given P.G. 600. Gilts received P.G. 600 or no treatment (control) on the day of movement from finishing facilities to breeding pens and were then checked daily for estrus with mature boars. Treatment with P.G. 600 vs. controls increased ($P < 0.05$) the percentage in estrus within 7 (58 vs. 41%) or 28 days (73 vs. 60%) and average interval to estrus was reduced ($P < 0.05$) from 10.4 to 7.5 days. Farrowing rate, number of pigs born alive, and number of pigs weaned were unaffected ($P > 0.05$) by treatment. These results are supported by Tilton et al. (1995) and Knox et al. (2000) who also reported P.G. 600 and boar exposure vs. only boar exposure induced a faster and more synchronized estrus within a cohort of gilts. Currently using P.G. 600 is common management practice to induce estrus activity in prepubertal gilts that are "late responders" in the U.S. However this practice has two drawbacks, cost and gilts treated with P. G. 600 do not always commence estrus activity.

Ford and Teague (1978) reported space restriction did not influence the attainment of puberty in gilts. In their study controls were allotted 0.37 m^2 per pig at 23 kg. At 34.6 kg each pig was given 0.09 m^2 more space and the same increase at every 13.6 kg gain in average pen weight thereafter. Space restricted gilts received 25 or 50% less area than controls. However Rahe et al. (1987) established gilts allowed 1.06 m^2 from 30 to 65 kg and 1.25 m^2 from 65 to 100 kg vs. 50% the area had heavier adrenal ($P < 0.01$), pituitary ($P < 0.08$), brain ($P < 0.11$), uterine ($P < 0.09$), and ovarian ($P < 0.07$) tissues. Perhaps social crowding affects the development of endocrine organs that are involved in the reproductive process. This is supported by Young et al. (2008) who reported more ($P < 0.05$) gilts allowed 1.13 m^2 vs. 0.77 m^2 attained puberty by 200 days of age. However subsequent reproduction in parities 1 to 3 did not differ between space allocations. The studies by Rahe et al. (1987) and Young et al. (2008), unlike Ford and Teague (1978), confounded space restriction with feeder space. Thus the relationship between puberty attainment and space allocation remains unclear.

Mixing, relocation, and transport to stimulate gilt puberty attainment have been studied either on their own or in combination with boar contact (Zimmerman et al., 1976; Close et al., 1982; Hughes et al., 1997). Collectively these studies established management “stressors” improve synchrony and reduce age at puberty used in conjunction with boar exposure. Without boar exposure these management techniques have little influence on age at puberty. From an animal standpoint relocation and transport may minimize injuries relative to mixing.

Standing reflex

The use of mature boars is the best way to elicit a standing reflex response. However increased boar exposure (more specifically continuous exposure) is not always better. Hemsworth et al. (1988) examined the effects of gilt estrous behavior when housing 45 Landrace × Large White crossbred gilts near or adjacent to boars. The three treatments applied included housing gilts; adjacent to a mature boar with a wire mesh wall separating them, adjacent to a mature boar with a solid wall separating them, and opposite a mature boar with a 1 m wide corridor and wire mesh separating them. A higher ($P < 0.05$) percentage of females exhibited the standing reflex using the back-pressure test when penned 1 meter away vs. adjacent to mature boars and separated by wire mesh (93 vs. 53%). Adjacent to boars with solid walls was intermediate (73%). The authors concluded the practice of housing gilts adjacent to boars may result in gilts habituating to the boar stimuli which facilitate the standing reflex. These results are supported by findings from Hemsworth et al. (1984) and Hemsworth et al. (1986). Thus housing males at least 1 meter from females appears optimal to elicit the standing reflex during estrus detection.

Season has been reported to influence the strength of standing reflex. Cronin et al. (1982) established weak standing reflexes were more ($P < 0.01$) likely to occur during summer vs. winter months (16.5 vs. 10.7%) in gilts. The same study reported moderate or strong standing reflexes were more ($P < 0.05$) common during winter or spring vs. summer or fall months (83 vs. 79%).

Length of standing estrus

Steverink et al. (1999) established average length of standing estrus ranged from 31 to 64 hours between farms. Thus farm accounted for 23% of the total variation in length of standing estrus. Farms were highly repeatable from month to month ($r = 0.86$). Perhaps discrepancies between farms are partially explained by different interpretations of behavioral signs of estrus although a standardized protocol was utilized. Nonetheless farm appears significantly associated with variation in length of standing estrus.

Gilts on average have a shorter length of standing estrus than sows. This is supported by Steverink et al. (1999) who reported a shorter ($P < 0.01$) length of standing estrus in gilts vs. sows (41 vs. 49 hours). The same study reported an interaction ($P < 0.05$) between farm and parity as 10 of the 52 farms length of standing estrus did not differ between gilts and sows. In sows, Steverink et al. (1997) established parity 1 and 2 vs. 3 to 7 females had a shorter ($P < 0.01$) length of standing estrus (55 vs. 62 hours) in 115 terminal line sows. From these results it is unclear whether length of standing estrus increases with parity and/or young females with a short duration of estrus are more likely to be culled. Steverink et al. (1999) established that repeat-breeder sows, which are more likely to be culled for reproductive failure, had a shorter ($P < 0.01$) length of standing estrus compared to sows first inseminated after weaning (47 vs. 50 hours). Thus these results support females with a short length of standing reflex are more likely to be removed from the herd.

Wean-to-estrus interval (WEI) has a negative association with length of standing estrus. Steverink et al. (1999) reported length of standing estrus decreased ($P < 0.05$) when WEI increased from 4 to 5 days (56 vs. 50 hours) and 5 to 6 days (50 vs. 46 hours). In agreement, Belstra (2004) established length of standing estrus decreased ($P < 0.05$) when WEI increased from 3 to 4 days (65 vs. 58 hours) and 4 to 5 days (58 vs. 52 hours). These findings are supported by Sterning (1995) who established a negative correlation between length of standing estrus and WEI (-0.19, $P = 0.01$).

Maternal effects, more specifically intrauterine position, have been shown to influence length of standing estrus. Rohde et al. (1990) studied the effects of uterine position, relative to the sex of adjacent fetuses, on subsequent behavior and reproductive performance of pigs. Uterine position was recorded for each pig as between 2 females (0M, $n = 16$), between a male and a female (1M, $n = 25$) or between 2 male fetuses (2M, $n = 17$). Length of standing estrus was similar among groups until the third estrus when the duration of standing heat was shorter for 2M females, both when measured in the presence (2.8, 2.7 and 2.1 days for 0M, 1M and 2M, respectively; $P < 0.10$) and the absence of a boar (2.1, 1.3 and 0.9 days for 0M, 1M and 2M, respectively; $P < 0.01$).

Andersson et al. (1984) reported no difference in length of standing estrus between second and fourth estrus gilts (52 vs. 52 hours). Similarly, Andersson and Einarsson (1980) reported no differences in length of standing estrus over the first six estrous cycles except the third was longer than the fourth (2.3 vs. 1.9 days, $P < 0.05$). However Karlbom et al. (1982) reported gilts had lower peak estradiol levels at puberty vs. second estrus. These results indicate length of standing estrus would be shorter at puberty relative to second estrus. This is supported by Eliasson-Selling (1991) who reported length of standing estrus at puberty was shorter than second estrus. In sows, Sterning et al. (1994) established the first vs. second estrus after weaning tended ($P < 0.10$) to be shorter (2.0 vs. 2.2 days). It appears gilts may have a shorter length of standing estrus at puberty relative to subsequent estrous cycles.

Belstra (2004) examined the effects of season, parity, genotype, lactation length, and WEI on length of standing estrus in three North Carolina sow farms. Estrus detection occurred every 6 hours from day 2 to 10 postweaning in 535 sows. Average length of standing estrus for the study was 55.2 hours. Weaning-to-estrus interval, season, lactation length, parity, farm, and genotype explained 67.5, 23.0, 7.4, 1.3, 0.6, and 0.2%, respectively, of the variation in length of standing estrus.

Vulva swelling and coloring

Studies indicate pro-estrus symptoms reduce after the first or second estrus in gilts. Andersson et al. (1984) reported length of pro-estrus was longer ($P < 0.01$) for the second vs.

fourth estrus. In agreement Andersson and Einarsson (1980) reported length of vulva reddening and swelling were longer in the first and second estrus relative to the third through sixth estrus. Eliasson-Selling (1991) established length of pro-estrus at puberty was longer ($P < 0.05$) than the two subsequent ones. However in sows Sterning et al. (1994) reported length and intensity of vulva reddening and swelling were lower ($P < 0.05$) in the first vs. second estrus after weaning (6.4 vs. 7.3 days, and 2.7 vs. 2.9, respectively). Perhaps these differing results are explained by lactation. Sow's vulva symptoms may be poorer directly after weaning since they are likely in a negative energy balance.

Little information is available relating boar exposure to vulva traits. However, Eliasson-Selling (1991) noted gilts reared in the presence of a boar vs. absence had a longer pro-estrus.

Genetic Evaluation

Before the advancement of statistics and computers the idea of selection on phenotype was utilized in animal breeding. Typically an animal's value is constituted of several traits of varying importance. Animal breeders assigned an animal's worth based on phenotype and possibly relative information. Often no physical records were recorded as the animal breeder stored the information in his or her memory.

Phenotypic selection allowed breeders to make genetic progress in traits that were highly heritable (i.e. frame size) but little to no improvement in lowly heritable traits (i.e. litter size). Lush (1940) suggested using the idea of heritability to account for environmental effects on phenotype, thus selection would be heredity based. This concept would help pave the way for constructing selection indexes.

L. N. Hazel, a student of Dr. Lush, constructed the idea of selection index, the basis for modern genetic evaluations. The selection index allows maximum genetic progress by giving the proper weight to each piece of information in multiple trait selection (Hazel, 1943). An index of an individual can be written as $I = b_1P_1 + b_2P_2 + b_3P_3 + ...$ where P is the phenotypic value of an individual or group of relatives and the b's are the weighting factors for each piece of information (Falconer and Mackay, 1996). The b's are obtained by solving a simultaneous set of equations using matrix methodology. Because livestock producers in 1943 were just beginning to collect data, the concept of selection index was slow to materialize (Hazel et al., 1994). In pigs, Farmers Hybrid started using the selection index for their genetic evaluation program in 1961 (Schneider, 2004).

C. R. Henderson, a student of Dr. Hazel, advanced the selection index theory. Dr. Henderson developed the concept of mixed model equations and a method to efficiently find the inverse of the relationship matrix. These advancements led to the development of BLUP (best linear unbiased predictor) technology. Essentially BLUP is a special case of selection index that estimates breeding values and fixed effects simultaneously while accounting for all known relationships between individuals. Nearly all genetic evaluations world-wide currently utilize BLUP (Van Vleck, 1998).

While BLUP was first introduced in dairy cattle in the 1970's (Van Vleck, 1998), swine genetic evaluation systems did not incorporate the technology until the early 1990's (See, personal communication). Currently, the National Swine Registry and the majority of United States pig breeding companies utilize BLUP to estimate breeding values for traits of interest. Then economic weights are multiplied by the breeding values to form an index. Subsequently the index is used to select herd replacements at the nucleus level.

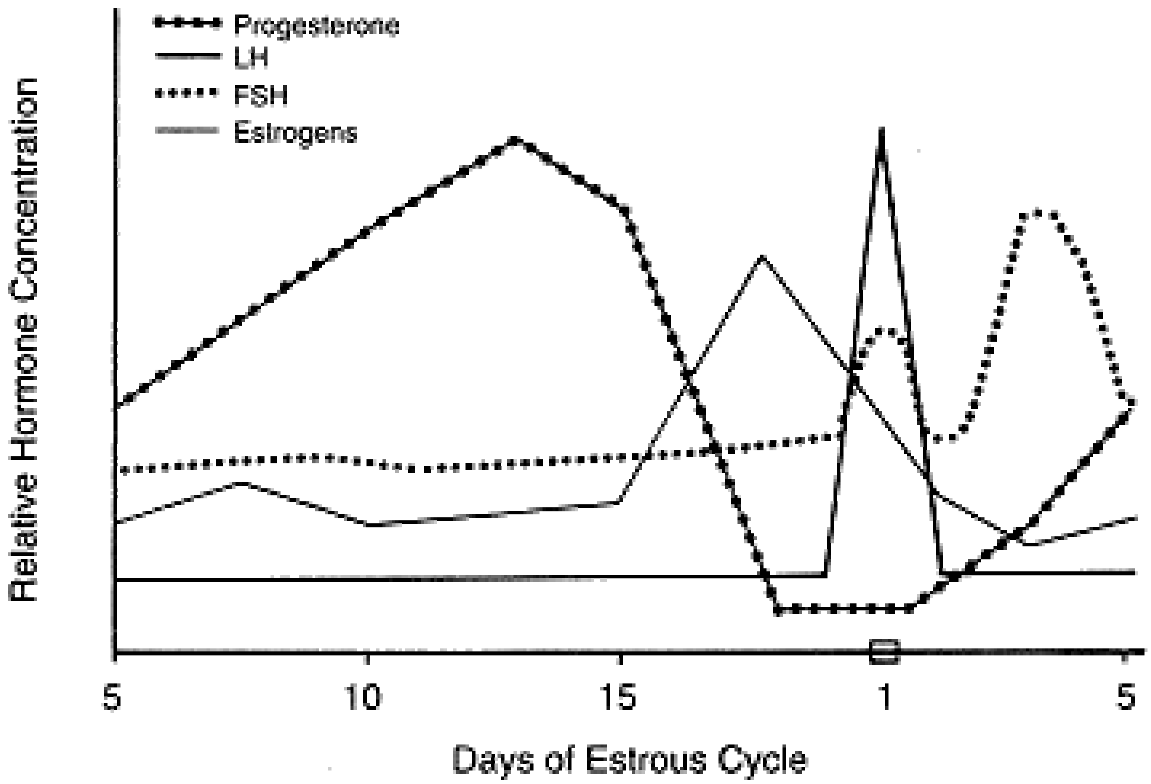

Figure 1.1. Relative hormone concentration of progesterone, luteinizing hormone, follicle-stimulating hormone, and estrogens during the estrous cycle in the female pig (Bearden and Fuquay, 2000).

Table 1.1. Summary of estrous behavior genetic studies.

Gilt traits		No.	Mean	SD	h^2
Age at puberty, days	[1]	-	-	-	0.20 – 0.32
	[2]	-	-	27	0.55
	[3]	740	208	21	0.32
	[4]	1,393	215	30	0.29
	[5]	2,132	206	30	0.31
	[6]	924	205	-	0.46
Age at first mating, days[7]		58,194	234	21	0.32
	[8]	56,042	220	32	0.31
Length of pro-estrus, days[3]		611	3.0	2.7	0.23
Length of standing estrus, days[3]		614	1.8	0.7	0.16
Length of vulva reddening and swelling, days[3]		687	6.0	4.1	0.38
Exhibiting the standing reflex, %[3]		737	87	-	0.12 – 0.29
Exhibiting vulva reddening and swelling, %[3]		730	83	-	0.11 – 0.24
Sow traits					
Estrus within 10 days of weaning, %[9]		452	78	-	0.31
Estrous behavior, scored 1 to 5[10]		9,717	1.9	0.70	0.09

[1]Lamberson et al. (1991), [2]Johnson et al. (1994), [3]Rydhmer et al. (1994),

[4]Bidanel et al. (1996) [5]Cassady et al. (2002), [6]Kuehn et al. (2009), [7]Hanenberg et al. (2001),

[8]Holm et al. (2005), [9]Sterning et al. (1998), [10]Gäde et al. (2006)

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Chapter 2

Estimates of variance components for genetic correlations among swine estrous traits

Abstract

Variance components and genetic correlations were estimated among estrus, puberty, growth, and composition traits in Landrace-Large White gilts (n=1,225, GIS of NC) from 59 sires and 330 dams. Four groups of gilts entered the NC Swine Evaluation Station, Clayton, NC at an average age of 162 d and were checked daily for estrus. Once 70% of gilts reached puberty, recording of estrous symptoms occurred every 12 h for 30 d utilizing fence-line boar contact. Subjective estrous traits were maximum strength of standing reflex with or without a boar present, total strength of standing reflex with or without a boar present, and strength of vulva reddening and swelling (VISUAL VULVA). Objective estrous traits consisted of vulva redness, vulva width, length of estrus, and age at puberty (AGEPUB). Growth and composition traits included puberty weight (PUBWT), days to 114 kg (DAYS), 10th rib backfat and 10th rib LM area at 114 kg (BF, LMA) and puberty (PUBBF, PUBLMA). Variance components were estimated using AIREMLF90 with an animal model. All models included gilt development diet class and breed composition as fixed effects, entry age as a covariate (except DAYS, BF, and LMA), a random common litter effect, and random animal genetic effect. Heritability estimates for length of estrus, maximum strength of standing reflex with a boar, total strength of standing reflex with a boar, maximum strength of standing reflex without a boar, total strength of standing reflex without a boar, vulva redness, VISUAL VULVA, vulva width, AGEPUB, PUBWT, PUBBF, PUBLMA, DAYS, BF, and LMA were 0.21, 0.13, 0.26, 0.42, 0.42, 0.26, 0.45, 0.58, 0.29, 0.39, 0.41, 0.38, 0.24, 0.47, and 0.39, respectfully. Common litter effect estimates ranged from 0.01 to 0.09. The estimated genetic correlation between length of estrus and maximum strength of standing

reflex with a boar was 0.99. Genetic correlations between AGEPUB with length of estrus, maximum strength of standing reflex with a boar, and vulva redness were -0.23, -0.32, and 0.20, respectively. Length of estrus had positive genetic associations with DAYS and BF (0.30 and 0.29, respectively). It was concluded that past selection for lean gain may have weakened the strength of standing reflex and sufficient genetic variation exists to make selection for improved swine estrous traits effective.

Introduction

Maximizing saleable pigs per female per year at the lowest cost is the goal of a modern swine industry. Pig reproductive genetic evaluations have chosen to focus predominantly on pigs per litter (Rydhmer, 2000). In practice, however, problems also exist with other reproductive traits such as estrus. Absent, short, or weak estrus symptoms increase the difficulty of detecting the standing reflex and mating in herds that utilize artificial insemination.

Few studies have reported (co)variance estimates for estrus traits. This is likely due to the difficulty associated with developing well defined measures of physiological and behavioral indicators of estrus and then validating their association with sexual receptivity. Rydhmer et al. (1994) and Gäde et al. (2006) reported genetic variation for estrus traits in gilts and sows, respectively. However, Rydhmer et al. (1994) noted that “practical methods of registering estrus traits in the field must be developed before they can be included in the breeding work”.

Increasing behavioral estrus strength is expected to offer several economic benefits to producers. Strong visible symptoms reduce labor needed for detecting estrus. This, in turn, reduces missed heat cycles, decreases non-productive sow days, and increases pigs per sow per year. Strong estrus symptoms reduce culling due to reproductive failure, improve reproductive lifetime, and reduce gilt replacement costs. Greater conception rates and fewer non-productive days reduce feed costs by decreasing the number of females needed for mating in order to maintain a constant level of production.

The objectives of this study were to develop quantitative methods for measuring estrus in swine and estimate variance components for genetic correlations among these variables and production traits.

Materials and methods

Four successive groups of Landrace-Large White gilts (n=1,225), from 59 sires and 330 dams, were provided by Genetic Improvement Services (Newton Grove, NC). Gilts entered the North Carolina Swine Evaluation Station (Clayton, NC) at about 162 d of age and were penned by weight. Group 1 gilts were placed 3 per pen while groups 2, 3, and 4 were placed in pens of 8 pigs. Groups 1, 2, 3, and 4 contained approximately 145, 360, 360, and 360 gilts respectively. Groups 3 and 4 were inoculated at entry with a live Porcine Reproductive and Respiratory Syndrome (PRRS) vaccine. This was done due to the PRRS status of the sow farms the gilts eventually entered. Gilts were off-tested when average pen weight reached 114 kg and placed on different gilt development diets. A summary of gilt development diet classes are presented in Table 2.1.

Puberty detection

Boars (8 to 20 mo of age) were used once daily (twice daily for gilt group 1) to check for gilts reaching puberty. The same group of boars was used for groups 2, 3, and 4. Age at puberty (AGEPUB) was the first observed standing reflex for the back-pressure test in the presence of a boar (Willemse and Boender, 1966). Puberty detection was carried out by bringing a pen of gilts to a boar and penning them together for 5 min. Once 70% of gilts reached puberty (approximately 2 mo after placement), recording of estrous traits began.

Estrous traits

Estrus traits were measured every 12 h for 30 d utilizing fence-line boar contact. Fence-line boar contact consisted of two boars in front of each pen for 2.5 min per pen (5 total min of boar exposure per pen).

The first standing reflex for the back-pressure test during the 30 d measurement period started the recording of estrus traits. Estrus length was number of consecutive days during which a gilt exhibited the standing reflex in response to the back-pressure test in the presence of a boar. The scoring systems for strength of standing reflex traits are summarized in Table 2.2. Strength of standing reflex in the presence of a boar was scored 1 (weak) to 5 (strong) every 12 h. This score was a composite of how well the gilt exhibited the standing reflex before, during, and after the back-pressure test. Maximum strength of standing reflex with a boar was the sum of the highest two consecutive scores received. For example, if a gilt's highest two consecutive scores were 4 and 3, then her maximum strength of standing reflex would be 7. Total strength of standing reflex with a boar was the sum of all strength of standing reflex scores in the presence of a boar (a composite trait of estrus length and strength). Strength of standing reflex without a boar was scored 0 (weak) to 7 (strong) (Table 2.2) at least 20 min after the boars had fence-line contact with the gilts. This score was created using concepts from Langendijk et al. (2000) where sows varied in the level of stimulus required to exhibit the standing reflex. In the current study, a technician applied back-pressure to the gilt. If she exhibited the standing reflex, the technician then sat on top of her and the highest score was recorded. Maximum strength of standing reflex without a boar was the sum of the highest two consecutive scores received. Total strength of standing reflex without a boar was the sum of all the standing reflex scores in the absence of boar exposure (a composite trait of estrus length and strength).

Vulva traits were assessed visually and using various instruments. Strength of vulva reddening and swelling (VISUAL VULVA) was scored via the following criteria: absent (0), weak (1), moderate (2), or strong (3). These measurements were obtained during the first standing reflex of the 30 d measurement period. Vulva width and redness were measured at this time. The width of the vulva was measured using a dial caliper (S-T Industries, Inc., Saint James, MN). Vulva redness was assessed using a colorimeter (Konica Minolta, U.S.). The L* value was recorded which corresponds to a dark-bright scale (0 to 100), a lower number indicated a darker color.

Puberty, growth, and composition traits

Growth and composition traits were measured at puberty and at 114 kg. Puberty weight (PUBWT) and days to 114 kg (DAYS) were calculated. Backfat and LM area were measured at puberty (PUBBF, PUBLMA) and at 114 kg (BF, LMA). Composition traits were measured from a cross sectional 10^{th} rib image using an Aloka 500V SSD ultrasound machine (Corometrics Medical Systems, Inc., Wallingford, CT).

Statistical Analysis

Fixed effects were tested for all traits using PROC MIXED in SAS (SAS Institute, 2003). All models contained fixed effects of gilt development diet class and breed composition, entry age as a covariate (except for DAYS, BF, and LMA), a random birth litter effect, and a random genetic animal effect. Off-test BF and LMA were pre-adjusted to 114 kg using recommendations in the Guidelines for Uniform Swine Improvement Programs (NSIF, 1997). Variance components were then estimated with AIREMLF90 (Misztal et al., 2002) using an animal model. Fixed effects and covariates for all traits were as previously stated. All variance components were estimated from two trait models. Heritability estimates presented are averages from estimates of multiple analyses. Heritability standard errors were estimated using the following equation

$s.e. = \left(\frac{h^2}{a}\right)\left\{\left(1-h^2\right)^2 \operatorname{var}(a) - 2\left(1-h^2\right)h^2 \operatorname{cov}(a,e) + \left(h^2\right)^2 \operatorname{var}(e)\right\}$ where h^2 = heritability, a = additive genetic variance, and e = environmental variance.

Results and discussion

Estrus traits

Significant genetic variation was found for all estrus traits. Descriptive statistics and heritability (h^2) estimates of estrus, puberty, growth, and composition traits for 1,225 Landrace-Large White gilts are shown in Table 2.3. Heritability estimates for estrus traits ranged from about 0.2 to 0.4. This is in agreement with Rydhmer et al. (1994) which reported heritability estimates for estrus traits of approximately 0.2 to 0.3. In the current study, heritability estimates of estrus length and VISUAL VULVA (0.21 and 0.45, respectively) were slightly higher than estimates reported by Rydhmer et al. (1994) (0.16 and 0.24, respectively). Gäde et al. (2006) reported a lower heritability (0.09) for estrus behavior (swelling and coloring of the vulva, interest in boar, and tolerance of mounting).

Common litter effects explained 1 to 8% of the variation in estrus traits. Common litter effect estimates for estrus length, total strength of standing reflex with a boar, and VISUAL VULVA were 0.07, 0.07, and 0.08, respectively. These estimates indicate the presence of a maternal component due to the intrauterine or pre-weaning environments. Drickamer et al. (1997) reported gilts and sows from litters with a high vs. low percentage of males were less likely to conceive. This is an example of how the intrauterine environment (sex ratio) affects subsequent reproductive traits. Nelson and Robison (1976) reported gilts reared in small vs. large litters farrowed more pigs born alive. This is an example of how pre-weaning maternal effects affect subsequent reproduction.

Genetic and phenotypic correlations between estrus, puberty, growth, and composition traits for 1,225 Landrace-Large White gilts are shown in Table 2.4. The genetic correlation between estrus length and maximum strength of standing reflex with a boar was 0.99. This indicates estrus length and strength were the same trait. Peak estradiol also appears highly associated with estrus length and strength. Dial et al. (1983) assigned five dosages of estradiol benzoate (0, 10, 20, 100 or 200 ug per kg of body weight) to prepubertal gilts. The authors reported a correlation of 0.82 between estradiol benzoate and estrus length. The same study also found a trend for increasing dose of estradiol benzoate to increase the proportion of prepubertal gilts in estrus. This indicates a threshold level of estrogen is needed to exhibit estrus behavior. In swine, peak estradiol, estrus length, and estrus strength appear to be related traits. This is supported by a study done in dairy Lyimo et al. (2000) reported a correlation of 0.66 between estradiol and a composite score of estrus length and strength.

Vulva traits had positive and negative genetic correlations with estrus length and the standing reflex traits. Vulva redness, VISUALVULVA, and vulva width had favorable genetic associations with all of the standing reflex traits (-0.06 to -0.39, 0.01 to 0.17, and 0.06 to 0.22, respectively). Thus selection on either vulva redness or standing reflex traits may result in darker red colored vulvas (on white pigs) and gilts that have stronger standing reflexes. Darker colored and larger vulvas were associated with a longer estrus length which is in agreement with Rydhmer et al. (1994). Perhaps estrogen explains the favorable genetic associations between vulva and standing reflex traits. Peak estradiol plays a significant role in the expression of vulva (Andersson et al., 1984) and standing reflex traits (Dial et al., 1983).

Age at puberty had negative genetic correlations with estrus length, maximum strength of standing reflex with a boar, and total strength of standing reflex with a boar (-0.23, -0.32, and -0.25, respectively). This means selecting for reduced age at puberty (or a similar trait such as age at first mating or age at first farrowing) would increase estrus length and strength. Rydhmer et al. (1994) reported lower genetic associations between age at puberty and estrus traits. However, in that study age at puberty was determined by combining progesterone and estrus records compared with the current study that utilized the first observed standing reflex. Perhaps the favorable genetic associations between age at puberty and estrus traits in the current study explain the favorable negative association between age at puberty with sow reproductive lifetime (Moeller et al., 2004; Knauer et al., 2009). Sows with good estrus symptoms are less likely to be removed from the herd for reproductive failure thus producing additional litters and more piglets in their lifetime.

The three vulva traits had favorable genetic associations. Both VISUAL VULVA and vulva width had negative genetic correlations with vulva redness (-0.39 and -0.29, respectively) indicating larger vulvas are also darker in color. Vulva width and VISUAL VULVA had a genetic correlation of 0.97 indicating they were effectively the same trait. However, those traits may have been somewhat confounded as they were measured at the same time (first standing reflex during the 30 d test period) by the same person.

Genetic correlations between estrus traits with growth and composition traits were generally low. However, estrus length and total strength of standing reflex with a boar had positive genetic associations with BF (0.29 and 0.27, respectively). This indicates a longer estrus length was associated with higher backfat. Vulva redness and vulva width had unfavorable genetic correlations with LMA (0.26 and -0.17, respectively). In agreement, Rydhmer et al. (1994) reported unfavorable genetic correlations between vulva traits and lean percentage. The current study and the one conducted by Rydhmer et al. (1994) indicate that selection in the swine industry for increased percent lean may have had adverse effects on estrus. The genetic correlation between estrus length and DAYS was positive (0.30), indicating a longer estrus length was associated with slower growth rate. This is supported by Rydhmer et al. (1994) who reported a negative relationship between estrus length and growth rate (-0.49). Unfavorable genetic relationships realized between estrus traits with composition and growth measures increases the need for a balanced breeding objective.

Puberty, growth, and composition traits

Heritability estimates of puberty traits ranged from 0.29 to 0.41. The heritability estimate for AGEPUB of 0.29 is similar to Rydhmer et al. (1994) and slightly lower than Kuehn et al. (2009) (0.32 and 0.46, respectively). However estimates from Rydhmer et al. (1994) and Kuehn et al. (2009) did not include a common litter effects. In the current study, heritability estimates for PUBWT (0.39) and PUBBF (0.41) were in agreement with Kuehn et al. (2009) (0.48 and 0.45, respectively). Hutchens et al. (1981) also reported a similar heritability estimate for puberty weight of 0.35 from paternal half sibs.

Age at puberty had a positive genetic correlation with PUBWT (0.93). Kuehn et al. (2009) reported a genetic association of 0.65 between age at puberty and puberty weight. Perhaps selecting for a younger age at puberty would reduce mature sow size and, thus, reduce sow feed costs. This is supported by Brooks and Smith (1980) who concluded that lowering age at puberty through early boar exposure reduced sow feed costs.

Puberty traits had high genetic correlations with corresponding off-test traits. Estimated genetic correlations between PUBWT and DAYS, PUBBF and BF, and PUBLMA and LMA were -0.57, 0.68, and 0.89, respectively. In agreement, Hutchens et al. (1981) reported a genetic correlation between puberty weight and average daily gain of 0.81. In the current study when puberty traits were adjusted for age or weight (PUBWT) the genetic associations between PUBWT and DAYS, PUBBF and BF, and PUBLMA and LMA were -1.00, 0.93, and 0.98, respectively. However, PUBWT, PUBBF, and PUBLMA were not adjusted for age or weight at measurement because the actual measures at the time of puberty were desired.

Heritability estimates for DAYS, BF, and LMA were 0.24, 0.47, and 0.39, respectively. These estimates are similar to those reported by Clutter and Brascamp (1998).

Improving estrus symptoms

Maximum strength of standing reflex with a boar is the breeding goal for improving estrus detection. This is because currently U.S. commercial pig farms use boars to detect females in estrus that exhibit the standing reflex. Estrus length, maximum strength of standing reflex with a boar, and total strength of standing reflex with a boar were similar measures (genetic correlations ≥ 0.94). Perhaps total strength of standing reflex with a boar had a higher heritability than estrus length (0.26 vs. 0.21) because a more accurate description of the beginning and ending of the estrus cycle was recorded. Conceivably total strength of standing reflex with a boar had a higher heritability than maximum strength of standing reflex with a boar (0.26 vs. 0.13) due to more phenotypic variation (CV 33% vs. 15%). Therefore total strength of standing reflex with a boar, although labor intensive to measure, would improve strength of standing reflex the fastest. However, an improved scoring system that increased phenotypic variation for maximum strength of standing reflex with a boar may be of interest.

Improving vulva size appears quite feasible as vulva width had a heritability of 0.58. Large vulvas that change color improve estrus detection in gilts. Therefore, increasing vulva size would aid in locating gilts that are potentially exhibiting the standing reflex.

Estrus length, age at puberty (or a similar trait such as age at first mating or age at first farrowing), or both may be the most promising of the estrus traits measured to incorporate into current nucleus selection schemes. Estrus length is relatively easy to measure (if measured once a day) and highly associated with strength of standing reflex. However a very short or long estrus length may not be desirable; there may be an intermediate optimum. A very short estrus length (less than 1 d) may be difficult to detect while in a very long estrus length timing of insemination relative to ovulation may be difficult. Age at puberty was shown to have favorable associations with strength of standing reflex, vulva redness, and growth rate. A younger age at puberty or age at first farrowing is also associated with reduced generation interval, reduced seasonal infertility (Knauer and See, unpublished data), increased proportion of gilts exhibiting estrus (Young, 1998), and increased sow reproductive lifetime (Knauer et al., 2009). Thus the benefits of a lower age at puberty appear numerous. Estimates of correlations between estrus traits and sow reproductive performance are needed.

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Table 2.1. Gilt development diet classes for 1,225 Landrace-Large White gilts.

	Gilt development diet class (GDD)						
	1	2	3	4	5	6	7
Gilt group	1	2		3		4	
Entry date	11/8/2006	6/25/2007		11/1/2007		3/4/2008	
Entry age, d	139	163	164	174	175	159	160
Age starting GDD, d	187	187	187	198	200	183	185
Days on GDD	27	73	77	69	69	74	75
Diet type	finisher	finisher	gestation	gestation	gestation	gestation	gestation
Moisture, %	NA[1]	5.5	12.7	13.1	13.1	12.0	12.0
Crude protein, % DM	NA	13.5	14.4	15.5	15.5	15.5	15.5
Crude fat, % DM	NA	7.1	3.7	3.7	3.7	4.5	4.5
Ash, % DM	NA	3.2	5.2	4.9	4.9	6.4	6.4
ADF, % DM	NA	2.6	3.5	3.5	3.5	9.7	9.7
NDF, % DM	NA	15.1	18.1	15.1	15.1	46.6	46.6
Total lysine, % DM	NA	0.70	0.65	0.72	0.72	0.68	0.68
Calcium, % DM	NA	0.43	0.97	0.85	0.85	1.03	1.03
Phosphorus, % DM	NA	0.38	0.73	0.72	0.72	0.85	0.85
Meal or pellet	meal	meal	meal	meal	meal	pellet	pellet
Feed per day, kg	ad lib[2]	ad lib	ad lib	ad lib	2.05	2.05	2.5
Gilts per pen	3	8	8	8	8	8	8

[1]not measured but formulated the same as GDD 2, [2]ad libitum

Table 2.2. Scoring systems for strength of standing reflex (SR) traits used to measure 1,225 Landrace-Large White gilts.

Score	Description
Strength of standing reflex in the presence of a boar	
1	Weakly exhibits the SR for the back-pressure test (BPT) after 5 min.
2	Weakly exhibits the SR for the BPT (stands some for the boar but moves around often) within 5 min.
3	Moderately exhibits the SR after the BPT (stands for boar but moves around some).
4	Strongly exhibits the SR after the BPT (stands firm without any movement, excellent ear play[1]).
5	Strongly exhibits the SR after the BPT (same as #4 but very strongly seeks the boar).
Strength of standing reflex without a boar	
0	Gilt does not stand.
1	Exhibits the SR for the back-pressure test after 10 s.
2	Exhibits the SR for the back-pressure test within 10 s.
3	Exhibits the SR for the human sit[2] but moves somewhat forward.
4	Exhibits the SR for the human sit after 20 s.
5	Exhibits the SR for the human sit within 20 s without ear play.
6	Exhibits the SR for the human sit within 20 s with ear play.
7	Exhibits the SR reflex without touching the gilt.

[1]ear play = whether the ears became erect relative to their normal posture, [2]human sit = human sitting on top of the gilt similar to the front half of a boar mounting

Table 2.3. Descriptive statistics and estimated variance components[1] for estrus, puberty, growth, and composition traits from 1,225 Landrace-Large White gilts.

	No.	Mean	Min.	Max.	σ_p^2	c^2	h^2	SE
Estrous traits[2]								
Length of estrus, d	1024	2.1	0.5	4	0.40	0.07	0.21	0.07
MAX BOAR STAND	1024	7.6	2	10	1.24	0.02	0.13	0.06
TOTAL BOAR STAND	1024	15.1	2	29	24.3	0.07	0.26	0.08
MAX NO BOAR STAND	1024	8.2	0	14	15.6	0.01	0.42	0.09
TOTAL NO BOAR STAND	1008	12.6	0	34	59.2	0.01	0.42	0.09
Vulva redness	999	60.5	50.1	71.9	8.0	0.02	0.26	0.08
VISUAL VULVA	1028	1.7	0	3.5	0.49	0.08	0.45	0.09
Vulva width, mm	1006	39.8	26	58	23.5	0.04	0.58	0.09
Puberty traits								
Age at puberty, d	1054	211.9	143	292	745	0.07	0.29	0.08
Puberty weight, kg	1054	137	89	213	831	0.04	0.39	0.09
Puberty backfat, cm	1054	2.1	0.7	4.7	0.117	0.01	0.41	0.09
Puberty LM area, cm^2	1054	48	28	69	6.41	0.09	0.38	0.09
Growth and composition traits								
Days to 114 kg	1208	183.1	144	287	229	0.09	0.24	0.08
Backfat at 114 kg, cm	1208	1.6	0.8	3.2	0.049	0.01	0.47	0.09
LM area at 114 kg, cm^2	1208	47	28	64	3.65	0.03	0.39	0.09

[1]σ_p^2 = phenotypic variance, c^2 = random common litter effect (%), h^2 = heritability

[2]MAX BOAR STAND = Maximum strength of standing reflex with boar, TOTAL BOAR STAND = Total strength of standing reflex with boar, MAX NO BOAR STAND = Maximum strength of standing reflex without boar, TOTAL NO BOAR STAND = Total strength of standing reflex without boar, Vulva redness= L* value from a colorimeter, VISUAL VULVA = Strength of vulva reddening and swelling

Table 2.4. Estimated genetic (above diagonal) and phenotypic (below diagonal) correlations[1] between estrus, puberty, growth, and composition traits for 1,225 Landrace-Large White gilts.

Trait[2]	Length of estrus	MAX BOAR STAND	TOTAL BOAR STAND	MAX NO BOAR STAND	TOTAL NO BOAR STAND	Vulva redness	VISUAL VULVA	Vulva width	Age at puberty	Puberty weight	Puberty backfat	Puberty LM area	Days to 114 kg	Backfat at 114 kg	LM area at 114 kg
Length of estrus		**0.99**	**0.98**	**0.52**	**0.49**	-0.31	0.12	0.21	-0.23	-0.23	0.16	-0.03	0.30	0.29	0.00
MAX BOAR STAND	**0.59**		**0.94**	0.31	**0.59**	-0.39	0.16	0.06	-0.32	-0.11	0.08	0.09	0.17	0.06	0.03
TOTAL BOAR STAND	**0.95**	**0.70**		**0.46**	**0.47**	-0.27	0.17	0.22	-0.25	-0.18	0.17	0.03	0.14	0.27	0.01
MAX NO BOAR STAND	**0.36**	0.32	**0.36**		**0.99**	-0.12	0.01	0.12	-0.03	-0.10	-0.06	0.14	**0.34**	-0.06	0.13
TOTAL NO BOAR STAND	**0.48**	0.34	**0.48**	**0.88**		-0.06	0.03	0.13	0.06	0.00	0.05	0.16	0.25	0.02	0.20
Vulva redness	-0.05	-0.01	-0.05	-0.04	-0.02		**-0.39**	**-0.29**	0.20	0.11	-0.01	0.25	-0.19	0.12	0.26
VISUAL VULVA	0.19	0.13	0.21	0.08	0.12	-0.23		**0.97**	0.25	**0.29**	-0.08	**0.29**	-0.18	**-0.35**	-0.02
Vulva width	0.19	0.06	0.18	0.06	0.09	-0.09	**0.75**		0.16	0.21	-0.12	0.18	-0.16	**-0.26**	-0.17
Age at puberty	-0.21	-0.22	-0.24	0.01	0.02	0.03	0.07	0.11		**0.93**	**0.66**	**0.68**	0.23	-0.26	0.17
Puberty weight	-0.18	-0.17	-0.20	-0.01	0.00	-0.02	0.13	0.17	**0.78**		**0.67**	**0.71**	**-0.57**	-0.27	0.18
Puberty backfat	-0.04	-0.07	0.14	0.02	0.04	-0.07	0.01	0.02	**0.45**	**0.58**		0.20	-0.14	**0.68**	-0.16
Puberty LM area	-0.10	-0.07	-0.11	0.05	-0.01	0.09	0.08	0.11	**0.55**	**0.63**	0.16		**-0.54**	**-0.52**	**0.89**
Days to 114 kg	-0.03	-0.02	-0.05	0.07	0.05	-0.01	-0.08	-0.06	0.27	-0.31	-0.22	-0.28		0.13	-0.22
Backfat at 114 kg	0.07	0.06	0.09	0.01	0.01	-0.04	-0.10	-0.11	-0.21	-0.18	**0.55**	-0.27	-0.03		**-0.39**
LM area at 114 kg	-0.01	0.04	-0.01	0.02	0.03	0.13	0.01	-0.02	0.05	0.06	-0.16	**0.52**	-0.09	-0.23	

[1]those in bold are $P < 0.05$, [2]MAX BOAR STAND = Maximum strength of standing reflex with boar, TOTAL BOAR STAND = Total strength of standing reflex with boar, MAX NO BOAR STAND = Maximum strength of standing reflex without boar, TOTAL NO BOAR STAND = Total strength of standing reflex without boar, Vulva redness= L* value from a colorimeter, VISUAL VULVA = Strength of vulva reddening and swelling

Chapter 3

Phenotypic and genetic correlations between gilt estrus, puberty, growth, composition, and structural conformation traits with first litter sow reproductive measures

Abstract

The objective was to correlate gilt estrus, puberty, growth, composition, and structural conformation traits with first litter sow reproductive measures. Four groups of gilts (n=1,225, GIS of NC) entered the NC Swine Evaluation Station averaging 162 d of age and were checked daily for estrus. Once 70% of gilts reached puberty, recording of estrus symptoms occurred every 12 h for 30 d utilizing fence-line boar contact. Subjective estrus traits were maximum strength of standing reflex with or without a boar present, total strength of standing reflex with or without a boar present, and strength of vulva reddening and swelling. Objective estrus traits consisted of vulva redness, vulva width, length of estrus, and age at puberty. Growth and composition traits included puberty weight, d to 114 kg, 10th rib backfat and LM area at 114 kg and puberty. Subjective structural conformation traits were muscle mass, rib width, front leg side view, rear leg side view, front legs front view, rear legs rear view, and locomotion. Sow traits included whether or not a gilt farrowed (STAY1), age at first farrowing (AFF), first litter total number born (TNB1), and first litter weaning-to-conception interval (WCI1). Variance components were estimated with AIREMLF90 and THRGIBBS1F90 (STAY1) using an animal model. Heritability estimates for STAY1, AFF, and TNB1 were 0.14, 0.22, and 0.02, respectively. Genetic correlations between length of estrus, the standing reflex traits, and age at puberty with STAY1 (0.34, 0.34 to 0.74, and -0.27, respectively) and AFF (-0.11, -0.04 to -0.41, and 0.76, respectively) were favorable. Days to 114 kg had unfavorable genetic associations with STAY1 (0.52) and AFF (-0.25) and a favorable genetic correlation with TNB1 (-0.08). Backfat had favorable genetic associations with STAY1 (-0.29) and AFF (0.14) and an unfavorable genetic correlation with

TNB1 (0.47). Vulva redness and TNB1 had favorable phenotypic and genetic correlations (-0.14 and -0.53, respectively). Associations between structural conformation traits with STAY1, AFF, TNB1, and WCI1 were generally low to moderately favorable. It was concluded that selection for longer length of estrus, stronger standing reflex, or lower age at puberty would increase the proportion of gilts that farrow and reduce age at first farrowing.

Introduction

Maximizing full value saleable pigs per female per year at the lowest cost is the goal of a modern swine industry. Pig reproductive genetic evaluations have chosen to focus predominantly on pigs per litter (Rydhmer, 2000). In practice problems also exist with other traits related to expression of estrus and structural conformation that result in poor sow reproductive lifetime (defined as pigs per female per day of life).

Heritability estimates indicate that genetic selection for sow reproductive lifetime measures are possible (Yazdi et al., 2000; Serenius and Stalder, 2004). However, direct genetic selection in nucleus herds for reproductive lifetime is difficult because it is a sex-limited trait measured late in life. To maximize genetic progress nucleus females are frequently culled before their maximum reproductive life is attained. Indirect selection for sow reproductive lifetime traits would provide an opportunity for genetic improvement while maintaining or reducing generation intervals. Therefore, it is important to know the genetic and phenotypic associations between lifetime reproductive performance in sows and other measureable traits in gilts or early parity sows.

Most sow longevity studies only include females which have produced at least one litter. However, a significant percentage of gilts selected to enter production never farrow a litter

(Cronin et al., 1983; Lucia et al., 2000; Moeller et al., 2004; Arango et al., 2005). This increases gilt development costs and reduces sow reproductive lifetime. We propose that a sow's reproductive lifetime begins when she enters the breeding herd as a gilt. Therefore, it is important to understand why gilts do not farrow.

The current study does not include a comprehensive evaluation of sow lifetime productivity but did measure component traits including whether or not a gilt farrowed (STAY1), age at first farrowing (AFF), first litter total number of piglets born (TNB1), and first litter weaning-to-conception interval (WCI1). The objective was to examine correlations between gilt estrus, puberty, growth, composition, and structural conformation traits with first litter sow reproductive measures (STAY1, AFF, TNB1, and WCI1).

Materials and methods

Gilt development

Four successive groups of Landrace-Large White gilts (n=1,225) from 59 sires and 330 dams were provided by Genetic Improvement Services (Newton Grove, NC). Gilts entered the North Carolina Swine Evaluation Station (Clayton, NC) at about 165 d of age and were penned by weight. Group 1 gilts were placed 3 per pen while groups 2, 3, and 4 were placed in pens of 8 pigs. Groups 1, 2, 3, and 4 contained approximately 145, 360, 360, and 360 gilts respectively. Groups 3 and 4 were inoculated at entry with a live Porcine Reproductive and Respiratory Syndrome (PRRS) vaccine. This was done due to the PRRS status of the sow farms the gilts entered. Gilts were off-tested when average pen weight reached 114 kg and placed on different gilt development diets. A summary of gilt development diet classes are presented in Table 2.1.

Puberty detection

Boars (8 to 20 mo of age) were used once daily (twice daily for gilt group 1) to check for gilts reaching puberty. The same group of boars was used for groups 2, 3, and 4. Age at puberty (AGEPUB) was the first observed standing reflex for the back-pressure test (Willemse and Boender, 1966). Puberty detection was carried out by bringing a pen of gilts to a boar and penning them together for 5 min. Once 70% of gilts reached puberty (approximately 2 mo), recording of estrous traits began.

Gilt estrous traits

Estrus traits were measured every 12 h for 30 d utilizing fence-line boar contact. Fence-line boar contact consisted of two boars in front of each pen for 2.5 min per pen (5 total min of boar exposure per pen).

The first standing reflex for the back-pressure test during the 30 d measurement period started the recording of estrus traits. Estrus length was number of consecutive days during which a gilt exhibited the standing reflex in response to the back-pressure test in the presence of a boar. The scoring systems for strength of standing reflex traits are summarized in Table 2.2. Strength of standing reflex in the presence of a boar was scored 1 (weak) to 5 (strong) every 12 h. This score was a composite of how well the gilt exhibited the standing reflex before, during, and after the back-pressure test. Maximum strength of standing reflex with a boar was the sum of the highest two consecutive scores received. For example, if a gilt's highest two consecutive scores were 4 and 3, then her maximum strength of standing reflex would be 7. Total strength of standing reflex with a boar was the sum of all strength of standing reflex scores in the presence of a boar (a composite trait of estrus length and strength). Strength of standing reflex without a boar was scored 0 (weak) to 7 (strong) (Table 2.2) at least 20 min after the boars had fence-line contact with the gilts. This score was created using concepts from Langendijk et al. (2000) where sows varied in the level of stimulus required to exhibit the standing reflex. In the current study, a technician applied back-pressure to the gilt. If she exhibited the standing reflex, the technician then sat on her back and the highest score was recorded. Maximum strength of standing reflex without a boar was the sum of the highest two consecutive scores received. Total strength of standing reflex without a boar was the sum of all standing reflex scores in the absence of boar exposure (a composite trait of estrus length and strength).

Vulva traits were assessed visually and using various instruments. Strength of vulva reddening and swelling (VISUAL VULVA) was scored via the following criteria: absent (0), weak (1), moderate (2), or strong (3). These measurements were obtained during the first standing reflex of the 30 d measurement period. Vulva width and redness were measured at this time. Vulva width was measured using a dial caliper (S-T Industries, Inc., Saint James, MN). Vulva redness was assessed using a colorimeter (Konica Minolta, U.S.). The L* value was recorded which corresponds to a dark-bright scale (0 to 100), a lower number indicated a darker color.

Gilt puberty, growth, and composition traits

Growth and composition traits were measured at puberty and at 114 kg. Puberty weight (PUBWT) and days to 114 kg (DAYS) were calculated. Backfat and LM area were measured at puberty (PUBBF, PUBLMA) and at 114 kg (BF, LMA). Composition traits were measured from a cross sectional 10^{th} rib image using an Aloka 500V SSD ultrasound machine (Corometrics Medical Systems, Inc., Wallingford, CT).

Gilt structural conformation traits

Subjective structural conformation traits, scored at approximately 136 kg by a trained livestock evaluator, included muscle mass, rib width, front leg side view, rear leg side view, front legs front view, rear legs rear view, and locomotion. Muscle mass and rib width were scored on a five point scale (score of five was heavier muscled and wider through the center part of the rib cage, respectively). Front leg side view, rear leg side view, front legs front view, and rear legs rear view were scored on a seven point scale where four was optimal (score of one was softer in the pasterns, sickle-hocked, splay-footed, and cow hocked, respectively). Locomotion was scored on a seven point scale where one was most favorable.

Sow farms

Gilts entered two commercial sow farms near Rockingham, NC at an average age of 265 d. Farms were modern confinement facilities that housed approximately 4,200 or 2,400 sows. Each sow had its own individual space, sows were not group housed. Estrus detection was carried out once daily using fence-line boar contact. Gilts were bred using artificial insemination and fed according to body condition. During lactation sows were provided ad libitum access to feed. Both farms utilized computerized record keeping software (PigCHAMP, 1996).

Sow reproductive traits

Sow reproductive traits were collected on all gilts with a recorded entry date at the sow farm (n = 1,172 gilts). For unknown reasons data from 53 gilts were missing or incorrectly entered into PigCHAMP at the sow farms.

Sow traits included whether or not a gilt farrowed (STAY1), age at first farrowing (AFF), first litter total number of piglets born (TNB1), and first litter weaning-to-conception interval (WCI1). Only 1,064 of 1,172 gilts were included in the analysis for STAY1 due to discontinued production at the sow farms. The last load of gilts from group 4 (n = 108) were not mated in time for their data to be included in the analyses. All 1,172 gilts were used in the analysis of AFF, TNB1, and WCI1. Age at first farrowing was the first farrowing date minus the gilt's birth date. Total number born was the number of piglets born alive plus stillborns. Wean to conception interval was conception date for the second litter minus the first litter weaning date.

Statistical Analysis

Fixed effects were tested for all traits using PROC MIXED in SAS (SAS Institute, 2003). Models treated gilt development diet class and breed composition as fixed effects, entry age as a covariate (except DAYS, BF, and LMA), birth litter as a random effect, and animal as a random genetic effect. Off-test BF and LMA were pre-adjusted to 114 kg using recommendations in the Guidelines for Uniform Swine Improvement Programs (NSIF, 1997). Models for sow traits also had fixed effects of farm (STAY1, AFF, TNB1, and WCI1) and lactation length (WCI1).

Linear models

Variance components for linear sow traits (AFF, TNB1, and WCI1) were estimated with two trait (one sow and one gilt trait) animal models using AIREMLF90 (Misztal et al., 2002). Fixed effects and covariates for traits were as previously stated. Heritability estimates presented are averages of estimates from multiple analyses.

Threshold models

Methods used for analyzing continuous data are not suitable for categorical data (Gianola and Foulley, 1983). Therefore variance components for STAY1 were estimated using THRGIBBS1F90 (Misztal et al., 2002). The THRGIBBS1F90 program is a Fortran90 program that uses a Bayesian approach via the Gibbs sampling algorithm (Lee et al., 2002). After 10,000 Gibbs samples were discarded as burn-in, 500,000 samples (saving every 20th sample) were used to calculate posterior means. For analysis STAY1 was coded 1 (did not farrow) and 2 (farrowed a litter).

Results and discussion

Stayability

Of the 1,064 gilts analyzed for STAY1, 764 (72%) farrowed a litter. These findings are in agreement with Cronin et al. (1983), Lucia et al. (2000), and Arango et al. (2005) who reported 71, 81, and 73% of gilts, respectively, farrowed a litter. Moeller et al. (2004) reported 75, 77, 77, 77, 78, and 92% of gilts farrowed a litter from six genetic lines and of these same gilts 50, 50, 48, 52, 52, and 70%, respectively, reached parity four. These results indicate increasing the percentage of gilts that farrow a litter improves sow reproductive lifetime.

Descriptive statistics and variance components of sow, estrus, puberty, growth, composition, and structural conformation traits are presented in Table 3.1. Estimated heritability for STAY1 was 0.14. In agreement, an U.S. breeding company estimated heritability for STAY1 at 0.15 (J. Holl, Smithfield Premium Genetics, Rose Hill, NC, personal communication). In sows, López-Serrano et al. (2000) estimated the heritability for stayabilty from first to second parity (STAY12) in pure-line Landrace (0.07) and Large White (0.08). Based on these findings it was concluded that genetic improvement for stayability in pigs is possible.

Estimated common litter variance for STAY1 was 0.08 indicating the presence of maternal effects. Drickamer et al. (1997) reported intrauterine environment (sex ratio) effects conception rate, an indicator trait of STAY1. In that study, gilts from litters with a low vs. high proportion of males had higher conception rates (68 vs. 40%).

Phenotypic and genetic correlations between sow traits with estrus, puberty, growth, composition, and structural conformation traits are shown in Table 3.2.

Maximum strength of standing reflex with a boar and STAY1 had favorable phenotypic and genetic correlations (0.12 and 0.74, respectively). This means gilts with a strong rather than a weak standing reflex were more likely to farrow. Length of estrus, total strength of standing reflex with a boar, maximum strength of standing reflex without a boar, and total strength of standing reflex without a boar also had favorable phenotypic (0.06 to 0.10) and genetic (0.34 to 0.40) associations with STAY1. These findings are supported by Cronin et al. (1983) who categorized a gilt's strength of standing reflex in the presence of a boar as either low, moderate, or high. Of gilts that were detected in estrus and culled by 35 w of age, 71% had a low strength of standing reflex in the presence of a boar.

Growth rate (DAYS) and STAY1 had an unfavorable genetic correlation (0.52). This means fast growing gilts were less likely to farrow. These findings are supported by Rydhmer et al. (1994) who reported an unfavorable genetic association between growth rate and the ability to exhibit the standing reflex at puberty (-0.61). In sows, López-Serrano et al. (2000) established unfavorable genetic correlations between growth rate and STAY12 in Landrace (-0.06) and Large White (-0.28). Similarly, Serenius and Stalder (2004) reported low unfavorable genetic associations between growth rate and sow reproductive lifetime (-0.02 to -0.08). In contrast, Moeller et al. (2004) reported five genetic lines with a range of growth rates did not differ for STAY1. Relationships between growth rate and sow reproductive lifetime remain unclear. In the current study, the unfavorable genetic association between DAYS and STAY1 supports the conclusion that including growth and traits associated with sow reproductive lifetime would be most effective at improving maternal performance.

Genetic correlations between PUBBF and BF with STAY1 (-0.49 and -0.29, respectively) were favorable. These results disagree with López-Serrano et al. (2000), Yazdi et al. (2000), and Knauer (2006) who reported unfavorable or no relationship between gilt backfat and sow reproductive lifetime measures. Perhaps gilt age and weight explain differences between the studies. In the present study, gilts entered the sow farms older (265 d), heavier (161 kg), and fatter (relative to their BF at off-test 2.5 vs. 1.6 cm) than is typically practiced in industry. Perhaps excess backfat in gilts causes reproductive problems as documented in humans

(Norman and Clark, 1998). Based on these findings getting females too thin or too fat relative to their genetic potential is detrimental to reproductive lifetime.

The genetic correlation between AGEPUB and STAY1 (-0.27) was favorable. These findings are supported by Young (1995), Young (1998), and Moeller et al. (2004) who established a greater proportion of gilts expressed estrus from genetic lines that were younger at puberty. Dial et al. (1983) reported increasing level of administered estradiol benzoate increased the proportion of prepubertal gilts in estrus indicating a threshold level of estrogen needed to exhibit estrous behavior. In a subset of gilts (n=125) from the current study, age at puberty and urine estradiol (collected at first standing reflex) were favorably correlated (r = -0.19, P < 0.05). Sterning et al. (1998) established a favorable genetic correlation between ability to show the standing reflex and ovulate within 10 d after weaning with age at puberty (-0.50). Perhaps higher peak estradiol levels explain the superior subsequent estrous behavior in young vs. older puberty females.

Phenotypic and genetic correlations between structural conformation traits and STAY1 were generally low to moderately favorable. Few observations for front legs front view (n=8, 0.7%) and rear legs rear view (n=3, 0.3%) were made in categories 5 or 6. Thus, splay-footed and cow hocked gilts had unfavorable genetic associations with STAY1 (0.17 and 0.49, respectively). Rib width had a favorable genetic correlation with STAY1 (0.34), gilts wider through the center part of their rib cage were more likely to farrow. In agreement, Barczewski et al. (1990) established gilts with more girth had better stayability in early parities. In the current study, locomotion had low favorable phenotypic and genetic associations with STAY1 (-0.06 and -0.14, respectively). These findings are in agreement with López-Serrano et al. (2000) and Serenius and Stalder (2004) who reported low to moderate favorable genetic associations (0.00 to 0.36) between locomotion and sow reproductive lifetime. The population utilized had previously been selected for improved structural conformation. This may partially explain the low genetic correlation between STAY1 and locomotion. Locomotion, a similar trait to front leg side view (Serenius et al., 2001), will continue to be a factor in maximizing animal welfare and sow reproductive lifetime.

Age at first farrowing

Estimated heritability for AFF was 0.22. Hanenberg et al. (2001), Serenius and Stalder (2004), and Holm et al. (2005) reported higher heritabilities (0.31 to 0.47) for age at first mating or age at first farrowing. Perhaps our estimate was lower due to management procedures reducing genetic variation. Gilts entered the sow farm averaging 265 d of age. Thus multiple gilts already had several estrus cycles when they would typically be bred at their second or third.

The genetic correlation between AGEPUB and AFF was high and favorable (0.76). Hanenberg et al. (2001) reported a higher genetic correlation between a similar trait, age at first service, and age at first farrowing (0.98). Our estimate was likely lower because of management methods as the phenotypic correlation between AGEPUB and AFF was 0.18. Gilts in the current study entered the sow farms in groups from the GDU having had zero to six estrus cycles. Typically gilts would be mated at second or third estrus and not allowed to have six cycles. Still, age at puberty, age at first mating, and age at first farrowing are highly correlated.

Phenotypic and genetic correlations between AFF with length of estrus and the standing reflex traits (-0.09 to -0.17 and -0.04 to -0.41, respectively) were favorable. Thus, selecting for a lower age at first farrowing would improve length of estrus and strength.

Growth rate (DAYS) and AFF had a favorable phenotypic correlation (0.10) but an unfavorable genetic correlation (-0.25). In contrast, Serenius and Stalder (2004) and Rydhmer et al. (1995) reported favorable genetic correlations between average daily gain and age at first farrowing (-0.35 to -0.61). Typically gilts are mated at a minimum age and weight. This management practice increases the correlation between growth rate and age at first farrowing. In the current study, gilts arrived at the farm ready to breed reducing the correlation between DAYS and AFF relative to previous studies.

Phenotypic and genetic correlations between structural conformation traits and AFF were generally low to moderately favorable. Front legs front view, rear legs rear view, rib width, and locomotion had favorable genetic associations with AFF (-0.07, -0.30, -0.15, and 0.17, respectively). Serenius and Stalder (2004) reported a favorable genetic correlation between locomotion and age at first farrowing in Landrace (-0.37) and an unfavorable association in Large White (0.07).

Total number born

Estimated heritability of TNB1 (0.02) was below the literature average (0.11) (Rothschild and Bidanel, 1998). This low heritability further supports TNB1 is controlled mainly by environmental factors.

Common litter variance for TNB1 was higher than the heritability (0.06 vs. 0.02). Maternal effects for litter size are both genetic (See et al., 1993) and environmental (Nelson and Robison, 1976). Nelson and Robison (1976) reported gilts reared in small vs. large litters farrowed more pigs born alive, an example of a postnatal maternal effect.

Vulva redness and TNB1 had a favorable phenotypic and genetic correlation (-0.14 and -0.53, respectively), gilts with dark red vulvas farrowed more TNB1. Sows experience increased blood flow prior to estrus (Ford and Christenson, 1979) which causes reddening of the vulva. Ferrell (1991) suggested fetal growth is limited by uterine blood flow in cattle. More specifically increased uterine blood flow delivers extra nutrients to developing fetuses. Perhaps the favorable association between vulva redness and TNB1 is due to increased uterine blood flow. This association may be seasonal as uterine blood flow increases in colder temperatures (Roman-Ponce et al., 1978). The association between vulva redness and TNB1 warrants further investigation.

Length of estrus, maximum strength of standing reflex with a boar, and total strength of standing reflex with a boar had unfavorable phenotypic (-0.06, -0.11, and -0.11, respectively) and genetic correlations (-0.34, -0.06, and -0.06, respectively) with TNB1. In contrast, Cronin et al. (1982) established gilts with high strength of standing reflex on their first d of mating farrowed more piglets. Steverink et al. (1999) reported a favorable correlation between length of estrus and litter size (0.23) within farm (n=55), however length of estrus was not related to litter size in gilts. The same study established gilts first inseminated at expected ovulation vs. 4 to 20 h before had a smaller litter size. Rozeboom et al. (1997) also reported late inseminations reduce litter size. In the current study, perhaps females with a long duration of estrus were inseminated late.

Genetic correlations between PUBBF and BF with TNB1 (0.49 and 0.47, respectively) were unfavorable. In agreement, Serenius et al. (2004) reported unfavorable genetic associations between fat percentage and total number born (0.17 to 0.19). Holm et al. (2004) established lower genetic correlations between average backfat and number born alive (0.00 to 0.08). Perhaps differences between studies are due to different climates or management schemes.

Genetic correlations between front leg side view, front legs front view, rear legs rear view, rib width, and locomotion with TNB1 (-0.47, 0.07, 0.84, 0.54, and -0.51, respectively) were favorable. In contrast, Serenius et al. (2004) reported low unfavorable genetic correlations between locomotion and total number born (-0.07 to -0.11). Genetic associations between rear legs rear view and muscle mass with TNB1 appear high (0.84). Still, good structural conformation had a favorable relationship with TNB1.

Wean-to-conception interval

Models for WCI1 did not converge, therefore only phenotypic correlations are presented. Perhaps lack of convergence was related to low heritability (estimated < 0.005 using SAS).

Age at puberty and WCI1 had a favorable phenotypic correlation (0.12). In agreement, Sterning et al. (1998) established age at puberty and weaning-to-estrus interval had favorable phenotypic and genetic correlations (0.16 and 0.45, respectively). Holm et al. (2005) reported age at first service and weaning-to-estrus interval had favorable phenotypic and genetic correlations (0.17 and 0.22, respectively). Thus, a lower age at puberty reduces non-productive days in gilts and sows which in turn decreases culling for reproductive failure.

Structural conformation scores and WCI1 generally had low favorable phenotypic relationships. Rib width and locomotion had the greatest phenotypic associations with WCI1 (-0.13 and 0.13, respectively). Perhaps females wider through the center part of their rib cage have an increased lactation feed intake which improves subsequent reproductive performance (Prunier et al., 1993). Likewise, locomotion and lactation feed intake have a favorable association. Sows that get up and down easily during lactation may consume more feed than those with structural problems.

Phenotypic correlations between length of estrus and the standing reflex traits with WCI1 (0.05 to 0.12) were low and unfavorable. Steverink et al. (1999) reported sows first inseminated after expected ovulation had reduced farrowing rates. Typically commercial farms inseminate sows according to a schedule and not via length of estrus. Perhaps sows with a long duration of estrus were not mated after two days. However, Sterning et al. (1998) reported a low correlation between gilt and sow length of estrus (-0.03). The unfavorable phenotypic associations between length of estrus and the standing reflex traits with WCI1 remain unclear.

Summary

Results from the current study should aid geneticists in broadening the pig reproductive breeding goal. Age at puberty, length of estrus, and the standing reflex traits had favorable associations with whether a gilt farrowed or not and age at first farrowing. These findings suggest selection on these traits will improve estrous symptoms, estrus detection, and sow reproductive lifetime. Growth rate had unfavorable associations with whether a gilt farrowed and age at first farrowing, further supporting the need for a balanced selection objective. Vulva redness was favorably correlated with total number of piglets born. This relationship warrants further biological and applied studies.

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Table 3.1. Descriptive statistics and variance components[1] of sow, estrus, puberty, growth, composition, and structural conformation traits for 1,172 Landrace-Large White gilts.

Traits[2]	No.	Mean	Min.	Max.	σ_p^2	c^2	h^2	SE
Sow								
STAY1	1064	0.72	0	1	1.31	0.08	0.14	†
Age at first farrowing, d	801	405	309	538	390	0.01	0.22	0.08
Total number born	804	10.5	1	21	8.6	0.06	0.02	0.02
Wean-to-conception interval, d	368	11.0	2	45	87	*	*	*
Estrus								
Length of estrus, d	988	2.1	0.5	4	0.40	0.08	0.22	0.07
MAX BOAR STAND	988	7.6	2	10	1.17	0.04	0.15	0.07
TOTAL BOAR STAND	988	15.2	2	29	24.0	0.09	0.27	0.10
MAX NO BOAR STAND	988	8.3	0	14	15.5	0.01	0.44	0.09
TOTAL NO BOAR STAND	974	12.7	0	34	59	0.00	0.44	0.09
Vulva redness	963	60.5	50.1	71.8	7.9	0.01	0.28	0.08
VISUAL VULVA	991	1.7	0	3.5	0.49	0.08	0.45	0.09
Vulva width, mm	970	39.8	26	58	23.5	0.05	0.57	0.09
Puberty								
Age at puberty, d	1021	211.6	143	292	731	0.09	0.29	0.08
Puberty weight, kg	1017	137	89	212	826	0.03	0.38	0.09
Puberty backfat, cm	1017	2.06	0.74	4.67	0.114	0.00	0.40	0.09
Puberty LM area, cm^2	1017	47.7	28.4	69.0	6.39	0.09	0.36	0.09
Growth and composition								
Days to 114 kg	1162	183.0	144	287	218	0.12	0.19	0.07
Backfat at 114 kg, cm	1154	1.60	0.79	3.18	0.051	0.00	0.50	0.10
LM area at 114 kg, cm^2	1154	46.5	28.4	63.9	3.55	0.02	0.39	0.09
Structural conformation								
Muscle mass	681	2.0	1	4	0.44	0.01	0.53	0.09
Rib width	1169	2.8	1	5	0.78	0.00	0.37	0.09
Front leg side view	1169	4.1	1	7	0.85	0.02	0.37	0.09
Rear leg side view	1168	3.6	1	5	0.44	0.01	0.11	0.05
Front legs front view	1169	3.2	2	5	0.30	0.04	0.25	0.08
Rear legs rear view	1169	3.1	1	6	0.29	0.00	0.18	0.07
Locomotion	1158	3.3	1	6	0.90	0.02	0.36	0.09

[1] σ_p^2 = phenotypic variance, c^2 = random common litter effect (%), h^2 = heritability, [2] STAY1 = whether a gilt farrowed (1) or not (0), MAX BOAR STAND = Maximum strength of standing reflex with boar, TOTAL BOAR STAND = Total strength of standing reflex with boar, MAX NO BOAR STAND = Maximum strength of standing reflex without boar, TOTAL NO BOAR STAND = Total strength of standing reflex, without boar, VISUAL VULVA= Strength of vulva reddening and swelling, †not estimated *didn't converge

Table 3.2. Phenotypic (r_p) and genetic (r_g) correlations between sow traits with estrus, puberty, growth, composition, and structural conformation traits for 1,172 Landrace-Large White gilts.

Trait[1]	STAY1 r_p	STAY1 r_g	AFF r_p	AFF r_g	TNB1 r_p	TNB1 r_g	WCI1 r_p
Length of estrus	0.09	0.34	-0.15	-0.11	-0.06	-0.34	0.12
MAX BOAR STAND	0.12	0.74	-0.16	-0.41	-0.11	-0.06	0.05
TOTAL BOAR STAND	0.10	0.40	-0.17	-0.06	-0.11	-0.06	0.09
MAX NO BOAR STAND	0.06	0.34	-0.10	-0.23	0.03	0.00	0.08
TOTAL NO BOAR STAND	0.09	0.40	-0.09	-0.04	-0.02	0.20	0.09
Vulva redness	0.07	0.37	0.03	0.05	-0.14	-0.53	0.09
VISUAL VULVA	0.01	0.26	-0.02	0.14	-0.02	-0.45	-0.01
Vulva width	0.01	0.07	0.03	0.24	0.02	-0.33	-0.02
Age at puberty	-0.04	-0.27	0.18	0.76	0.02	-0.06	0.12
Puberty weight	-0.08	-0.27	0.16	0.76	0.05	0.41	0.08
Puberty backfat	-0.08	-0.49	0.07	0.64	0.05	0.49	0.02
Puberty LM area	-0.02	0.31	0.12	0.19	0.01	0.01	0.10
Days to 114 kg	0.03	0.52	0.10	-0.25	0.00	-0.08	0.05
Backfat at 114 kg	0.01	-0.29	-0.02	0.14	-0.04	0.47	0.01
LM area at 114 kg	-0.06	0.18	-0.02	-0.19	0.01	-0.20	0.01
Front leg side view	-0.05	0.09	-0.01	-0.04	0.00	-0.47	0.07
Rear leg side view	-0.02	0.17	-0.08	-0.21	-0.02	-0.29	0.02
Front legs front view	0.01	0.17	-0.05	-0.07	0.08	0.07	-0.02
Rear legs rear view	0.05	0.49	-0.02	-0.30	0.03	0.84	-0.05
Rib width	0.08	0.34	-0.05	-0.15	-0.01	0.54	-0.13
Muscle mass	0.04	0.38	-0.04	0.00	0.11	0.84	-0.02
Locomotion	-0.06	-0.14	0.04	0.17	-0.03	-0.51	0.13

[1]STAY1 = whether a gilt farrowed (1) or not (0), AFF = age at first farrowing, TNB1 = first litter total number born, WCI1= first litter weaning-to-conception interval, MAX BOAR STAND= Maximum strength of standing reflex with boar, TOTAL BOAR STAND=Total strength of standing reflex with boar, MAX NO BOAR STAND = Maximum strength of standing reflex without boar, TOTAL NO BOAR STAND = Total strength of standing reflex without boar, VISUAL VULVA = Strength of vulva reddening .

Chapter 4

Gilt development traits associated with gilt development diet class, genetic line, and fertility

Abstract

The objective of the current study was to relate gilt entry, estrus, puberty, growth, composition, sow farm entry and sow traits to gilt development diet class, genetic line, and fertility group. Gilts (n=1,225) were reared from 162 to 265 d of age at a gilt development unit (GDU) and then sent to one of two sow farms. Genetic lines included Landrace (L), Large White (LW), L × LW F_1 (F_1), and a L or LW boar bred to a L × LW composite female (BACKCROSS). Fertility groups were FG0 = did not farrow, not detected in estrus at GDU; FG1 = did not farrow, detected in estrus at GDU; FG2 = farrowed, not detected in estrus at GDU, FG3 = farrowed, detected in estrus at GDU). Entry traits into the GDU were entry age and weight. Estrus traits included age at puberty, length of estrus, maximum strength of standing reflex with or without a boar present, total strength of standing reflex with or without a boar present, vulva redness, strength of vulva reddening and swelling (VISUAL VULVA), and vulva width. Growth and composition traits were puberty weight, d to 114 kg, 10th rib backfat and LM area at 114 kg (BF, LMA) and puberty. Subjective structural conformation traits included muscle mass, rib width, front leg side view, rear leg side view, front legs front view, rear legs rear view, and locomotion (LOC). Sow farm entry traits were age, weight, backfat, and LM area. Sow traits included whether or not a gilt farrowed (STAY1) and first litter total number born. Amongst the estrus traits, crossbred (F_1, BACKCROSS, or both) performance was superior ($P < 0.10$) to the pure-line average for length of estrus, total strength of standing reflex with a boar, vulva redness, VISUAL VULVA, and vulva width. Length of estrus was shorter ($P < 0.05$) for LW vs. L, F_1, and BACKCROSS (1.91 vs. 2.16 to 2.21 d). There were no differences ($P = 0.22$) between

genetic lines for STAY1. Fertility groups 0, 1, 2, and 3 contained 45 (4%), 255 (24%), 66 (6%), and 698 (66%) gilts, respectively. Gilts from FG3 had a longer ($P < 0.05$) length of estrus (2.16 vs. 2.06), greater ($P < 0.05$) maximum standing reflex with a boar (7.6 vs. 7.4) and higher ($P < 0.05$) total strength of standing reflex with a boar (15.4 vs. 14.6) compared with FG1 females. The relationship between length of estrus and STAY1 was nonlinear. Fertility group 0 had less ($P < 0.05$) BF, poorer ($P < 0.05$) LOC, and was narrower ($P < 0.05$) ribbed compared with the other groups. It was concluded that gilts with length of estrus ≤ 1 d and a weak standing reflex were less likely to farrow a litter.

Introduction

Studies have quantified the effect of gilt traits on sow reproductive lifetime under field (Tholen et al., 1996; López-Serrano et al., 2000; Yazdi et al., 2000; Serenius and Stalder, 2004) and experimental (Knauer, 2006) conditions. These studies typically do not include gilts that fail to farrow which ranges from 8% (Moeller et al., 2004) to 29% (Cronin et al., 1983). Increasing the percentage of gilts that farrow a litter reduces gilt development costs, increases sow reproductive lifetime, and creates an opportunity for greater selection intensity at the nucleus level.

Associations between gilt traits and subsequent reproductive performance are not well quantified. Therefore, the objective of this study was to examine the association between gilt traits with gilt development diet class, genetic line, and fertility group.

Materials and methods

Gilt development unit

Four successive groups of gilts (n=1,225) with known parentage from 59 sires and 330 dams were provided by Genetic Improvement Services (Newton Grove, NC). Genetic lines included Landrace (L), Large White (LW), L × LW F_1 (F_1), and a L or LW boar bred to a L × LW composite female (BACKCROSS). Gilts entered the North Carolina Swine Evaluation Station (Clayton, NC) at about 162 d of age and were penned by entry weight. Group 1 gilts were placed 3 per pen (1.86 m^2 per pig) while groups 2, 3, and 4 were placed in pens of 8 pigs (1.39 m^2 per pig) by removing the pen divider. Pens had solid concrete floors, nipple waters, and self feeders (gilt group 1, 0.203 m per pig; gilt groups 2, 3, and 4, 0.152 m per pig). Groups 1, 2, 3, and 4 contained approximately 145, 360, 360, and 360 gilts respectively. Groups 3 and 4 were inoculated at entry with a live Porcine Reproductive and Respiratory Syndrome (PRRS) vaccine. This was done due to the PRRS status of the sow farms the gilts entered. Gilts were off-tested when average pen weight reached 114 kg and placed on different gilt development diets (GDD). A summary of GDD classes are shown in Table 2.1.

Puberty detection

Boars (8 to 20 mo of age) were used once daily (twice daily for gilt group 1) to check for gilts reaching puberty. The same group of boars was used for groups 2, 3, and 4. Age at puberty (AGEPUB) was the first observed standing reflex for the back-pressure test (Willemse and Boender, 1966). Puberty detection was carried out by bringing a pen of gilts to a boar and penning them together for 5 min. Once 70% of gilts reached puberty (approximately 2 mo), recording of estrous traits began.

Gilt estrous traits

Estrus traits were measured every 12 h for 30 d utilizing fence-line boar contact. Fence-line boar contact consisted of two boars in front of each pen for 2.5 min per pen (5 total min of boar exposure per pen).

The first standing reflex for the back-pressure test during the 30 d measurement period started the recording of estrus traits. Estrus length was number of consecutive days during which a gilt exhibited the standing reflex in response to the back-pressure test in the presence of a boar. The scoring systems for strength of standing reflex traits are summarized in Table 2.2. Strength of standing reflex in the presence of a boar was scored 1 (weak) to 5 (strong) every 12 h. This score was a composite of how well the gilt exhibited the standing reflex before, during, and after the back-pressure test. Maximum strength of standing reflex with a boar was the sum of the highest two consecutive scores received. For example, if a gilt's highest two consecutive scores were 4 and 3, then her maximum strength of standing reflex would be 7. Total strength of standing reflex with a boar was the sum of all strength of standing reflex scores in the presence of a boar (a composite trait of estrus length and strength). Strength of standing reflex without a boar was scored 0 (weak) to 7 (strong) (Table 2.2) at least 20 min after the boars had fence-line contact with the gilts. This score was created using concepts from Langendijk et al. (2000) where sows varied in the level of stimulus required to exhibit the standing reflex. In the current study, a technician applied back-pressure to the gilt. If she exhibited the standing reflex, the technician then sat on her back and the highest score was recorded. Maximum strength of standing reflex without a boar was the sum of the highest two consecutive scores received. Total strength of standing reflex without a boar was the sum of all standing reflex scores in the absence of boar exposure (a composite trait of estrus length and strength).

Vulva traits were assessed visually and using various instruments. Strength of vulva reddening and swelling (VISUAL VULVA) was scored via the following criteria: absent (0), weak (1), moderate (2), or strong (3). These measurements were obtained during the first standing reflex of the 30 d measurement period. Vulva width and redness were measured at this time. Vulva width was measured using a dial caliper (S-T Industries, Inc., Saint James, MN). Vulva redness was assessed using a colorimeter (Konica Minolta, U.S.). The L* value was recorded which corresponds to a dark-bright scale (0 to 100), a lower number indicated a darker color.

Gilt puberty, growth, and composition traits

Growth and composition traits were measured at puberty and at 114 kg. Puberty weight (PUBWT) and days to 114 kg (DAYS) were calculated. Backfat and LM area were measured at puberty (PUBBF, PUBLMA) and at 114 kg (BF, LMA). Composition traits were measured from a cross sectional 10^{th} rib image using an Aloka 500V SSD ultrasound machine (Corometrics Medical Systems, Inc., Wallingford, CT).

Gilt structural conformation traits

Subjective structural conformation traits, scored at an average weight of 136 kg by a trained livestock evaluator, included muscle mass, rib width, front leg side view, rear leg side view, front legs front view, rear legs rear view, and locomotion. Muscle mass and rib width were scored on a five point scale (score of five was heavier muscled and wider through the center part of the rib cage, respectively). Front leg side view, rear leg side view, front legs front view, and rear legs rear view were scored on a seven point scale where four was optimal (score of one was softer in the pasterns, sickle-hocked, splay-footed, and cow hocked, respectively). Locomotion was scored on a seven point scale where one was most favorable.

Sow farms

Gilts entered two commercial sow farms near Rockingham, NC at an average age of 265 d. Farms were modern confinement facilities that housed approximately 4,200 or 2,400 sows. Each sow had its own individual space, sows were not group housed. Estrus detection was carried out once daily using fence-line boar contact. Gilts were bred using artificial insemination and fed according to body condition. During lactation sows were provided ad libitum access to feed. Both farms utilized computerized record keeping software (PigCHAMP, 1996). Sow reproductive traits were collected on all gilts with a recorded entry date at the sow farms (n = 1,172 gilts). For unknown reasons data from 53 gilts were missing or incorrectly entered into PigCHAMP at the sow farms. Only 1,064 of 1,172 gilts were included in the analysis due to discontinued production at the sow farms. The last load of gilts from group 4 (n = 108) were not mated in time for their data to be included in the analyses. Sow traits included whether or not a gilt farrowed (1) or not (0) (STAY1) and first litter total number of piglets born (TNB1). Fertility groups (FG) included (FG0 = did not farrow, not detected in estrus at gilt development unit (GDU); FG1 = did not farrow, detected in estrus at GDU; FG2 = farrowed, not detected in estrus at GDU, FG3 = farrowed, detected in estrus at GDU).

Statistical Analysis

Fixed effects were tested for continuous traits using PROC MIXED in SAS (SAS Institute, 2003). Models contained fixed effects of GDD class, genetic line, fertility group, and covariate entry age (except entry age, DAYS, BF, LMA, and sow farm entry weight, backfat, and LM area). Off-test BF and LMA were pre-adjusted to 114 kg using recommendations in the Guidelines for Uniform Swine Improvement Programs (NSIF, 1997). Fixed effects (GDD, genetic line, and farm) for the categorical traits STAY1 and PUB (percentage of gilts pubertal at GDU) were analyzed using PROC GLIMMIX in SAS. Presented means are LS MEANS. Therefore unadjusted means and LS MEANS may differ. Contrasts were used to compare some groups or GDD's, thus excluding some animals. For example a contrast was used to compare AGEPUB between GDD 1 and GDD's 2 to 4, thus excluding GDD's 5 to 7 in the analysis.

Results and discussion

Gilt development diets

The study was designed to compare GDD's across gilt groups. However, gilt group 4 received pellets instead of meal diets that were also different in composition (Table 2.1). Because of these differences diets are not comparable across all gilt groups. However, comparisons within gilt group of GDD's are valid. For example, a comparison of length of estrus between GDD 2 and 3 (2.23 vs. 2.15 d) is valid but not GDD 2 and 6 (2.23 vs. 2.08 d).

Unadjusted means and LS MEANS of estrus and puberty traits by gilt development diet class are shown in Table 4.1.

Within gilt group 3, GDD 4 vs. GDD 5 had a heavier ($P < 0.05$) PUBWT and more ($P < 0.05$) PUBBF. These findings are in agreement with Beltranena et al. (1991), Newton and Mahan (1993) and Klindt et al. (2001) who reported gilts fed ad libitum vs. restricted were heavier and fatter at puberty. Decreasing puberty weight and backfat through restricted feed intake reduces gilt development costs while maintaining similar reproductive performance.

Age at puberty decreased ($P < 0.05$) from gilt group 2 (219 and 220 d) to gilt group 4 (201 and 204 d). Boar age is one justification. The same group of boars was used for gilt groups 2, 3, and 4. Older boars can hasten attainment of puberty (Kirkwood and Hughes, 1981). Of the gilts on ad libitum GDD's, AGEPUB was lower ($P < 0.05$) for GDD 1 (207) vs. GDD's 2 to 4 (216 to 220). Frequency of boar exposure is one explanation. Gilts from GDD 1 vs. 2 to 4 were exposed to a boar twice daily vs. once daily. Increased exposure can reduce age at puberty (Philip and Hughes, 1995). Increased pen space (Young et al., 2008), boar exposure per gilt or reduced group size (Hughes, 1993) are other explanations for AGEPUB differences in GDD 1 vs. 2 to 4. Within gilt group 3, gilts fed ad libitum (GDD 4) vs. 2.05 kg d (GDD 5) had a higher ($P < 0.05$) AGEPUB (216 vs. 209 d). In contrast, Beltranena et al. (1991), Newton and Mahan (1993) and Klindt et al. (2001) reported restricted feeding increased or had no effect on age at puberty.

Differences between GDD's for maximum strength of standing reflex without a boar, total strength of standing reflex without a boar, and VISUAL VULVA may be in part explained by human error. These subjective traits were generally not different within gilt groups. Differences between gilt groups for vulva redness are partially explained by the colorimeter. The colorimeter was recalibrated several times throughout the study, especially during gilt group 1.

Gilts from GDD 4 (ad libitum) vs. GDD 5 (2.05 kg d) had darker ($P < 0.05$) vulva redness (61.3 vs. 62.0) and higher ($P < 0.05$) VISUAL VULVA (1.8 vs. 1.6) scores. The explanation of these results remains unclear.

Unadjusted means and LS MEANS of gilt entry, growth, composition, sow farm entry, and sow traits by gilt development diet classes are shown in Table 4.2.

Days to 114 kg was lower ($P < 0.05$) for gilt group 1 (168) vs. gilt group's 2 to 4 (184 to 192). Females from gilt group 1 vs. gilt group's 2 to 4 had more pen (1.86 vs. 1.39 m^2) and feeder (0.203 vs. 0.152 m) space per pig. Increased pen and feeder space increases growth rate (Randolph et al., 1981; Brumm et al., 2001) but not for pigs kept in intact groups (Brumm et al., 2001). In the current study gilts were mixed at entry into the GDU. Perhaps higher ($P < 0.05$) DAYS for gilt group 2 vs. gilt group 4 is due to high summer temperatures which reduces growth rate (Hyun et al., 1998).

Front leg side view tended ($P = 0.14$ and 0.20) to be lower for GDD 2 vs. 3 and GDD 3 vs. 4, respectively. This indicates weaker front pasterns for gilts fed a higher energy diet which agrees with Barczewski et al. (1990). The opposite of weak pasterns, buck-knees are unfavorable for locomotion (Serenius et al., 2001). However, high energy diets are not good for locomotion (Jørgensen, 1995). The current results support this as locomotion was numerically poorer for higher energy diets (GDD 2 vs. 3, GDD 4 vs. 5, and GDD 7 vs. 6).

Differences between GDD's for BF, LMA, rear leg side view, front legs front view, and rear legs rear view may be partially explained by human error. Different ultrasound technicians were used to measure BF and LMA for gilt group's 1 to 2 and 3 to 4, thus technician and gilt group are confounded. Gilt group differences for rear leg side view, front legs front view, and rear legs rear view indicate the evaluator adjusted his scoring over time.

Large differences were observed between GDD's for sow farm entry weight (146 to 171 kg), backfat (1.8 to 3.0 cm) and LMA (47.5 to 53.3 cm^2). The average sow farm entry age (265 d) was higher than previously reported studies (Rozeboom et al., 1996; Klindt et al., 1999). Average sow farm entry weight (162 kg) was near that recommended by Young and Aherne (2005) (135 to 150 kg) to ensure adequate body protein reserves for a productive life.

The unadjusted means between GDD's for STAY1 (0.61 to 0.83) were similar to the reported LS MEANS (0.57 to 0.84).

There were no differences ($P > 0.05$) for STAY1 or TNB1 between GDD's within gilt group. Stalder et al. (1998) reported higher STAY1, but not litter size, for gilts fed restrictively vs. ad libitum from 82 kg to 180 d of age. Newton and Mahan (1993) reported gilts fed ad libitum vs. 60% of ad libitum from 150 to 240 d of age had a similar number of pigs born alive but an increased pre-weaning mortality. Klindt et al. (2001) established gilts fed 50 to 87.5% ad libitum from 90 to 175 d of age had comparable ovulation rates and number of live embryos. In contrast gilts fed ad libitum vs. 2.0 kg per d from 98 d of age until puberty had higher ovulation rates (Beltranena et al. 1991). However the negative effect of restricted feeding on ovulation rate was alleviated at second estrus by increasing feed intake (Beltranena et al. 1991). In a review of gilt development, Young and Aherne (2005) stated that under good management there is no association between age, live weight, backfat depth and subsequent reproductive performance. Future studies relating gilt development to sow reproductive lifetime should be large in size to detect small differences that exist.

Genetic Line

Associations of estrus and puberty traits with genetic line are shown in Table 4.3. Crossbred (F_1, BACKCROSS, or both) performance was better ($P < 0.10$) than the pure-line average for length of estrus, total strength of standing reflex with a boar, vulva redness, VISUAL VULVA, and vulva width.

Length of estrus and total strength of standing reflex with a boar was shorter ($P < 0.05$) for LW vs. L, F_1, and BACKCROSS. Dial et al. (1983) reported peak estradiol has a high favorable association with length of estrus and the proportion of females that exhibit the standing reflex. Perhaps lower gilt peak estradiol levels partially explain longer wean-to-conception intervals in LW vs. L reported between the two breeds (Tummaruk et al., 2000; Serenius et al., 2004).

Maximum strength of standing reflex without a boar and total strength of standing reflex without a boar was higher ($P < 0.05$) for LW vs. L, F_1, and BACKCROSS females. Perhaps this was partially due to ear play. It may be easier to detect ear movement in the already erect ears of the LW relative to the droopy ears of L or intermediate ears of the F_1 or BACKCROSS.

Genetic lines did not differ ($P > 0.05$) for AGEPUB or PUBWT. In agreement, Hutchens et al. (1982) reported non-significant heterosis (0.3%) for age at puberty between Landrace and Yorkshires. However heterosis for age at puberty in other breed crosses ranged 1.4 to 7.2%. The same study established Landrace × Yorkshire F_1's vs. the pure-line average were 4.5 kg heavier at puberty, higher than our estimate (1.9 kg, P = 0.49). The current study indicates heterosis is not useful in greatly reducing age or weight at puberty in Landrace and Large White F_1 or BACKCROSS females.

Associations between gilt entry, growth, composition, sow farm entry, and sow traits with genetic line are shown in Table 4.4.

Pure-line average vs. F_1 females had lower DAYS ($P < 0.05$) and numerically higher ($P = 0.24$) BF, heterosis 2.5 and 3.6%, respectively. McLaren et al. (1987) reported heterosis estimates for ADG (8.5%) and backfat (3.9%) between Landrace and Yorkshires. Overall heterosis for that study was 10.5% for ADG and 3.2% for backfat.

Rear leg side view and rear legs rear view were the only structural conformation traits that differed ($P < 0.05$) between genetic lines. Landrace vs. LW were more ($P < 0.05$) sickle-hocked and less ($P < 0.05$) cow hocked which is in agreement with Serenius et al. (2001).

There were no differences ($P = 0.22$) between genetic lines for STAY1. Cronin et al. (1983) reported more Large White gilts were mated by 35 w of age than Landrace or Landrace × Large White synthetics. In sows, culling rate is higher (Dagorn and Aumaitre, 1979; Sehested and Schjerve, 1996; Jørgensen, 2000) or not different (Dagorn and Aumaitre, 1979) in pure-lines vs. crossbreds.

Pure-line average vs. F_1 had fewer ($P < 0.05$) TNB1 (10.5 vs. 11.5). In agreement Rothschild and Bidanel (1998) established average heterosis for litter size is 0.8 piglets. The F_1 vs. BACKCROSS females had more ($P < 0.05$) TNB1.

Fertility group

Associations of estrus and puberty traits with fertility group are shown in Table 4.3. Only 4% (n = 45) of gilts were in FG0. Similarly, Cronin et al. (1983) established 3% of gilts did not exhibit estrus. Moeller et al. (2004) reported 3 to 13% of gilts, from six genetic lines, were not detected in estrus. Fertility group 1 contained 24% (n = 255) of gilts. Cronin et al. (1982) and Moeller et al. (2004) reported 26% and 5 to 14%, respectively, of gilts were detected in estrus and did not farrow. From these studies, getting pubertal gilts bred is a larger hindrance than females not reaching puberty. Results from the current study indicate poor estrous symptoms are part of the problem.

Gilts from FG3 vs. FG1 had a longer ($P < 0.05$) length of estrus (2.16 vs. 2.06), greater ($P < 0.05$) maximum standing reflex with a boar (7.6 vs. 7.4) and higher ($P < 0.05$) total strength of standing reflex with a boar (15.4 vs. 14.6). The relationship between length of estrus and STAY1 was nonlinear (Figure 4.1). Length of estruss of 0.5 and 1.0 d vs. longer were less ($P < 0.05$) likely to farrow. Estrus detection on the sow farms was conducted once daily hence short vs. long length of estruss were more likely missed and subsequently removed from the herd.

Field studies report reproductive failure is the leading cause of gilt (Lucia et al., 2000; Tarrés et al., 2006) and sow (Stalder et al., 2004) removals. However, reported farm culling reasons contain errors (Knauer et al., 2007a). Examination of reproductive tracts at harvest facilities can confirm farm records. Post mortem examinations in gilts and sows (Heinonen et al., 1998) and sows (Knauer, 2007b) reveal most females culled have normal ovaries. Results from the current study suggest a proportion of these females have short or poor estrous symptoms.

Age at puberty was not associated (P = 0.55) with fertility group. These results are not supported by Moeller et al. (2004) who reported a genetic line younger for age at puberty was more likely to farrow. Perhaps results from the current study are partially explained by prenatal uterine effects. Lamberson et al. (1988) reported a lower age at puberty for gilts from litters with an increased proportion of males which reduces subsequent fertility (Drickamer et al., 1997). Generally, a younger age at puberty, age at first mating, or age at first farrowing is associated with increased sow reproductive lifetime (Holder et al., 1995; Koketsu et al., 1999; Knauer, 2006).

Associations of entry, growth, composition, sow farm entry, and sow traits with fertility group are shown in Table 4.4.

Entry age was not different (P = 0.23) between fertility groups. However, FG0 and FG1 vs. FG2 and FG3 were older (P = 0.05) at entry. In contrast, Brooks and Smith (1980) reported no differences in reproductive lifetime when gilts received boar exposure starting at 160 or 200 d of age. In that study average mating age was 198 and 237 d, respectively, much younger than in the present study (290 d).

Entry weight differed (P < 0.05) between fertility groups. Fertility group 1 vs. FG3 tended (P = 0.10) to be heavier at entry (100 vs. 99 kg). However sow farm entry weights did not differ (P = 0.98) between FG1 and FG3, (161 and 161 kg, respectively). Maternal effects on growth rate erode over time (Blunn et al., 1953). Perhaps a subpopulation of high growth rate gilts in FG1 had poorer fertility due to unfavorable maternal effects (i.e. sex ratio).

Backfat at 114 kg differed ($P < 0.05$) between fertility groups. Fertility group 0 vs. FG1, FG2, and FG3 had less ($P < 0.05$) BF. However, BF did not differ ($P = 0.16$) between FG0 and FG1 vs. FG2 and FG3. These results indicate low BF was more detrimental to whether a gilt expressed estrus than if she farrowed. Gilt backfat generally has an unfavorable or no relationship with sow reproductive lifetime measures (López-Serrano et al., 2000; Yazdi et al., 2000; Knauer, 2006).

Rib width was different between fertility groups. Fertility group 0 vs. FG1, FG2, and FG3 was narrower ($P < 0.05$) through the center part of their rib cage. Barczewski et al. (1990) established gilts with more girth had better stayability in early parities.

Locomotion was not different ($P = 0.12$) between fertility groups. However, FG0 vs. FG1, FG2, and FG3 had poorer ($P < 0.05$) locomotion. There was no culling of gilts going to the sow farms and gilts with poor locomotion farrowed. However, these gilts should be removed at an early age from commercial herds as they are more likely to have problems during lactation and are welfare concerns. Good locomotion has a favorable association with sow reproductive lifetime (López-Serrano et al., 2000; Serenius and Stalder, 2004).

Fertility group 2 and FG3 were not different ($P = 0.99$) for TNB1. Young et al. (2008) reported young puberty gilts (15%) vs. older tended ($P = 0.10$) to have more first litter total number born. Holder et al. (1995) established no differences for first litter total number born in a line selected for reduced age at puberty vs. control.

Summary

Different GDD's created large differences in weight and backfat of gilts entering sow farms. However these differences had little effect on estrous symptoms and subsequent reproduction.

Heterosis was reported for most estrous measures including length of estrus, total strength of standing reflex with a boar, and the vulva traits indicating crossbreeding would improve these traits. However heterosis does not appear to greatly reduce age at puberty in Landrace × Large White females.

This study identified several factors associated with whether a gilt farrowed or exhibited estrus. Gilts with longer (> 1 d) and stronger standing reflexes were more likely to farrow. Only 4% of gilts were not detected in estrus. However, the gilts that were not detected vs. detected in estrus were leaner, narrower ribbed and had poorer locomotion. Selection to improve the strength of standing reflex would increase the percentage of gilts that farrow thus improving sow reproductive lifetime.

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Table 4.1. Unadjusted means ± SD and LS MEANS of estrus and puberty traits by gilt development diet class.

			Gilt group							
			1	2		3		4		
			Gilt development diet class (GDD)[1]							
Trait[2]	Mean	SD	1	2	3	4	5	6	7	P-value
Estrus										
Length of estrus, d	2.15	0.65	2.20	2.23	2.15	2.03	2.19	2.08	2.09	0.09
MAX BOAR STAND	7.60	1.10	7.6	7.5	7.5	7.5	7.6	7.6	7.6	0.95
TOTAL BOAR STAND	15.3	5.0	15.5	15.6	14.9	14.4	15.8	15.2	15.1	0.23
MAX NO BOAR STAND	8.3	4.0	7.4[ab]	8.7[b]	8.2[b]	7.9[ab]	8.3[b]	7.1[a]	7.2[a]	0.04
TOTAL NO BOAR STAND	12.9	7.9	12.2[ab]	13.7[b]	12.3[ab]	11.6[ab]	13.1[b]	10.7[a]	10.8[a]	0.04
Vulva redness	60.5	3.3	56.2[a]	61.1[d]	61.0[d]	61.3[d]	62.0[c]	59.1[b]	59.0[b]	<0.01
VISUAL VULVA	1.7	0.7	2.1[c]	1.8[bc]	1.8[bc]	1.8[bc]	1.6[a]	1.7[ab]	1.9[bc]	0.01
Vulva width, mm	40	5	38[a]	43[d]	42[d]	40[c]	39[abc]	39[ab]	40[b]	<0.01
Puberty										
PUB	90	31	90	89	83	87	87	90	87	0.32
Age at puberty, d	211	29	207[abc]	219[d]	220[d]	216[cd]	209[b]	201[a]	204[ab]	<0.01
Puberty weight, kg	137	21	151[c]	142[b]	140[b]	142[b]	133[a]	128[a]	129[a]	<0.01
Puberty backfat, cm	2.1	0.6	2.5[cd]	2.4[d]	2.4[cd]	2.3[c]	2.1[b]	1.9[a]	1.9[a]	<0.01
Puberty LM area, cm^2	47.5	6.8	50.4[b]	46.2[a]	45.6[a]	46.9[a]	46.4[a]	46.6[a]	47.1[a]	<0.01

[abcd]Means within a row with different subscripts differ ($P < 0.05$), [1]comparisons of LS MEANS for GDD's are valid within but not across gilt groups because GDD's 6 and 7 received pelleted vs. meal diets, [2]MAX BOAR STAND= Maximum strength of standing reflex with boar, TOTAL BOAR STAND= Total strength of standing reflex with boar, MAX NO BOAR STAND = Maximum strength of standing reflex without boar, TOTAL NO BOAR STAND = Total strength of standing reflex without boar, VISUAL VULVA = Strength of vulva reddening and swelling, PUB = percentage of gilts pubertal at gilt development unit.

Table 4.2. Unadjusted means and LS MEANS of gilt entry, growth, composition, sow farm entry, and sow traits by gilt development diet classes.

			Gilt group							
			1	2		3		4		
			Gilt development diet class (GDD)[1]							
Trait[2]	Mean	SD	1	2	3	4	5	6	7	P-value
Entry										
Age, d	162	13	140^{a}	162^{c}	164^{d}	173^{e}	174^{e}	158^{b}	160^{b}	<0.01
Weight, kg	97	12	99^{b}	95^{a}	94^{a}	94^{a}	94^{a}	101^{b}	100^{b}	<0.01
Growth and composition										
Days to 114 kg	183	17	168^{a}	192^{d}	192^{d}	190^{cd}	188^{c}	185^{bc}	184^{b}	<0.01
Backfat at 114 kg, cm	1.6	0.4	1.8^{c}	1.7^{bc}	1.7^{b}	1.4^{a}	1.5^{a}	1.5^{a}	1.5^{a}	<0.01
LM area at 114 kg, cm^2	46.1	6.4	42.9^{b}	41.0^{a}	41.2^{a}	48.8^{c}	49.3^{c}	50.7^{d}	51.3^{d}	<0.01
Structural conformation										
Rib width	2.9	0.9	3.0	2.7	2.7	2.6	2.5	2.7	2.5	0.12
Muscle mass	2.0	0.7				1.8	1.8	1.9	1.9	0.91
Front leg side view	4.0	0.9	4.0^{abc}	3.8^{a}	4.0^{ab}	4.0^{ab}	4.1^{bc}	4.2^{bc}	4.2^{c}	0.01
Rear leg side view	3.6	0.7	3.9^{d}	3.6^{c}	3.5^{bc}	3.4^{ab}	3.5^{bc}	3.5^{abc}	3.4^{a}	<0.01
Front legs front view	3.2	0.6	3.5^{b}	3.5^{b}	3.4^{b}	2.9^{a}	2.9^{a}	3.1^{a}	3.0^{a}	<0.01
Rear legs rear view	3.1	0.7	2.9^{a}	3.7^{c}	3.7^{c}	2.9^{ab}	2.9^{ab}	3.0^{b}	3.0^{ab}	<0.01
Locomotion	3.3	1.0	3.3^{abc}	3.3^{ab}	3.2^{a}	3.4^{abc}	3.3^{ab}	3.5^{bc}	3.6^{c}	0.01
Sow farm entry										
Age, d	265	21	225^{a}	274^{c}	276^{d}	278^{d}	280^{e}	266^{b}	268^{b}	<0.01
Weight, kg	162	18	156^{b}	171^{d}	169^{cd}	167^{c}	153^{b}	148^{a}	146^{a}	<0.01
Backfat, cm	2.6	0.8	3.0^{de}	3.0^{e}	2.8^{d}	2.5^{c}	2.0^{b}	1.9^{ab}	1.8^{a}	<0.01
LM area, cm2	51.6	6.3	47.5^{a}	53.3^{d}	52.8^{d}	51.2^{c}	49.7^{b}	48.7^{ab}	48.0^{a}	<0.01
Sow										
STAY1	0.72	0.45	0.84^{d}	0.61^{a}	0.57^{a}	0.73^{bc}	0.78^{cd}	0.66^{ab}	0.67^{ab}	<0.01
TNB1	10.4	3.0	10.1	10.6	10.7	10.6	10.5	10.8	10.8	0.67

[abcde]Means within a row with different subscripts differ ($P < 0.05$), [1]comparisons of LS MEANS for GDD'S within gilt group are valid within but not across gilt groups because GDD's 6 and 7 received pelleted vs. meal diets, [2]STAY1 = whether or not a gilt farrowed a litter, TNB1 = first litter total number born.

Table 4.3. LS MEANS of estrus and puberty traits by genetic line[1] and fertility group[2].

	Genetic Line[3]					Fertility group[3]				
	F_1	BACK	L	LW		0	1	2	3	
Trait[4]	n=113	n=610	n=60	n=283	P-value	n=45	n=257	n=66	n=698	P-value
Estrus										
Length of estrus, d	2.21^{b}	2.16^{b}	2.16^{b}	1.91^{a}	<0.01		2.06		2.16	0.04
MAX BOAR STAND	7.6	7.6	7.5	7.5	0.93		7.4		7.6	0.01
TOTAL BOAR STAND	15.5^{b}	15.4^{b}	15.4^{b}	13.7^{a}	<0.01		14.6		15.4	0.03
MAX NO BOAR STAND	7.4^{ab}	8.2^{b}	6.9^{a}	9.1^{c}	<0.01		7.8		8.0	0.42
TOTAL NO BOAR STAND	11.1^{a}	12.6^{a}	11.0^{a}	13.9^{b}	0.03		11.7		12.6	0.16
Vulva redness	59.5^{a}	60.5^{b}	59.9^{ab}	60.9^{c}	<0.01		60.1		60.4	0.16
VISUAL VULVA	1.9^{b}	1.7^{a}	1.8^{ab}	1.7^{a}	0.04		1.8		1.8	0.92
Vulva width, mm	41^{b}	39^{a}	40^{ab}	39^{a}	0.01		40		40	0.89
Puberty										
PUB	0.91	0.86	0.82	0.86	0.41					
Age at puberty, d	211	212	213	215	0.51		214		213	0.55
Puberty weight, kg	141	137	139	138	0.48		140		138	0.15
Puberty backfat, cm	2.3	2.2	2.3	2.1	0.11		2.24		2.18	0.18
Puberty LM area, cm^2	47.6	47.6	47.5	47.2	0.89		47.6		47.4	0.59

[abc]Means within a row with different subscripts differ ($P < 0.05$), [1]L = Landrace, LW = Large White, F_1 = L × LW F_1, BACK= backcross of L or LW on L × LW composite female, [2]0= did not farrow, not detected in estrus at gilt development unit (GDU), 1 = did not farrow,detected in estrus at GDU, 2 = farrowed, not detected in estrus at GDU, 3 = farrowed, detected in estrus at GDU, [3]LS MEANS, [4]MAX BOAR STAND = Maximum strength of standing reflex with boar, TOTAL BOAR STAND = Total strength of standing, reflex with boar, MAX NO BOAR STAND= Maximum strength of standing reflex without boar, TOTAL NO BOAR STAND = Total strength of standing reflex without boar, VISUAL VULVA = Strength of vulva, reddening and swelling, PUB = percentage of gilts pubertal at gilt development unit.

Table 4.4. LS MEANS of gilt entry, growth, composition, sow farm entry, and sow traits by genetic line[1] and fertility group[2].

	Genetic Line[3]					Fertility group[3]				
	F_1	BACK	L	LW		0	1	2	3	
Trait[4]	n=113	n=610	n=60	n=283	P-value	n=45	n=257	n=66	n=698	P-value
Entry										
Age, d	162^{a}	162^{a}	161^{a}	164^{b}	<0.01	164	163	161	162	0.23
Weight, kg	99^{b}	97^{b}	97^{ab}	95^{a}	0.01	95^{a}	100^{b}	95^{a}	99^{b}	<0.01
Growth and composition										
Days to 114 kg	182^{a}	184^{a}	185^{ab}	188^{b}	<0.01	190^{b}	180^{a}	189^{b}	181^{a}	<0.01
Backfat at 114 kg, cm	1.6^{b}	1.6^{b}	1.6^{b}	1.5^{a}	0.02	1.5^{a}	1.6^{b}	1.6^{ab}	1.6^{b}	0.04
LM area at 114 kg, cm^2	47.0	47.2	47.0	46.3	0.12	47.1	47.2	46.5	46.6	0.40
Structural conformation										
Rib width	2.8	2.7	2.5	2.6	0.37	2.2^{a}	2.9^{c}	2.6^{b}	2.9^{c}	<0.01
Muscle mass	1.9	1.9	1.8	1.8	0.50	1.7	2.0	1.8	2.0	0.17
Front leg side view	4.0	4.2	4.0	4.1	0.22	4.2	4.1	4.1	4.0	0.44
Rear leg side view	3.6^{ab}	3.5^{a}	3.4^{a}	3.7^{b}	<0.01	3.5	3.6	3.6	3.5	0.98
Front legs front view	3.2	3.1	3.2	3.2	0.56	3.1	3.2	3.1	3.2	0.31
Rear legs rear view	3.2^{b}	3.0^{a}	3.3^{b}	3.0^{a}	<0.01	3.1	3.1	3.2	3.1	0.71
Locomotion	3.3	3.5	3.4	3.4	0.25	3.7	3.3	3.3	3.3	0.12
Sow farm										
Age, d	265^{a}	268^{c}	268^{abc}	270^{b}	<0.01	273^{b}	263^{a}	272^{b}	263^{a}	<0.01
Weight, d	160	157	156	157.0	0.41	154^{a}	161^{b}	153^{a}	161^{b}	<0.01
Backfat, cm	2.4^{ab}	2.4^{b}	2.4^{ab}	2.2^{a}	0.03	2.0^{a}	2.6^{b}	2.2^{a}	2.6^{b}	<0.01
LM area, cm2	50.2	50.4	49.1	50.0	0.51	48.6^{a}	50.7^{b}	49.5^{ab}	50.9^{b}	0.04
Sow										
STAY1	0.69	0.77	0.67	0.72	0.22					
TNB1	11.5	10.4	10.4	10.6	0.08			10.7	10.7	0.99

[abc]Means within a row with different subscripts differ ($P < 0.05$), [1]L = Landrace, LW = Large White, F_1 = L × LW F_1, BACK= backcross of L or LW on L × LW composite female, [2]0= did not farrow, not, detected in estrus at gilt development unit (GDU), 1 = did not farrow detected in estrus at GDU, 2 = farrowed, not detected in estrus at GDU, 3 = farrowed, detected in estrus at GDU, [3]LS MEANS, [4] STAY1 = whether or not a gilt farrowed a litter, TNB1 = first litter total number born.

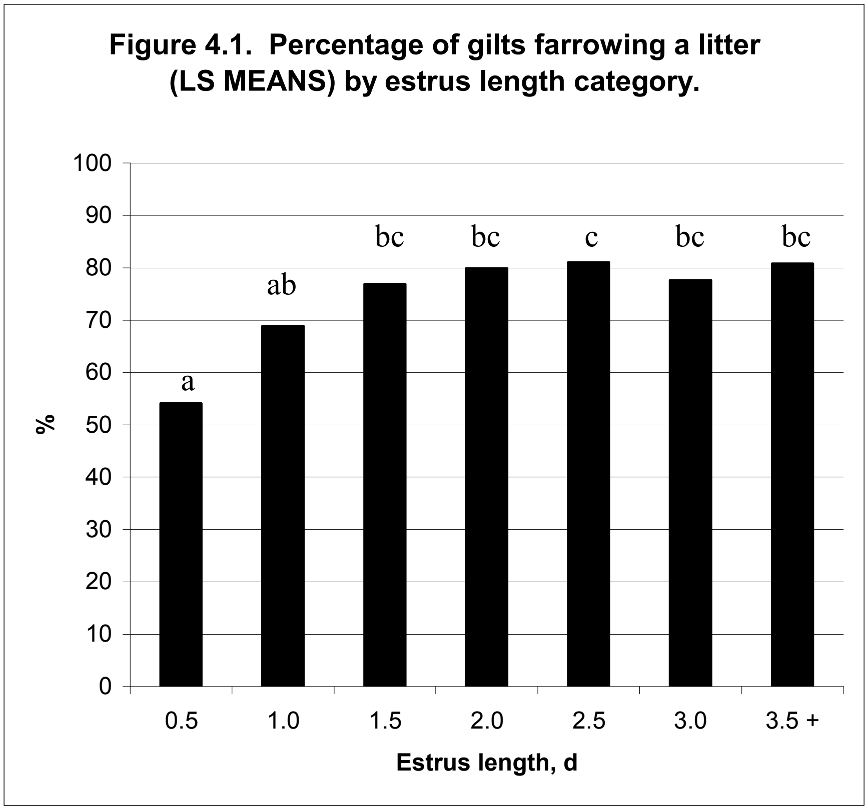

Figure 4.1. Percentage of gilts farrowing a litter (LS MEANS) by length of estrus category.
[abc]Means within a row with different subscripts differ ($P < 0.05$).

Chapter 5

General conclusions

In chapter 2 heritability estimates for length of estrus, maximum strength of standing reflex with a boar, total strength of standing reflex with a boar, maximum strength of standing reflex without a boar, total strength of standing reflex without a boar, vulva redness, strength of vulva reddening and swelling, vulva width, and age at puberty were 0.21, 0.13, 0.26, 0.42, 0.42, 0.26, 0.45, 0.58, and 0.29, respectfully. Thus quantitative measures of gilt estrous behavior appear heritable. The estimated genetic correlation between length of estrus and maximum strength of standing reflex with a boar was 0.99. This suggests length and strength of estrus are the same traits. Thus selection for a stronger standing reflex would be possible through direct or indirect selection. Genetic correlations between age at puberty with length of estrus, maximum strength of standing reflex with a boar, and vulva redness were (-0.23, -0.32, and 0.20 respectively). Thus selection for a younger age at puberty would have a correlated response of improved estrous symptoms, more specifically a stronger standing reflex and darker red vulvas. Length of estrus had positive genetic associations with growth rate and backfat (0.30 and 0.29, respectively). Thus selection for fast growth and low backfat may have had detrimental effects on estrous behavior. Perhaps there is a need for a more balanced selection objective.

In chapter 3 heritability estimates for whether a gilt farrowed (STAY1), age at first farrowing (AFF), and first litter total number born (TNB1) were 0.14, 0.22, and 0.02, respectively. Genetic correlations between length of estrus, the standing reflex traits, and age at puberty with STAY1 were (0.34, 0.34 to 0.74, and -0.27, respectively) and AFF were (-

0.11, -0.04 to -0.41, and 0.76, respectively). These associations indicate selection for a stronger standing reflex would have correlated benefits of a higher proportion of gilts farrowing and a younger age at first farrowing. Growth rate had unfavorable genetic associations with STAY1 (0.52) and AFF (-0.25) and a favorable genetic correlation with TNB1 (-0.08). Backfat had favorable genetic associations with STAY1 (-0.29) and AFF (0.14) and an unfavorable genetic correlation with TNB1 (0.47). These findings demonstrate that selection for fast growth and low backfat have unfavorable associations with subsequent reproductive performance. Vulva redness and TNB1 had a favorable phenotypic and genetic correlations (-0.14 and -0.53, respectively). This association would allow breeders to add accuracy to number born alive at a relatively early age. Associations between structural conformation traits with STAY1, AFF, TNB1, and WCI1 were generally low to moderately favorable.

In chapter 4 amongst the estrus traits, crossbred (F_1, BACKCROSS, or both) performance was superior to the pure-line average for length of estrus, total strength of standing reflex with a boar, vulva redness, strength of vulva reddening and swelling, and vulva width. These findings suggest heterosis may be used to improve estrous behavior. Fertility groups 0, 1, 2, and 3 contained 45 (4%), 255 (24%), 66 (6%), and 698 (66%) gilts, respectively. Thus getting gilts bred that were detected in estrus was a larger problem than gilts that appeared to have never been detected in estrus. Gilts from FG3 vs. FG1 had a longer length of estrus (2.16 vs. 2.06), greater maximum standing reflex with a boar (7.6 vs. 7.4) and higher total strength of standing reflex with a boar (15.4 vs. 14.6). These phenotypic results support the genetic relationships found in chapter 3. The relationship between length of estrus and STAY1 was nonlinear. This suggests a threshold length of estrus needed to farrow in systems that detect estrus once daily. Thus, length of estruss of ≤ 1 day would be unfavorable. Fertility group 0 compared to FG1, FG2, and FG3 had less backfat, poorer locomotion, and was narrower ribbed.

Selection for quantitative measures of gilt estrous behavior appears feasible. Favorable associations between estrous traits and components of reproductive lifetime warrant their consideration in current selection objectives. Unfavorable associations between estrus and production traits further support their inclusion. Deciding which estrous traits to incorporate depends on a system's ease of measurement, heritabilities, genetic correlations, and economic values.