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Marja Tellervo Nikkila
Iowa State University, marja.nikkila@hotmail.com

Kenneth J. Stalder
Iowa State University, stalder@iastate.edu

B. E. Mote
Iowa State University

Max F. Rothschild
Iowa State University, mfrothsc@iastate.edu

F. C. Gunsett
Newsham Choice Genetics

See next page for additional authors

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Abstract

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Authors

Marja Tellervo Nikkila, Kenneth J. Stalder, B. E. Mote, Max F. Rothschild, F. C. Gunsett, Anna K. Johnson, Locke A. Karriker, Mark Boggess, and T. V. Serenius

Genetic associations for gilt growth, compositional, and structural soundness traits with sow longevity and lifetime reproductive performance[1]

M. T. Nikkilä,* K. J. Stalder,*[2] B. E. Mote,* M. F. Rothschild,*
F. C. Gunsett,† A. K. Johnson,* L. A. Karriker,‡ M. V. Boggess,§ and T. V. Serenius*

*Iowa State University, Department of Animal Science, Ames 50011; †Newsham Choice Genetics, West Des Moines, IA 50265; ‡Iowa State University, Department of Veterinary Diagnostic and Production Animal Medicine, Ames 50011; and §National Pork Board, Des Moines, IA 50325

ABSTRACT: The objective of this study was to estimate genetic associations for gilt growth, compositional, and structural soundness with sow longevity and lifetime reproduction. Performance and pedigree information from 1,447 commercial females from 2 genetic lines were included in the data analyzed. Growth was expressed as days to 113.5 kg BW (DAYS) and compositional traits included loin muscle area (LMA), 10th rib backfat (BF10), and last rib backfat (LRF). Structural soundness traits included body structure traits [length (BL), depth (BD), width (BWD), rib shape (BRS), top line (BTL), and hip structure (BHS)], leg structure traits [front legs: legs turned (FLT), buck knees (FBK), pastern posture (FPP), foot size (FFS), and uneven toes (FUT); rear legs: legs turned (RLT), leg posture (RLP), pastern posture (RPP), foot size (RFS), and uneven toes (RUT)], and overall leg action (OLA). Lifetime (LT) and removal parity (RP) were considered as longevity traits whereas lifetime reproductive traits included lifetime total number born (LNB), lifetime number born alive (LBA), number born alive per lifetime day (LBA/LT), and percentage productive days from total herd days (PD%). Genetic parameters were estimated with linear animal models using the average information REML algorithm. Second, to account for censored longevity and lifetime reproduction records, genetic parameters were estimated using Markov Chain Monte Carlo and Gibbs sampling methods. Similar estimates were obtained across the analysis methods. Heritability estimates for growth and compositional traits ranged from 0.50 to 0.70 and for structural soundness traits from 0.07 to 0.31. Longevity and lifetime reproductive trait heritability estimates ranged from 0.14 to 0.17 when REML was used. Unfavorable genetic correlations were obtained for DAYS with LT, RP, LNB, LBA, and PD% and for LRF with PD%. However, LMA was favorably associated with LT, RP, and LNB. Moderate to high correlations were obtained for BL and BRS with all longevity and lifetime reproductive traits. Correlations of BWD with LT and RP were moderate. Associations for leg soundness traits with longevity and lifetime reproductive traits were mainly low and nonsignificant ($P \geq 0.10$). However, RLP was moderately correlated with LBA/LT and PD%. Current results indicate that selection for fewer DAYS has an antagonistic effect on lifetime performance. Furthermore, great BL, flat BRS, narrow BWD, and upright RLP seem detrimental to sow longevity and lifetime reproduction.

Key words: body composition, censoring, genetic parameter, lifetime reproduction, sow, structural soundness

INTRODUCTION

Reproductive performance and sow productive lifetime (**SPL**) form the cornerstones for commercial sow herd profitability and set boundaries for the yearly and lifetime number of piglets a sow farrows and weans. A mature sow herd is expected to be more prolific and therefore to improve herd productivity

(Friendship et al., 1986; Koketsu, 2005; Engblom et al., 2007). Yet, recent average annual sow removal rate (combined culling and mortality rate) of 56% in United States commercial breeding herds (PigCHAMP, 2011) indicates that an excessive proportion of sows are replaced at early parities before reaching peak productivity. This is detrimental to producer profitability because for the initial replacement gilt investment to become profitable, a sow should on average complete 3 parities (Stalder et al., 2003). The main causes for culling in early parities are reproductive failure and leg/locomotion problems (Boyle et al., 1998; Lucia et al., 2000; Engblom et al., 2007). Therefore, it is important to identify gilt composition and conformation traits associated with good reproductive performance throughout several parities.

Gilt growth and backfat measures have been reported to be unfavorably associated with sow longevity and lifetime prolificacy (López-Serrano et al., 2000; Yazdi et al., 2000a; Serenius and Stalder, 2004; Engblom et al., 2009; Knauer et al., 2010) whereas leg soundness traits are reported to be favorably associated with SPL (Brandt et al., 1999; López-Serrano et al., 2000; Serenius and Stalder, 2004, 2007; Tarrés et al., 2006; Fernàndez de Sevilla et al., 2008). However, no study has investigated genetic parameters for a wide range of structural soundness traits in relation to SPL and lifetime reproduction. Consequently, the objective of this study was to estimate genetic correlations for gilt growth, compositional, and structural soundness traits with sow longevity and lifetime reproductive traits in commercial maternal lines.

MATERIALS AND METHODS

All management and trial practices for this study were approved by the Iowa State University Institutional Animal Care and Use Committee.

Data Description and Sow Management

The study was a cooperative effort between the Department of Animal Science, Veterinary Diagnostic and Production Animal Medicine faculty at Iowa State University and industry partners including an Iowa-based integrator (Swine Graphics Enterprises, Webster City, IA) and a United States swine genetic supplier (Newsham Choice Genetics, West Des Moines, IA). All females were supplied by the same multiplier within the production system of the genetic supplier, where the gilt management was maintained as equal as possible. The gilts used in this study were preselected at the multiplier production facilities based on the guidelines of the genetic supplier for overall conformation,

structural soundness, and lameness. Gilts were high health (porcine reproductive and respiratory syndrome and *Mycoplasma* free) females without obvious defects or deformities and had high lean growth potential (within the top 75% of the contemporary group).

The study was conducted at a new commercial farm that had 3,790 sow spaces and it involved 1,447 gilts entering the herd between October 2005 and July 2006. Females represented 2 commercial genetic lines, 461 gilts were from a grandparent maternal line (Newsham line 3) and 986 were from a parent maternal line (SuperMom 37). Newsham line 3 was a maternal synthetic line, which originated from English Large White. SuperMom 37 line was a cross between Newsham lines 3 and 7, with the Newsham line 7 being a maternal synthetic cross that included the Nebraska Index line and Yorkshire genetic origins. The Nebraska Index line was a composite originating from Large White and Landrace populations produced at the University of Nebraska. From 1981, this line was selected based on an index that included ovulation rate, embryonic survival, and litter size at birth (number of fully formed piglets) only (Johnson et al., 1999).

The females involved in this study were progeny from 58 known sires and 835 dams. Sire information was not available for 52 gilts. In total, the pedigree included 2,901 animals.

Gilts and sows were managed according to standard procedures in the commercial operation and were treated as similarly as possible. Gilts were housed in groups of 10 to 12 females until being moved into breeding stalls when first estrus was observed. Group pens were 2.4 by 4.9 m in size (i.e., space per gilt ranged from 1.0 to 1.2 m^2). Isolation, breeding, and gestation barns had fully slatted concrete floors with 14.6 cm wide slats and 2.5 cm wide openings. Breeding and gestation stall size was 2.1 by 0.6 m. Farrowing stalls were 2.3 by 0.6 m in size and had triangular-steel bar flooring. The dimensions of piglet areas located on both sides of the sow were 2.0 by 0.4 m. The flooring was plastic-coated expanded metal and piglets were provided with heat lamps for 3 d at minimum. Feeding was based on nutrient analyses and all rations met or exceeded the requirements for the particular swine production phase (NRC, 1998). In group pens, gilts were fed ad libitum with a corn–soybean meal based diet. During the breeding and gestation periods, sows were fed once per day and after farrowing 3 times per day. Group pens had 2-hole feeders and cup waterers. The breeding and gestation stalls had individual drop-feeders and animals were provided water via a trough system during nonfeeding periods. The farrowing stalls had a shelf type feeder and individual nipple waterer. All animals had ad libitum access to water.

The studied gilts averaged 180 d of age (SD = 5 d) at herd entry and daily fence-line boar exposure and gilt estrus detection started immediately on arrival to the farm. Estrus synchronization was not in use, and estrus induction was used only if attempts to stimulate the females by mixing them in pens and moving them to a different barn failed. The goal of management was to mate gilts at second or third estrus and at approximately 136 kg BW. The studied gilts averaged 244 d of age (SD = 18 d) at first mating. If breeding targets of the farm allowed, first parity females were not mated until at second estrus after weaning. This practice provided first parity sows time to recover from their first farrowing and lactation and consequently alleviated the commonly observed smaller litter size in second parity ("the second parity dip"). In subsequent parities, the aim was to mate sows at first estrus after weaning. During standing estrus, AI was performed once per day. A boar was present in the alley in front of the stall of the mated sow. Pregnancy check was performed with a Bantam II ultrasound scanner (E.I. Medical Imaging, Loveland, CO) 35 to 42 d postinsemination. Females were usually not rebred more than twice before they were culled, if both failed attempts were classified as reproduction problems. Normal management practices were used at farrowing [e.g., induced farrowing (no earlier than d 115 of gestation) and oxytocin use during farrowing] but when used were noted for each female when possible. Litters were standardized within 24 h from birth and the targeted piglet number after transfer was 11 piglets with a range of 8 to 16 piglets. After weaning their own standardized litter, some sows acted as nurse sows, thus nursing more than 1 litter during their lactation period. The average lactation length among studied females was 18 d (SD = 6 d).

Gilt Compositional and Structural Soundness Traits

All gilts involved in the research trial were evaluated for compositional and structural soundness traits after an acclimation period (9 ± 5 d; mean ± SD) that occurred after the gilts arrived at the farm. Evaluation was performed on 14 separate dates, and the gilts averaged 124 kg BW (SD = 11 kg) and 190 d of age (SD = 7 d) when the evaluation occurred.

A Smidley Mini-Scale (Marting Mfg. of Iowa, Inc., Britt, IA) was used to obtain BW measurements. Gilt growth was assessed by calculating the number of days to reach a constant 113.5 kg BW (**DAYS**). Evaluated compositional traits included ultrasonically measured loin muscle area (**LMA**), 10th rib backfat (**BF10**), and last rib backfat (**LRF**). Ultrasonic images were obtained with a Pie Medical 200 (Classic Medical Supply, Inc., Tequesta, FL) by a single certified (Bates

and Christian, 1994) technician. Additionally, a tissue sample was collected from each female using the TypiFix ear tag system (IDnostics, Schlieren-Zürich, Switzerland).

Soundness traits evaluated included 6 body structure traits [body length (**BL**), body depth (**BD**), body width (**BWD**), rib shape (**BRS**), top line (**BTL**), and hip structure (**BHS**)], 5 leg structure traits per leg pair [front legs: legs turned (**FLT**), buck knees (**FBK**), pastern posture (**FPP**), foot size (**FFS**), and uneven toes (**FUT**); rear legs: legs turned (**RLT**), leg posture (**RLP**), pastern posture (**RPP**), foot size (**RFS**), and uneven toes (**RUT**)], and overall leg action (**OLA**). The structural evaluation was completed independently by 2 scorers using a 9-point scale. Depending on the evaluated body structure trait, score 1 indicated short BL, deep BD, narrow BWD, round BRS, weak BTL, or level BHS; score 5 indicated level BTL; and score 9 indicated long BL, shallow BD, wide BWD, flat BRS, high BTL, or steep BHS. In regards to leg structure traits, score 1 indicated outward turned FLT or RLT, upright side view angle of front legs (opposite extremity in FBK), weak RLP, weak FPP or RPP, large FFS or RFS, or even FUT or RUT; score 2 indicated normal side view angle in FBK; score 5 indicated straight posture in FLT or RLT, normal RLP, or intermediate FPP or RPP; and score 9 indicated inward turned FLT or RLT, severely buck-kneed FBK, upright RLP, upright FPP or RPP, small FFS or RFS, or uneven FUT or RUT. For OLA, score 1 indicated excellent movement and score 9 severely impaired movements or inability to walk.

Before the genetic analyses, the original scores for FLT and RLT were transformed to deviations from the intermediate score {i.e., score 5 [front legs turned (deviation from optimum score; **FLTD**) and rear legs turned (deviation from optimum score; **RLTD)**]}. Consequently, the modified scale had 5 points (the original 5 score was assigned a 1 score, scores of 4 and 6 were assigned a 2 score, scores of 3 and 7 were assigned a 3 score, scores of 2 and 8 were assigned a 4 score, and scores of 1 and 9 were assigned a 5 score). This was performed because there were very few observations in the score classes greater than 5 and an intermediate score was considered optimum within the scale used.

Sow Longevity and Lifetime Reproductive Traits

Sow lifetime (**LT**), which was measured in days from birth to removal or termination of data collection, and removal parity (**RP**) were considered as longevity traits. Lifetime reproductive traits included lifetime total number born (**LNB**), lifetime number born alive (**LBA**), number born alive per lifetime day (**LBA/LT**),

and percentage productive days from total herd days (**PD%**). Productive days included such time periods when a sow was either gestating or lactating. However, if she failed to farrow, gestation days were included to nonproductive days. Herd days were counted from herd entry to removal date or end of data collection.

Longevity and lifetime reproduction records included females removed as gilts (i.e., females with RP and lifetime reproduction equal to 0). For animals that were not removed during the data collection period, only complete parities were considered when obtaining PD% and LBA/LT. In their case, PD% was determined by using productive days and herd days until the last weaning and LBA/LT by using lifetime until the last weaning. Animals ($n = 5$) with missing litter size information in any parity were excluded from the analyses conducted to LNB, LBA, and LBA/LT.

Statistical Analyses

Mixed model methodology (PROC MIXED, SAS Inst. Inc., Cary, NC) was used for developing the models for variance component estimation of the traits evaluated in this study. Growth, compositional, structural soundness, longevity, or lifetime reproductive traits were the dependent variables and sire and dam were included as random effects as various fixed effects and linear covariates were evaluated for statistical significance. A common litter effect was not included into the statistical model because there were relatively few numbers of littermate gilts (56% of litters were represented by a single gilt) in the female population used in the present study.

Among compositional and structural soundness traits, genetic parameters were estimated with multivariate linear animal models using the average information REML algorithm (Johnson and Thompson, 1995; Jensen et al., 1997) in the DMU package (Madsen and Jensen, 2008). The data on longevity and lifetime reproductive traits included incomplete records (i.e., censored records) because 13.8% of females were still in production at data collection termination. When an analysis included longevity or lifetime reproductive trait, 2 different methods were used for genetic parameter estimation. First, single trait or bivariate analyses were completed using the average information REML algorithm in the DMU package including incomplete records into the analysis but ignoring censoring (i.e., censored records were treated as uncensored). Second, because DMU software did not account for censored records, censoring was implemented using Markov Chain Monte Carlo (**MCMC**) approach and Gibbs sampling (**GS**) procedures in GIBBS2CEN (S.

Tsuruta, University of Georgia, Athens, GA, personal communication).

Identical statistical models were used across the 2 analyses. The statistical model for BF10, LMA, and DAYS included

$$y_{ijk} = \mu + \text{LINE}_i + \text{CG1}_j + a_k + e_{ijk},$$

in which y_{ijk} = the trait measured on gilt k, μ = intercept, LINE_i = fixed effect of genetic line i ($i = 1,2$), CG1_j = fixed effect of contemporary group j ($j = 1$ to 14; contemporary group was based on evaluation date), a_k = additive genetic effect of gilt k with $a_k \, N \sim (0, \sigma^2_a)$, and e_{ijk} = random residual with $e_{ijk} \, N \sim (0, \sigma^2_e)$. The aforementioned traits were preadjusted to a constant BW of 113.5 kg (NPPC, 2000).

In the absence of a preadjustment formula, the statistical model for LRF included BW at evaluation as a linear covariate:

$$y_{ijk} = \mu + \text{LINE}_i + \text{CG1}_j + b_1 \text{BW}_k + a_k + e_{ijk},$$

which is identical to the previous model, except BW_k = BW of gilt k, and b_1 is a coefficient of linear regression.

The statistical model for analyzing structural soundness traits was

$$y_{ijkl} = \mu + \text{LINE}_i + \text{CG1}_j + \text{SCORER}_k + b_1 \text{BW}_l + a_l + e_{ijkl},$$

in which y_{ijkl} = the trait measured on gilt l, μ = intercept, LINE_i = fixed effect of genetic line i ($i = 1,2$), CG1_j = fixed effect of contemporary group j ($j = 1$ to 14; contemporary group was based on evaluation date), SCORER_k = fixed effect of scorer k ($k = 1,2$), BW_l = BW of gilt l, a_l = additive genetic effect of gilt l with $a_l \, N \sim (0, \sigma^2_a)$, e_{ijkl} = random residual with $e_{ijkl} \, N \sim (0, \sigma^2_e)$, and b_1 is a coefficient of linear regression.

The statistical model for longevity and lifetime reproduction traits included

$$y_{ijk} = \mu + \text{LINE}_i + \text{CG2}_j + a_k + e_{ijk},$$

in which y_{ijk} = the trait measured on sow k, μ = intercept, LINE_i = fixed effect of genetic line i ($i = 1,2$), CG2_j = fixed effect of contemporary group j ($j = 1$ to 16; contemporary group was based on herd entry date), a_k = additive genetic effect of sow k with $a_k \, N \sim (0, \sigma^2_a)$, and e_{ijk} = random residual with $e_{ijk} \, N \sim (0, \sigma^2_e)$.

Compositional and structural soundness trait heritability estimates were obtained by simultaneously including all traits within a trait group (body composition, body structure, front leg structure and OLA, and rear leg structure and OLA) into a single

multivariate analysis. However, single trait analyses were performed to estimate heritabilities for longevity and lifetime reproductive traits. Genetic correlations of compositional and structural soundness traits with longevity and lifetime reproductive traits were estimated with bivariate analyses.

In the DMU package, asymptotic SE for the variance and covariance component estimates were derived from the average information matrix. The SE computations for the genetic correlations were based on Taylor series approximation. A change in the update vector norm that was less than 10^{-7} was used as the convergence criterion.

Variance and covariance components obtained from DMU were used as starting values for analyses performed in GIBBS2CEN. Each analysis was run as a single chain of 250,000 cycles with a burn-in period of the first 50,000 cycles. After the burn-in period, every 20th sample was stored, which resulted in 10,000 samples for computing posterior means and SD. The sampled variance and covariance components for calculating heritabilities, genetic correlations, and SD were obtained using POSTGIBBSF90, a program developed by S. Tsuruta (Misztal et al., 2002).

RESULTS AND DISCUSSION

Descriptive Statistics

At data collection termination in September 2009, 13.8% of the females were still in production and on their sixth to ninth parity at the commercial sow herd. Regarding females that were removed from the breeding herd, reproductive failure was the most frequent culling reason causing 22.6% of all removals (data not shown). Reproductive problems were most pronounced in gilts to third parity females. In published literature, reproductive failure among removed females ranges from 27 to 34% (D'Allaire et al., 1987; Dijkhuizen et al., 1989; Boyle et al., 1998; Lucia et al., 2000; Engblom et al., 2007). It has been noted that for mature sows (third parity and greater) culling for reproductive failure is a lesser issue whereas litter performance and age start to increase in their importance (D'Allaire et al., 1987; Boyle et al., 1998; Lucia et al., 2000). Feet/leg or lameness problems accounted for 12.9% of removals and a little over two-thirds of these removals occurred before sows reached parity 3 (data not shown). Similar removal frequencies and early parity associations have been reported (D'Allaire et al., 1987; Boyle et al., 1998; Lucia et al., 2000; Hughes et al., 2010).

Descriptive statistics for longevity and lifetime reproductive traits are presented in Table 1. These data include observations on sows remaining in production at data collection termination. The proportion of incomplete records (i.e., right-censored records) was 13.8%, which causes raw means to be slightly underestimated. The mean for LT was 823.4 d, which corresponded to a 3.6 RP mean. Many other studies have measured length of productive lifetime in days from first conception or first farrowing to removal and excluded females removed as gilts whereas currently presented numbers include gilts that were culled without ever producing a litter. The mean for herd days was 643.0 d, which is slightly greater than 582.7 d reported by Lucia et al. (2000) for all females including gilts. In previous studies conducted in North America, mean RP ranged from 3.3 to 3.8 (D'Allaire et al., 1987; Lucia et al., 2000) whereas in studies conducted elsewhere (The Netherlands, Ireland, Sweden, and Japan), mean RP varied from 4.3 to 4.6

Table 1. Descriptive statistics[1] and heritability (h^2) estimates for longevity and lifetime reproductive traits in commercial sow lines used in a compositional, structural soundness, maternal performance, and sow productive lifetime study[2]

Trait[3]	n[4]	Mean	SD	Min.	Max.	$h^2 \pm$ SE (REML)	$h^2 \pm$ SD (GS[5])
Longevity							
LT, d	1,447	823.42	423.65	220	1,614	0.14 ± 0.06	0.13 ± 0.06
HD, d	1,447	643.02	423.63	41	1,431	0.14 ± 0.06	0.12 ± 0.06
RP	1,447	3.57	2.89	0	9	0.16 ± 0.06	0.13 ± 0.06
Lifetime reproduction							
LNB	1,442	42.21	36.18	0	142	0.16 ± 0.06	0.13 ± 0.06
LBA	1,442	38.49	32.93	0	126	0.17 ± 0.06	0.13 ± 0.06
LBA/LT	1,442	0.04	0.02	0	0.08	0.16 ± 0.06	0.15 ± 0.06
PD%	1,447	60.69	30.00	0	94.36	0.14 ± 0.06	0.14 ± 0.06

[1]Min = minimum; Max = maximum.

[2]The study was conducted at a commercial facility.

[3]LT = lifetime; HD = herd days; RP = removal parity; LNB = lifetime total number born; LBA = lifetime number born alive; LBA/LT = number born alive per lifetime day; PD% = percentage productive days from total herd days.

[4]The data included 1,447 females (except the records for LNB, LBA, and LBA/LT, from which 5 sows were excluded due to missing litter size information in some parity) from 2 commercial genetic lines; 461 sows belonged to a grandparent maternal line (Newsham line 3) and 986 to a parent maternal line (SuperMom 37).

[5]Variance component estimation was carried out with 2 different methods: REML and Gibbs sampling (GS). Censoring was implemented in GS procedures.

(Dijkhuizen et al., 1989; Boyle et al., 1998; Engblom et al., 2007; Sasaki and Koketsu, 2011).

Females averaged 42.2 LNB, 38.5 LBA, 0.04 LBA/LT, and 60.7 PD%. Lucia et al. (2000) reported 45.0 LNB and 41.3 LBA for North American commercial breeding females. In Sweden, commercial sows averaged 55.9 LNB and 52.7 LBA (Engblom et al., 2007). Sasaki and Koketsu (2011) observed an average lifetime performance of 52.5 LBA in Japanese commercial females. Unlike the average lifetime reproductive performances reported in the aforementioned studies, the current statistics include records on gilts, that is, females with lifetime productivity equal to 0. When excluding gilt records, the means increased to 50.5 LNB and 46.0 LBA (data not shown). Lucia et al. (2000) investigated the percentage of lifetime non-productive days from total herd days and reported a non-productive day percentage of 36.4% for all females (gilts included), which is consistent with the findings from the current study where this value was 39.3% (100% − PD%). Fewer reproductive problems, better reproductive management, and decreased removal rates would result in considerable PD% improvement. Efforts should be targeted, especially, toward reducing gilt removals, as these females create costs without any income or profits for the producers.

Heritability Estimates

Heritability estimates for growth and body composition traits ranged from 0.50 to 0.70. The estimates for body structure traits ranged from 0.15 to 0.31 whereas the estimates for leg structure traits ranged from 0.07 to 0.31 and the estimate for OLA was 0.12 (data not shown).

Heritability estimates obtained for longevity and lifetime reproductive traits using REML, which did not account for censoring, ranged from 0.14 to 0.17 (Table 1). When implementing censoring in GS, longevity and lifetime reproductive trait heritability estimates ranged from 0.12 to 0.15. All heritability estimates differed significantly from 0 ($P < 0.05$), except the estimate for FLTD, which only approached statistical significance ($0.05 < P < 0.10$).

Longevity and lifetime reproductive trait heritability estimates obtained in the current study are consistent with published literature estimates and indicate that sow longevity and lifetime reproductive traits have a genetic component, but rapid genetic improvement cannot be expected. In previous studies, linear model heritability estimates for length of productive life or stayability ranged from 0.02 to 0.11 (Tholen et al., 1996; López-Serrano et al., 2000; Serenius and Stalder, 2004; Engblom et al., 2009). Guo et al. (2001) used linear model with record censoring and reported a 0.25

heritability estimate. Heritability estimates obtained using survival analysis ranged from 0.05 to 0.31 (Yazdi et al., 2000a,b; Serenius and Stalder, 2004; Fernàndez de Sevilla et al., 2008). Previous linear model heritability estimates reported for LBA ranged from 0.03 to 0.12 (Serenius and Stalder, 2004; Engblom et al., 2009) and an estimate of 0.23 was obtained by incorporating censoring (Guo et al., 2001).

Genetic Correlations

Because REML and GS genetic correlation estimates were similar, only the REML estimates are discussed in the next paragraphs. However, Table 2 includes both REML and GS results. The genetic correlation magnitude for a given trait pair was similar regardless of whether the estimates were obtained using average information REML where censored records were treated as uncensored or GS implementing censoring. This would seem to indicate that a program capable of analyzing right-censored data was not required when a relatively small proportion of the records were censored; in this case only 14% of the records were censored.

Moderately unfavorable genetic correlations (r_g) were obtained for DAYS with LT, RP, LNB, LBA, and PD% ($r_g = 0.42$ to 0.58). Additionally, a weak unfavorable association between DAYS and LBA/LT approached statistical significance ($r_g = 0.33$; $0.05 < P < 0.10$). This indicates that selection for fewer DAYS might have a negative effect on longevity and lifetime reproductive performance. These observations agree with several previous findings, but it is important to note that results obtained from this study need to be interpreted within the distributions of observations present in the dataset. The animals included into the study were preselected for their growth potential and structural soundness by the genetic supplier, and therefore the gilt population evaluated in the present study primarily consisted of females that grew well and were free of obvious structural defects. The average DAYS was 178 d and ranged from 144 to 227 d. Additionally, 84% of the females reached 113.5 kg BW by 190 d of age (data not shown).

Fast growth rate increased culling risk in previously published work involving Yorkshire sows (Yazdi et al., 2000a; Hoge and Bates, 2011), but such effect was not observed in Swedish Landrace (Yazdi et al., 2000b). Knauer et al. (2010) reported negative regression coefficients for stayability on ADG in crossbred maternal lines. Furthermore, Tholen et al. (1996), López-Serrano et al. (2000), and Engblom et al. (2009) reported unfavorable genetic correlations between growth rate and stayability both in purebred and crossbred sows of white breed origins. However, Serenius and Stalder (2004) and Stalder et al. (2005) did not find growth rate significantly

associated with longevity traits or LBA in Finnish Landrace and Large White sows or in United States Landrace sows, respectively. Instead, Stalder et al. (2005) reported an unfavorable association between DAYS and lifetime number of piglets weaned. Hoge and Bates (2011) reported antagonistic association between DAYS and LBA in United States Yorkshire. Tummaruk et al. (2001) reported a favorable association between growth rate up to 100 kg BW and litter size in parities 1 to 5 in Swedish Landrace and Yorkshire nucleus sows. Based on previously published findings, genetic correlation estimates for growth rate with longevity and lifetime reproductive traits are dependent on the population evaluated. However, most studies imply that fast growing gilts have inferior longevity and lifetime reproduction, which is consistent with the current findings.

Low to moderate favorable correlations were obtained for LMA with LT, RP, and LNB (r_g = 0.36 to 0.44) and a weak correlation between LMA and LBA approached significance (r_g = 0.33; $0.05 < P < 0.10$). Stalder et al. (2005) reported that LMA was favorably associated with LBA and RP whereas Knauer et al. (2010) did not find LM depth to have any significant effect on stayability. This seems to indicate that selection for greater LMA has no antagonistic effect on longevity or lifetime reproduction and it may even cause a favorable response on lifetime performance.

Table 2. Genetic correlation estimates (r_g)[1,2] of longevity and lifetime reproductive traits with growth, body composition, and structural soundness traits in commercial sow lines[3] used in a compositional, structural soundness, maternal performance, and sow productive lifetime study

Trait[4]	LT REML	LT GS	RP REML	RP GS	LNB REML	LNB GS	LBA REML	LBA GS	LBA/LT REML	LBA/LT GS	PD% REML	PD% GS
Growth												
DAYS	0.58***	0.52	0.56***	0.51	0.42*	0.43	0.47**	0.46	0.33	0.35	0.50*	0.46
Body composition												
LMA	0.44**	0.39	0.37*	0.32	0.36*	0.33	0.33	0.31	0.24	0.22	0.16	0.15
BF10	0.16	0.19	0.24	0.26	0.14	0.20	0.14	0.20	0.14	0.19	0.37	0.33
LRF	0.23	0.28	0.28	0.33	0.19	0.43	0.18	0.42	0.18	0.39	0.38*	0.38
Body structure												
BL	−0.69***	−0.64	−0.64**	−0.61	−0.56**	−0.55	−0.56**	−0.55	−0.57**	−0.55	−0.70***	−0.64
BD	−0.28	−0.23	−0.28	−0.22	−0.22	−0.19	−0.20	−0.17	−0.06	−0.09	−0.14	−0.13
BWD	0.53*	0.52	0.44*	0.44	0.35	0.37	0.34	0.36	0.11	0.15	0.10	0.14
BRS	−0.72***	−0.68	−0.69***	−0.67	−0.63**	−0.64	−0.63**	−0.63	−0.56*	−0.56	−0.61**	−0.59
BTL	−0.25	−0.25	−0.18	−0.20	−0.18	−0.21	−0.14	−0.18	−0.07	−0.10	−0.11	−0.11
BHS	−0.42	−0.40	−0.35	−0.35	−0.30	−0.31	−0.29	−0.30	−0.18	−0.20	−0.32	−0.31
Front leg structure												
FLTD	0.48	0.46	0.49	0.44	0.56*	0.51	0.59*	0.52	0.66**	0.61	0.44	0.46
FBK	0.13	0.11	0.12	0.09	0.16	0.13	0.20	0.16	0.30	0.24	0.10	0.08
FPP	−0.06	−0.11	−0.05	−0.09	0.05	0.01	−0.01	−0.04	0.07	0.04	0.11	0.04
FFS	−0.04	0.05	0.02	0.14	0.02	0.08	0.01	0.07	−0.12	−0.06	−0.05	0.02
FUT	−0.00	0.02	0.05	0.07	−0.08	−0.07	−0.06	−0.04	−0.01	−0.01	0.19	0.20
Rear leg structure												
RLTD	−0.30	−0.29	−0.29	−0.28	−0.16	−0.16	−0.16	−0.16	0.05	0.01	−0.16	−0.17
RLP	−0.30	−0.22	−0.35	−0.25	−0.37	−0.30	−0.39	−0.31	−0.51*	−0.42	−0.50*	−0.39
RPP	0.11	0.13	0.07	0.10	0.01	0.02	0.02	0.04	−0.09	−0.07	−0.03	0.00
RFS	0.51*	0.54	0.51*	0.58	0.46	0.49	0.47	0.50	0.37	0.41	0.39	0.46
RUT	−0.13	−0.16	−0.07	−0.15	−0.18	−0.23	−0.20	−0.24	0.00	−0.06	0.30	0.23
Overall leg action	0.11	0.15	0.15	0.19	0.23	0.22	0.19	0.18	0.27	0.25	0.21	0.24

[1]Variance component estimation was carried out with 2 different methods: REML and Gibbs sampling (GS). Censoring was implemented in GS procedures.

[2]Standard error for REML estimates ranged from 0.17 to 0.20 for growth and body composition traits and from 0.20 to 0.33 for structural soundness traits. Standard deviation for GS estimates ranged between 0.18 and 0.37.

[3]The data included females from 2 commercial genetic lines; 461 sows belonged to a grandparent maternal line (Newsham line 3) and 986 to a parent maternal line (SuperMom 37). The study was conducted at a commercial facility.

[4]LT = lifetime; RP = removal parity; LNB = lifetime total number born; LBA = lifetime number born alive; LBA/LT = number born alive per lifetime day; PD% = percentage productive days from total herd days; DAYS = days to a constant BW of 113.5 kg; LMA = loin muscle area adjusted to a constant BW of 113.5 kg; BF10 = 10th rib backfat adjusted to a constant BW of 113.5 kg; LRF = last rib backfat; BL = body length; BD = body depth; BWD = body width; BRS = rib shape; BTL = top line; BHS = hip structure; FLTD = front legs turned (deviation from optimum score); FBK = buck knees; FPP = front pastern posture; FFS = front foot size; FUT = uneven front toes; RLTD = rear legs turned (deviation from optimum score); RLP = rear leg posture; RPP = rear pastern posture; RFS = rear foot size; RUT = uneven rear toes.

*REML genetic correlation estimate differs from 0 by $P < 0.05$; **$P < 0.01$; ***$P < 0.001$.

Regarding backfat measurements, only the weakly unfavorable association between LRF and PD% (r_g = 0.38) reached statistical significance and the correlation between BF10 and PD% approached significance (r_g = 0.37; 0.05 < P < 0.10). Solely on the basis of these findings, selection for lower backfat thickness would not be expected to have great detrimental effects on longevity or lifetime reproductive performance. However, Onteru et al. (2011) conducted a whole-genome association study on a subpopulation of the current data and the findings reinforced the associations of fat regulation with longevity and lifetime reproductive traits.

Stalder et al. (2005) reported that BF10 was unfavorably associated with RP and LBA and proposed that some minimum level of backfat thickness may be essential for good lifetime reproduction. Possibly, both backfat thickness and LMA impact longevity or lifetime reproductive traits in such a threshold manner, where longevity and lifetime reproduction get compromised unless a certain backfat or muscle depth level is reached. On the other hand, when the threshold is exceeded, the animal experiences no effect of backfat or muscle depth on her lifetime performance. Along these assumptions, as maternal line females, gilts from the current population may have had sufficient backfat and therefore antagonistic associations remained weak in the quantitative analyses.

Yazdi et al. (2000a) and Hoge and Bates (2011) reported that Yorkshire females with greater backfat thickness experienced a decreased culling risk, but according to Yazdi et al. (2000b) side-fat thickness was not associated with risk of culling in Swedish Landrace sows. Fernàndez de Sevilla et al. (2008) found low backfat thickness increasing risk of culling in Spanish Landrace but not in Large White sows. Knauer et al. (2010) observed positive regression coefficients of stayability on gilt backfat. Similarly, Tholen et al. (1996) and López-Serrano et al. (2000) obtained unfavorable genetic correlations between backfat thickness and stayability. Serenius and Stalder (2004) reported unfavorable genetic correlations for backfat thickness with length of productive life and LBA in Finnish Large White, but no association was present in Finnish Landrace breed. Furthermore, backfat thickness was not associated with the risk of culling in Finnish crossbred sows (Serenius and Stalder, 2007).

Moderate to high genetic correlations were obtained for BL and BRS with all longevity and lifetime reproductive traits (r_g = –0.56 to –0.72). Females with shorter BL (i.e., within this data set close to intermediate BL) and rounder BRS remained for a greater number of days in the herd and had greater and more efficient lifetime reproduction. Within the studied population, shorter BL meant intermediate BL, as 89% of the observations were distributed into scores 4 to 6 and 5 described intermediate BL. López-Serrano et al. (2000) investigated the genetic relationship of stayability with BL, but the association was nonsignificant. Brandt et al. (1999) reported an increased culling risk for larger framed animals in parities 4 and 5. In the current study, BWD was moderately favorably correlated with LT and RP (r_g = 0.53 and 0.44, respectively). Furthermore, a favorable association between BHS and LT approached statistical significance (r_g = –0.42; 0.05 < P < 0.10). According to the current results, selection for more optimal body structure would improve longevity and lifetime reproductive performance.

The great majority of genetic correlations obtained for leg soundness traits with longevity and lifetime reproductive traits were low and nonsignificant ($P \geq$ 0.10).Moderate associations were obtained for FLTD with LNB, LBA, and LBA/LT (r_g = 0.56 to 0.66). Additionally, correlations of FLTD with LT and RP approached significance (r_g = 0.48 and 0.49, respectively; 0.05 < P < 0.10). After transforming records of FLT into FLTD, 79% of the observations were distributed into 2 best scores. Hence, genetic correlations implied that slightly outward turned front leg posture was associated with greater longevity and lifetime reproduction; however, this finding needs to be considered with caution. Fernàndez de Sevilla et al. (2008) reported that splayed feet increased risk of culling in Duroc sows but not in Landrace or Large White sows. Kirk et al. (2008) concluded that front legs turned out were indicative of osteochondrotic and arthrotic elbow joint lesions.

Regarding rear leg traits, RLP was associated with LBA/LT and PD% (r_g = –0.51 and –0.50, respectively). Less upright RLP coincided with greater reproductive efficiency. According to Tarrés et al. (2006), sows with upright rear legs had an increased culling risk that approached statistical significance (P = 0.08). Moderate correlations were obtained for RFS with LT and RP (r_g = 0.51) and its associations with LNB and LBA approached significance (r_g = 0.46 and 0.47, respectively; 0.05 < P < 0.10). As 87% of the observations for RFS were distributed in 3 best scores, ideal foot size being large, correlations seem to indicate that females with intermediate RFS had greater longevity and larger litters.

In general, weak favorable genetic correlations have been reported for stayability, length of lifetime, and lifetime reproduction with leg conformation and OLA score (López-Serrano et al., 2000; Serenius and Stalder, 2004, 2007). Brandt et al. (1999) and Fernàndez de Sevilla et al. (2008) reported increased risks of culling for sows with suboptimal leg conformation. In the study by Brandt et al. (1999) the risk remained increased until weaning the fourth litter. Jørgensen (2000) concluded that FBK and weak RLP at the gilt stage increased the

culling risk whereas Fernàndez de Sevilla et al. (2008) reported increased culling risks for Spanish Large White sows with straight pasterns and for Spanish Landrace, Large White, and Duroc sows with weak pasterns. According to Tarrés et al. (2006), optimal scores for turned rear legs, size of rear inner claws, and greater phenotypic feet and leg index values decreased the risk of the sow being culled. Rothschild et al. (1988) did not find clear trends in responses of litter size traits to divergent selection for front leg structure in Duroc sows, but there seemed to be a weak favorable association between front leg soundness and conception rate.

The associations of leg traits with longevity measures and lifetime reproduction were weaker than anticipated in the study initiation. Unexpectedly, FBK and OLA had weakly unfavorable although nonsignificant genetic correlations with all longevity and lifetime reproductive traits. Weak and sometimes opposite estimates compared with the literature may at least partly be explained by suboptimal and challenging evaluation conditions. The farm was brand new at the time of structural soundness evaluation and the slatted floor was slippery and edges of the slats were sharp and rough, which affected animal posture and movement. Furthermore, preselection performed by the genetic supplier probably introduced some estimate bias and diseases encountered at the farm may have impacted the power of analyses as superior performing animals may have been impacted to a greater degree when compared with lower producing sows including greater morbidity and mortality rate. On the other hand, inferior females may have been retained in the herd to maintain adequate female numbers to meet breeding targets of the farm when the disease outbreaks occurred. In the current analyses, no corrections were implemented to the data regarding these effects.

Implications

This study was conducted at a typical United States commercial farm and provides insight to the gilt compositional and structural soundness trait associations with sow longevity and lifetime reproductive performance. Reproductive and feet/leg soundness or locomotion related removal frequencies imply that genetic improvements in both reproductive and structural soundness traits as well as good reproductive management practices are needed to improve SPL. In general, LMA and body structure traits had a favorable trend and DAYS had an unfavorable trend in their genetic correlations with longevity measures and lifetime reproductive traits. The genetic correlations obtained in this study indicate that for improving sow longevity and lifetime reproductive performance and hence the profitability for pork producers, the most important gilt

growth, compositional, and structural soundness traits in commercial replacement gilt selection are closer to intermediate DAYS and BL, wider BWD, rounder BRS, and less upright RLP. With right-censored records representing only 14% of the total records evaluated, average information REML appeared as a sufficient analysis method. This seems beneficial because REML estimates are easier and faster to obtain than GS estimates.

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