RESEARCH REPORT
ANIMAL SCIENCE

Title: Association of compositional traits and structural soundness with the ability of commercial line of sows to complete parities two and **three – NPB#06-031**
(A continuation of the original project titled: Association of compositional, structural soundness, and health with the ability of a commercial line of young sows to successfully complete parity one **(NPB#05-081)**

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Date submitted: 23 - June - 2009

Industry Summary

Poor sow longevity has both economic and welfare ramifications for the commercial swine industry. According to PigCHAMP ™ reports, between years 1998 and 2008, the average culling frequency of breeding herd females in U.S. commercial swine herds has been 45% and sow mortality rate has risen to nearly 8%. In some cases, individual herds have experienced culling and mortality rates above 50% and 15%, respectively. Since reproductive failure and leg problems are the primary culling reasons for young sows, maintaining acceptable reproduction rates in younger females and selecting structurally sound replacement gilts are important factors in increasing sow productive lifetime. Lower replacement rates would not only improve the outlook of the swine industry, but also increase the profitability of pork producers in terms of reduced replacement costs. Furthermore, reduced number of gilt litters would improve herd productivity, as gilt litters tend to be smaller, and their offspring experience greater mortality and poorer average daily gain throughout the nursery and grow – finish phases of production.

The objective of this study was to estimate the phenotypic and genetic associations of gilt compositional and structural soundness traits with reproductive and longevity traits (longevity defined as the ability to complete the second and the third parity). The ultimate goal of this project is to analyze data gathered from commercial females until culling at the end of their productive life (or at least across five parities), in order to determine factors measured or evaluated early in a sow's life that are associated with superior sow productive lifetime.

The study involved in total 2064 commercial females from two genetic lines, but the number of pedigree animals available for the purposes of genetic analyses was 1447. Gilts were on average 190 days of age and 125 kg body weight at the time of body composition and structural evaluation. Evaluated compositional traits included body weight, loin muscle area, last rib backfat and 10^{th} rib backfat. Soundness traits consisted of six body structure traits (body size: length, depth, width; body shape: rib shape, top line, hip structure), five leg structure traits per leg pair (front legs: legs turned, buck knees, pastern posture, foot size and uneven toes; rear legs: legs turned, weak/upright legs, pastern posture, foot size and uneven toes) and overall leg action. Two

scorers independently evaluated all structural soundness traits on a nine-point scale. Studied reproductive traits included cumulative total number born, number born alive and number weaned across three parities. These traits described the reproductive performance across three parities and were affected by both the litter size in individual parities and the removals. Lifetime, herd days and removal parity were considered as longevity traits.

The degree in which a trait is controlled by the genetics (heritability) and the genetic relationship between traits (genetic correlation) were estimated simultaneously for several traits using available genetic software. The model used to obtain the genetic parameter estimates for compositional traits included (fixed effects); genetic line of the gilt (two genetic lines) and evaluation day (to account for differences in the 14 groups of gilts delivered to the farm). The model used animal as a random effect, since each animal has a random sample of genes from each of its parents contributing to its genetic make up. Furthermore, standard formulas were applied to adjust 10^{th} rib backfat, loin muscle area and the number of days to a constant body weight of 113.5 kg. In the absence of an adjustment formula, last rib backfat measurements were adjusted during the genetic analyses to the constant average weight at evaluation (124 kg among pedigree females). Structural soundness traits were analyzed with an identical model to last rib backfat, except scorer was included as an additional fixed effect (to account for differences between two scorers). The model for cumulative reproductive traits and longevity traits included genetic line and herd entry group (contemporary group) as fixed and animal as a random effect.

The total proportion culled or died before fourth parity was 56%. Reproductive failure and feet and leg problems were the most frequent culling reasons, causing the loss of 16.0% and 7.4% of the research females. Poor body condition and litter performance had frequencies of 4.6% and 4.5%, respectively. The median survival times (time by which 50% of the females had been removed) were 529 herd days or 721 days of age, corresponding a mean removal parity of 2.5. No significant difference was observed in survival times between the studied genetic lines. Relatively low heritability estimates were obtained for longevity traits (0.10 – 0.14).

By the time of second farrowing, the females averaged 520 days of age and had been in the herd for 341 days. On average the second parity sows had 11.6 piglets born in total and 94 % of the piglets were born alive. Number of piglets weaned was 9.7. The third farrowing occurred on average at the age of 672 days when the females had been for 492 days in the herd. Total number born was 11.8 piglets with 93% of them being born alive. On average 9.7 piglets were weaned. Thus, the litter sizes both in birth and at weaning were very similar in parities two and three. Parental line females were significantly younger both at second and third farrowing with less non-productive days, and they farrowed larger litters than females of grandparental line ($P < 0.05$). From arrival to the farm throughout the first three parities, the backfat of parental line females was significantly thicker and loin muscle area smaller than corresponding measurements of grandparental line females ($P \leq 0.001$). During lactation parental line lost more backfat and loin muscle area than grandparental sows. At the time of removal, females had farrowed on average 28.2 piglets of which 26.4 were born alive and they had weaned 21.3 piglets. The amount of live sows i.e. censored records was 44%. Since large censoring percentage biases the means downward, these figures are expected to increase as further parities will be added into the analyses. Cumulative litter sizes across three parities did not differ significantly between the genetic lines and they were lowly to moderately heritable (0.10 – 0.20).

Body weight had significant phenotypic associations with all longevity traits ($P \leq 0.05$), but not with reproductive traits. Backfat measurements were highly significantly associated with removal parity and cumulative reproductive traits ($P < 0.001$) and loin muscle area was associated with herd days ($P = 0.02$). Longevity and/or reproductive performance improved with lower gilt weight, greater backfat and greater loin muscle area. Cumulative litter size at birth was largest for females that had backfat depth of 1.5 – 2.0 cm as gilts. However, cumulative number weaned was largest for gilts with tenth rib backfat greater than 2.5 cm. Also, parity at removal increased with increasing backfat depth. The heritabilities for compositional traits were high (0.50 – 0.70). Slower growth rate, greater backfat and larger loin muscle area were also genetically associated with improved reproductive performance and longevity, although, only adjusted days to 113.5 kg and loin muscle area were significantly correlated with these traits.

From structural traits, body length, rib shape, buck knees, front foot size, weak / upright rear legs and overall leg action had significant phenotypic associations ($P \leq 0.05$) across reproductive performance and longevity traits. Slightly shorter body than average and more shaped ribs appeared favorable across most longevity and reproduction variables. For leg structure traits, usually the most extreme inferior scores seemed

detrimental regarding longevity and reproductive performance. Weak rear legs seemed to phenotypically affect longevity and reproductive performance more than upright rear legs. Surprisingly the category of smallest front foot size had the greatest expected values for reproductive and longevity variables. However, the gilts were pre-selected by the genetic supplier before shipping to the farm, which means that the foot size was unlikely the smallest in the entire population. The heritability estimates were low to moderate (0.11 – 0.34) for body structure traits (see the appendix for a visual description of evaluated traits). In general, body structure had favorable genetic associations with reproductive and longevity traits. As seen from phenotypic analyses, also genetic results indicated that females with shorter body and more shaped ribs farrowed and weaned more piglets during the first three parities and remained longer in the herd. Furthermore, greater body width was significantly associated with improved longevity. The majority of the heritability estimates for leg structure were relatively low (0.02 – 0.17). However, upright rear legs and pastern posture had moderate heritabilities (0.21 - 0.31). The heritability of overall leg action was 0.12. The only leg trait showing significant genetic associations with reproductive performance and longevity was upright rear legs. Structural improvements were associated with improved longevity and reproductive performance. Only 1.7% of the pedigree females had the two most extreme scores for weak rear legs, which is likely the reason for genetic analyses failing to show the unfavorable association with reproductive and longevity traits seen from the phenotypic results.

This study was conducted at a typical U.S. commercial farm offering the pork producers results that are obtained at a comparable environment to theirs. The removal reason frequencies across parities show that genetic improvements in both reproductive and structural soundness traits are needed to increase the profits of the producers. Compositional, structural soundness, reproductive performance and longevity traits are to some extent both phenotypically and genetically associated with each other. More favorable scores for at least body length, width, rib shape, buck knees, weak / upright rear legs and leg action are associated with improvements in longevity and reproductive performance. Replacement gilt selection should target females with sufficient body composition and good structural soundness, as this would likely improve sow longevity and reproductive performance and hence the profitability for pork producers.

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III Scientific Abstract

The objective of this study was to estimate the phenotypic and genetic associations of gilt compositional and structural soundness traits with reproductive and longevity traits (longevity defined as the ability to complete the second and the third parity). The ultimate goal of this project is to analyze data gathered from commercial females until culling at the end of their productive life (or at least across five parities), in order to determine factors measured or evaluated early in a sow's life that are associated with superior sow productive lifetime.

The study involved in total 2064 commercial females from two genetic lines, but the number of available pedigree animals for the purposes of genetic analyses was 1447. Evaluated compositional traits included body weight, loin muscle area, last rib backfat and 10^{th} rib backfat. Soundness traits consisted of six body structure traits (body length, depth and width, rib shape, top line and hip structure), five leg structure traits per leg pair (front legs: legs turned, buck knees, pastern posture, foot size and uneven toes; rear legs: legs turned, weak/upright legs, pastern posture, foot size and uneven toes) and overall leg action. Studied reproductive traits included cumulative total number born, number born alive and number weaned across three parities. Lifetime, herd days and removal parity were considered as longevity traits.

The summary statistics were conducted using SAS software. The least square means were calculated using PROC GLM and models used for variance component estimation were developed with PROC MIXED. PROC LIFETEST was used for phenotypic survival analyses. AI-REML and the DMU-package were used to estimate variance components using bivariate or multivariate animal models.

The total proportion culled or died before reaching fourth parity was 56%. Reproductive failure and leg problems were the most frequent culling reasons across the first three parities (16.0% and 7.4%, respectively). The median survival times were 529 herd days, 721 days of age or a mean removal parity of 2.5. The heritabilities of longevity traits were relatively low. At the time of removal females had farrowed on average 28.2 piglets of which 26.4 were born alive and they had weaned 21.3 piglets. Cumulative reproductive traits were low to moderately heritable.

Body weight was significantly associated with all longevity traits, but not with cumulative reproductive traits. Backfat measurements were significantly associated with removal parity and cumulative reproductive traits and loin muscle area was associated with herd days. Longevity and/or reproductive performance improved with lower gilt weight, greater backfat and greater loin muscle area. The heritability estimates for body composition traits were high. Slower growth rate, greater backfat and larger loin muscle area were also genetically associated with improved reproductive performance and longevity.

Body length, rib shape, buck knees, front foot size, weak / upright rear legs and overall leg action had significant phenotypic associations across reproductive and longevity traits. Slightly shorter body than average and more shaped ribs appeared favorable. For leg structure traits, the most extreme inferior scores seemed detrimental regarding longevity and reproduction. The heritabilities were low to moderate for body structure and relatively low for leg traits. A favorable genetic trend was observed in the associations of body structure with reproductive and longevity traits. Body length and rib shape had significant genetic associations with reproduction and longevity; females with shorter body and more shaped ribs farrowed and weaned more piglets and remained longer in the herd. Furthermore, greater body width was significantly associated with improved longevity. Upright rear legs had significant favorable correlations with reproductive performance and longevity.

IV Introduction

Poor sow longevity has both economic and welfare ramifications for the U.S. commercial swine industry. On the basis of PigCHAMP ™ reports, between years 1998 and 2008 the average culling frequency of breeding herd females in U.S. commercial swine herds has been 45% and sow mortality rate during this same period was nearly 8%. Reported average removal or culling rates have generally been between 26% and 70% (Svendsen *et al.*, 1975; Kroes and Van Male, 1979; Dagorn and Aumaitre, 1979; Friendship *et al.*, 1986; D'Allaire *et al.*, 1987; Boyle *et al.*, 1998; Sukumarannair *et al.*, 2003). Increased replacement rates as a result of involuntary and voluntary culling, as well as sow mortality, increase a breeding herd's need for purchased or internally supplied replacement females. The welfare impact arises through early culling and sow mortality. Reducing mortalities associated with high replacement rates can improve the demoralizing situation that arises, when swine operation workers are required to remove sow mortalities from stalled swine facilities, and reduces the concerns about so called factory farms. Thus, lower replacement rates would not only improve the outlook of the swine industry, but also increase the profitability for pork producers in terms of reduced replacement gilt expenses and associated development, isolation and acclimation costs.

Numerous studies have shown that herd productivity is negatively influenced by high culling rates. This productivity decrease is attributed to culling an excessive proportion of lower parity sows before they reach peak productive parities (Einarsson and Settergren, 1974; Dagorn and Aumaitre, 1979; Friendship *et al.*, 1986; te Brake, 1986; D'Allaire *et al.*, 1992). Therefore, improved longevity would be expected to give higher return on gilt investment, as a greater proportion of sows would not be culled before they have "paid" for themselves (Stalder *et al*., 2003). Furthermore, reducing replacement rates to a more acceptable level would likely increase the net income of pork operations, as a more mature sow herd is expected to have more pigs born alive, which in turn is likely to result in more pigs marketed, regardless of type of pork operation. Additionally, older sows provide their offspring better disease protection through their colostrum when compared to the offspring from

gilts. This is reflected in lower nursery and finisher mortality rates and greater nursery and finisher average daily gains for offspring of older sows, which again increase producer profit potential.

When examining the reasons sows are culled by individual parity, slightly different trends can be seen. Reproductive failure is the largest reported reason for sow culling, and it appears to disproportionately affect younger sows (D'Allaire *et al*., 1987). Failing to cycle, conceive, and farrow all fall within the reproductive failure heading. Reproductive failure and feet and leg problems are the major reasons young sows (sows having three parities or less) are culled (Boyle *et al*, 1998; Lucia *et al*., 2000a; Engblom *et al*., 2007). Lucia *et al.* (2000b) examined the lifetime productivity of sows that were culled based on reproductive problems or performance issues and noted that lifetime number of piglets born alive was lower in females culled for reproductive problems. These findings are supported by D'Allaire *et al.* (1987) who found that sows removed for inadequate performance produced an average of 5.11 litters while the average parity of sows removed for reproductive failure was only 2.37. These studies illustrated that young sows are being removed at a higher rate for reproductive problems when compared to older sows. Once sows reach maturity (above three parities), culling for reproductive failure becomes a lesser issue and problems of poor performance, age, and even death can be responsible for removals (Boyle *et al*., 1998; Lucia *et al*., 2000a).

Since reproductive failure and feet and leg problems are the primary culling reasons for young sows, maintaining acceptable reproduction rates in younger females and selecting structurally sound females as replacements are important factors in increasing sow productive lifetime. Structural defects can also lead to impaired welfare, which weakens reproductive performance. In addition, sow with poor legs might expose her piglets to a greater risk of getting stepped or laid on. Due to all these aspects, it is important to determine which reproduction (number and weight of pigs at birth and weaning), compositional (backfat, loin muscle area, and weight), and structural soundness traits (feet and leg defects, locomotion irregularities, and structural abnormalities) have an impact on sow's ability to have a long and productive life. Additionally, determining the genetic parameters (heritabilities and genetic correlations) for these traits will help to determine the role genetics plays in longevity and its associated traits.

Only limited genetic studies have been conducted that have identified line differences and their effects on productive life. Advances in molecular genetics and genome sequencing have resulted in scientists recently identifying genes in model organisms that have shown associations with longevity. The overriding theme gathered from studying these genes, is their role in reduction of caloric intake that enables animals to live longer. However, a casual observation in confinement swine production is that leaner gilts tend to be removed from the herd earlier. These results from previous studies were generally flawed as they either used few sows (less than 200) or used producer records from multiple farms and genetic lines supplying extremely large data sets (greater than 100,000 records) without pedigree information, thus limiting the validity of the results. Furthermore, because of the logistics, most studies were only conducted up to either sow parity three (Rozeboom *et al*., 1996) or four (Moeller *et al.*, 2004) allowing for some understanding as to why sows leave the herd in early parities, but never accounting for reasons why other sows can thrive well beyond four parities. Though some previous studies revealed significant line interactions on sow longevity, they noted that further studies should be conducted to identify the genetic mechanisms associated with sows having advanced numbers of parities.

This report comprises the second part of the three-parted project (grants: NPB#05-081, NPB#06-031 and NPB#06-192, submitted by Stalder). The long term goal of this project has been to follow the females from entry to a standard commercial swine farm until culling at the end of their productive life (or at least through five parities), and to determine the factors that are associated with superior sow longevity. Females have been housed in a totally slatted, stalled production system that is typical for most of U.S. pork operations. Identifying compositional, productivity, structural soundness, and genetic factors that influence sow longevity in a typical U.S. production system allows U.S. producers to focus on improving those identified factors within their own operations.

V Objectives

The objectives of this research are to determine the associations between the ability to complete second and third parities including rebreeding for parity four as a measure of longevity and: 1) compositional traits (gilt backfat, loin muscle area, age, and weight), 2) structural soundness that was subjectively evaluated on the gilts upon entry into the herd, 3) health indicator measures, and 4) sow productivity. Additional objectives are to determine heritability and genetic correlations between various longevity measures and compositional, structural soundness, and health traits with measures of sow longevity.

This is a comprehensive project designed to follow females from introduction as breeding gilt candidates to a commercial swine unit through culling at the end of their productive life. This will allow for the determination of factors that are associated with superior sow longevity and develop recommendations for compositional traits, including emphasis on structural soundness and health to improve sow longevity. Tissue samples were obtained for other grants for determination of the association of improved sow longevity with genetic marker status.

VI Materials and Methods

This study is a cooperative study between faculty of the Department of Animal Science, Veterinary Diagnostic and Production Animal Medicine, and industry partners including an Iowa-based integrator and a national supplier of genetic material. The study was conducted at a new commercial farm of 3790 sow spaces and involved in total 2064 animals entering the herd between October 2005 and July 2006. The genetic analyses were conducted for a subpopulation of 1447 animals, as only this group had pedigree information and date of birth available. Therefore, all age related variables include data from pedigree animals only. The pedigree females were progeny of 58 known sires and 835 dams. Sire information was not available for 52 animals.

All females were supplied by a genetic supplier, where the management of females was maintained as equal as possible. The studied gilts were high health females without obvious deformities and had high lean growth potential (within the top 75 % of the contemporary group). They represented two commercial genetic lines, 998 gilts belonging to a grandparent maternal line (line 3) and 1066 to a parent maternal line (line 37). From pedigree females, 461 were grandparental and 986 were parental females.

Sows were managed according to the normal protocol in the commercial operation and were treated as similarly as possible. All management and trial practices were approved in advance by the Iowa State University Institutional Animal Care and Use Committee. Feeding was based on nutrient analyses and the requirements of a particular production stage of swine (NRC, 1998). During the breeding and gestation periods sows were fed once a day and after farrowing three times a day with a completely balanced corn-soybean meal diet. All animals had full access to water at all hours. No special feeding was conducted for this trial.

The breeding and gestation stalls were 2.1 m x 0.6 m on fully slatted concrete floors with 14.61 cm wide slats and 2.54 cm wide openings. Animals had individual drop-feeders and were provided water via a trough system, during non-feeding periods. The farrowing stalls were 2.3 m x 0.6 m in size with a shelf type feeder and individual nipple waterer. The farrowing stalls had a triangular-steel bar flooring for the sow and a plastic-coated woven wire for the 0.4 m x 2.0 m piglet areas on both sides of the sow. Isolation, breeding and gestation barns had full lights on between 5:00 and 22:30; during other hours the barns had night-lights. The temperature of isolation, breeding and gestation barns was maintained at 18˚C. Farrowing rooms were at 23.5˚C at farrowing and piglets were provided with heat lamps; the room temperature was gradually reduced to 20.5˚C by weaning.

Daily fence-line boar exposure and heat checks of gilts were started immediately upon arrival to the farm. Heat synchronization was not used, and heat induction was used only if attempts to stress the females by mixing them in pens and moving them to a different barn failed. Management aimed to mate the gilts at second or third heat at approximately 136 kg body weight. Studied pedigree gilts averaged 244 ± 18 days of age at the time of first mating. In order to give the young females time to recover from the first farrowing and consequently to alleviate the commonly observed “second-parity-dip”, if breeding targets of the farm allowed the first parity females were not bred until for the second heat after weaning. In consecutive parities, the aim was to breed the sows to the first heat after weaning. Artificial insemination was carried out once a day during standing heat equaling about two to three inseminations per heat with a boar being present in front of the females during insemination. Pregnancy check was performed with an ultrasound scanner between days 35 to 42 of gestation.

The females were usually not rebred more than twice before culling them due to reproduction problems. Normal management practices were used at farrowing (i.e. oxytocin, induction of farrowing, etc.), but were noted for each female if possible. Litters were standardized within 24 hours from birth and the targeted number of piglets after transfer was 11 piglets, the total range being 8 - 16 piglets. After weaning their own standardized litter, some sows acted as nurse sows, thus nursing more than one litter during their lactation period.

All incoming research gilts were evaluated for compositional traits and structural soundness. Additionally, a tissue sample (ear punch) was collected from each female at ear tagging to obtain DNA for conducting molecular evaluation in a related study (see grant, NPB#06-019, submitted by Rothschild and Stalder). Evaluation was carried out on 14 separate dates, and the gilts averaged 125 ± 11 kg body weight and 190 ± 7 days age at the time of appraisal. Body weights were measured on a standard, commercially available, digital scale. Evaluated body composition traits included ultrasonically measured loin muscle area, last rib backfat and 10^{th} rib backfat. Ultrasonic images were taken with a Pie Medical 200 (Classic Medical Supply, Inc., Tequesta, FL) by a single technician who was certified by the National Swine Improvement Federation (Bates and Christian, 1994). Prior to analyzing, standard formulas were applied to adjust 10^{th} rib backfat, loin muscle area and the number of days to a constant body weight of 113.5 kg (NPPC, 2000).

Soundness traits consisted of six body structure traits (body length, depth and width, rib shape, top line and hip structure), five leg structure traits per leg pair (front legs: legs turned, buck knees, pastern posture, foot size and uneven toes; rear legs: legs turned, weak/upright legs, pastern posture, foot size and uneven toes) and overall leg action. The structural evaluation was completed independently by two scorers using a nine point scale (Appendix 1). Top line, turned front legs, turned rear legs and weak/upright rear legs were each cut into two traits prior to analyses due to intermediate optimum. Cutting point was determined for an individual trait on the basis of the mean of the trait, the score distribution and trait's regression on overall leg action. For top line and weak/upright rear legs the assigned cutting point was score 5, and for turned front and rear legs it was score 4. Cutting point equals score 1 on the new scale, and also the observations having scores that belonged to the opposite trait received the score of 1. E.g. in case of top line, the original observation scores equal or larger than 5 had a score of 1 for weak top line and original score of 1 was score 5 on the new scale. Similarly, the scores equal or less than 5 had a score of 1 for high top line and the original score of 9 was score 5 on the new scale.

Reproduction traits were measured and recorded as each female was mated and succeeded to farrow. Recorded information included matings, farrowing and weaning dates, total number of piglets born, number of piglets born alive, stillborns, mummies, litter weight at birth (liveborn piglets), number of piglets died during the lactation, number of piglets weaned, litter weaning weight and culling dates and culling reasons for the sows. Also, the same compositional traits, which were evaluated as gilts entered the farm, were measured at each farrowing and weaning. Adjustment formula was used for adjusting litter weaning weight to 21 days weighing age (NSIF, 1997). Cumulative reproductive traits (cumulative total number born, cumulative number born alive and cumulative number weaned) were created by summation of litter size records across three parities. These traits describe sow's reproductive performance across three parities, therefore, being affected by both the litter size in individual parities and the removals. Animals with missing litter size information in any of the three parities were excluded from the analyses conducted to that particular cumulative trait. Lifetime, herd days and removal parity were considered as longevity traits. The cutting point for determining lifetime and herd days was the last parity three removal date among research females.

The summary statistics were conducted using SAS (SAS, 2006). PROC MEANS was used for obtaining the summary statistics and PROC FREQ for calculating observation frequencies for class variables. PROC GLM was used for calculating the least squares means of the traits and PROC MIXED for developing the models for variance component estimation. Compositional, structural, reproductive or longevity trait was the dependent variable and sire and dam were included as random effects as the statistical significance of various fixed effects and linear covariates was tested. PROC LIFETEST was used to conduct phenotypic survival analyses concerning the effect of compositional and structural soundness traits on several survival variables (lifetime, herd days, removal parity and cumulative reproductive traits). Wilcoxon test statistic which gives more weight to early event times than late ones was used for reporting significance levels (*P*-values).

Variance components were estimated with bivariate or multivariate animal models using the AI-REML algorithm in the DMU-package (Madsen and Jensen, 2008). The statistical model for compositional traits

included genetic line and evaluation day as fixed effects and animal as a random additive genetic effect. Pre-adjustments were used for adjusting 10th rib backfat, loin muscle area and the number of days to a constant body weight of 113.5 kg (NPPC, 2000). In the absence of an adjustment formula, body weight at evaluation was used as a linear covariate for last rib backfat. Structural soundness traits were analyzed with an identical model to last rib backfat, except scorer was included as an additional fixed effect. The model for cumulative reproductive traits and longevity traits included genetic line and herd entry group as fixed effects and animal as a random additive genetic effect. The genetic parameters for cumulative reproductive traits and longevity traits are preliminary as DMU cannot take censoring into account. We are currently working on finding a more optimal method for analyzing these censored traits.

VII Results

Longevity i.e. ability to complete three parities

The total proportion culled or died before the first farrowing was 16% of the studied animals (Table 1). The combined culling and mortality frequencies in the first three parities were 17%, 15% and 9%, respectively. Thus, less than half of the females reached fourth parity.

Reproductive failure was the most frequent culling reason across three parities and it caused the loss of 16% of the research females before fourth parity. Lameness or feet and leg problems were the second most important culling reason when considering either the total number culled over three parities (7%) or removal frequencies of young females before the second farrowing. Among the twice farrowed females, poor body condition caused the second highest number of culls and litter performance became the second most important culling reason in the third parity. This illustrates the management's decision of not to cull first or second parity sows due to poor performance. Epidemics encountered at the farm increased the mortality rates from the second gestation until the third farrowing. Among the females that failed to farrow even once, the higher frequency of culls assigned to miscellaneous category was due to the initial lack of linkage between identification methods. The animals were ear tagged in the beginning of the trial, but as the farm's database is based on tattoo numbers, the removal reasons of 96 animals were lost before establishing the linkage between animal's ear tag number and tattoo number. More detailed removal reason frequencies for parities two and three are listed in tables 2 and 3.

The median survival times obtained with PROC LIFETEST were 529 herd days (mean 506.3 ± 5.4) or 721 days of age (mean 688.3 ± 6.6), which corresponded a mean removal parity of 2.48 ± 0.03. Survival curves based on lifetime and herd days are presented in graphs 1 and 2. There was no statistically significant difference in survival times between the two genetic lines (Table 4). The amount of live animals i.e. censored records was 44%. Since large censoring percentage biases the means downward, these figures are expected to increase as further parities will be added into the analyses.

In the genetic analyses, low heritability estimates were obtained for longevity traits, estimates ranging between 0.10 – 0.14 (Table 4). These heritability estimates are preliminary as the method used for variance component estimation could not take censoring into account. We are currently trying to find a more optimal method for analyzing censored data.

Reproductive performance

Females averaged 520 ± 33 days of age and had been in the herd for 341 ± 34 days at the time of second farrowing (Table 5). On average the second parity sows had in total 11.6 ± 3.4 piglets born and number born alive was 10.8 ± 3.3 piglets, thus about 94 % of piglets were born alive. The litter birth weight of live born piglets was 14.9 ± 4.0 kg. The number of pre-weaning mortalities was 1.8 ± 1.3 piglets per litter. Number of piglets weaned was 9.7 ± 1.7 with an average litter weaning weight of 56.2 ± 14.0 kg. Adjustment formula was used for adjusting litter weaning weight to 21 days weighing age (NSIF, 1997). The adjusted litter weaning weight was 60.2 ± 14.6 kg. The body weight of the sows was 243.3 ± 23.1 kg at farrowing and they lost on average 23.3 ± 18.6 kg by weaning. Backfat depth at farrowing was 2.12 to 2.14 cm depending on location of

measurement (last rib or 10th rib), and backfat loss during lactation was from 0.26 to 0.37 cm. The average loin muscle area at farrowing was 51.24 ± 6.05 cm², and the loin muscle area loss was 2.58 ± 5.12 cm².

The third farrowing occurred on average at the age of 672 ± 41 days, which time the females had been for 492 ± 44 days in the herd (Table 6). Total number born averaged 11.8 ± 3.6 piglets and 93% i.e. 11.0 ± 3.3 piglets were born alive. The litter birth weight of live born piglets was 15.4 ± 4.6 kg. Pre-weaning mortality rate was 1.9 ± 1.5 piglets per litter. On average 9.7 ± 1.5 piglets were weaned with a litter weaning weight of 56.4 ± 13.8 kg. The adjusted litter weaning weight was 59.6 ± 13.6 kg. At farrowing, the sows weighed 250.3 ± 21.9 kg and average lactation weight loss was 25.4 ± 17.0 kg. Backfat depth at farrowing was 1.98 to 2.04 cm and females lost 0.24 to 0.30 cm of backfat by weaning. The average loin muscle area at farrowing was 48.80 ± 5.90 cm², and the loin muscle area loss was 1.58 ± 5.48 cm².

Parental line females (line 37) were significantly younger both at second and third farrowing with less non-productive days and they farrowed more piglets than females of grandparental line (line 3) (Tables 7 and 8). As noted in the final report for the first parity, they were also younger at the arrival to the farm. Furthermore, a significant difference in body composition traits between these maternal lines was observed already upon the entry to the farm, and the same trend has been apparent at every farrowing and weaning, parental line sows having thicker backfat and smaller loin muscle area. Lactation losses of backfat and loin muscle area were greater for parental line than for grandparental sows.

At the time of removal females had farrowed on average 28.23 ± 0.42 piglets of which 26.38 ± 0.39 were born alive and they had weaned 21.27 ± 0.35 piglets. Cumulative litter sizes across three parities did not differ significantly between the genetic lines (Table 4).

Cumulative reproductive traits were lowly to moderately heritable, estimates ranging between 0.12 – 0.20 (Table 4). The same way as longevity traits, analyses of cumulative reproductive traits would need the ability of censoring, but the current method used for variance component estimation could not take censoring into account. Therefore, these heritability estimates are preliminary.

Associations of compositional traits with longevity and reproductive performance

The gilts were on average 190 ± 7 days of age at the time of compositional and structural soundness evaluation and their average body weight was 125 ± 11 kg (124 ± 11 kg among pedigree females). The heritabilities obtained for gilt body composition and growth traits were high, days to 113.5 kg body weight having the lowest (h^2 = 0.50) and last rib backfat the highest estimate (h^2 = 0.70). Descriptive statistics, heritabilities and genetic correlations of these traits were more extensively discussed in the final report submitted regarding the first parity.

From gilt compositional traits, body weight was significantly associated with all longevity traits ($P \leq 0.05$), but not with cumulative reproductive traits (Table 9). Backfat measurements were highly significantly associated with removal parity and cumulative reproductive traits ($P < 0.001$) and loin muscle area was associated with herd days ($P = 0.02$). The coefficients obtained with PROC LIFETEST indicated that longevity and/or reproductive performance improved with lower gilt weight, greater backfat and greater loin muscle area.

As backfat was highly significant for several variables, it was divided into classes with increments of half a centimeter to investigate the optimal backfat depth (Table 10). Class indicated with "2.0 ≤ BF < 2.5", includes also last rib backfat observations greater than 2.5 as there very few of them. Litter size at birth favored backfat depth between 1.5 cm and 2.0 cm. However, cumulative number weaned was largest for gilts with tenth rib backfat greater than 2.5 cm. Also, parity at removal increased with increasing backfat depth.

Slower growth rate, greater backfat and larger loin muscle area were also genetically associated with improved reproductive performance and longevity (r_g = 0.07 - 0.54; Table 12). However, only adjusted days to 113.5 kg and loin muscle area had significant genetic correlations with these traits.

Associations of structural soundness traits with longevity and reproductive performance

Traits indicating body size (length, depth and width) had moderate heritability estimates ranging between 0.25 and 0.34. Heritability estimates for body shape traits were low to moderate, ranging from 0.11 to 0.26. The majority of the heritability estimates for leg structure (turned legs, buck knees, weak rear legs, foot size and uneven toes) were low to moderate (h^2 = 0.02 - 0.17). However, upright rear legs and pastern posture of both leg

pairs were highly heritable, ranging between 0.21 - 0.31. Overall leg action, which reflects both structural soundness and freedom of other defects or diseases affecting the movements, had a heritability of 0.12. Across all evaluated traits, only the heritability estimates for turned front legs did not differ significantly from zero ($P > 0.05$). As noted also for the compositional traits, the descriptive statistics, heritabilities and genetic correlations of the structural soundness traits were more extensively discussed in the final report of the first parity.

For the purposes of phenotypic survival analyses, structural scores with only few observations were combined with adjacent scores so that no class contained less than 30 observations. Body length, rib shape, buck knees, front foot size, weak / upright rear legs and overall leg action had significant phenotypic associations ($P \leq 0.05$) across reproductive performance and longevity traits (Table 9). Reproductive or longevity expectations within a structural score are given in tables 11 and 12 for such soundness traits that had significant associations. For body length score 4, indicating slightly shorter body than average, appeared favorable across most longevity and reproduction variables. Optimal rib shape score was most frequently 2 or 3, indicating more shaped ribs. For buck knees scores from 6 upwards seemed inferior. Surprising result was that the category of smallest front foot size had the greatest expected values for reproductive and longevity variables. Regarding weak / upright rear legs, scores 5 and 6 seemed most optimal, score 5 being considered as the normal posture and 6 as slightly upright. Weak rear legs reduced longevity and reproductive performance more than upright rear legs. For overall leg action scores 7 and greater were inferior.

In the genetic analyses, a favorable trend was observed in the associations of body structure with reproductive and longevity traits (r_g = -0.90 – 0.57; Table 13). Body length and rib shape had significant associations with reproduction and longevity (r_g = -0.90 – (-0.61)); females with shorter body and more shaped ribs farrowed and weaned more piglets during the first three parities and remained longer in the herd. Furthermore, greater body width was significantly associated with improved longevity (r_g = 0.46 – 0.57). The genetic correlations of leg structure traits with reproductive and longevity traits were less consistent (Table 13). In general, the genetic correlations of leg structure traits with reproduction and longevity did not differ significantly from zero ($P > 0.05$). Upright rear legs was the only leg trait in which structural improvements were significantly associated with better reproductive performance and longevity (r_g = -0.63 – (-0.50)). Only 1.7% of the pedigree females had the two most extreme scores for weak rear legs, which is likely to explain why genetic analyses failed to recognize the unfavorable association with reproductive and longevity traits seen in the phenotypic results. These genetic results are preliminary as censoring has not been taken into account in the analyses.

Health indicator measures

Abortions and sow deaths occurred in more frequent manner in the end of the year 2006 due to mycoplasma and influenza epidemic, which broke out at the farm in the beginning of November of that year. The worst period was over by December and recovered females were rebred. In January 2007, the farm encountered PRRSV epidemic, which again led to frequent abortions as well as piglet and sow mortalities. This epidemic lasted until June 2007.

These incidences are bound to have some impact on the power of analyses as superior animals may have been deceased, and on the other hand inferior females have likely been kept in the herd longer in order to maintain adequate female numbers. In the current analyses, no corrections have been implemented to the data regarding these effects, but some corrections may be applied in the future if considered necessary.

VIII Discussion

The studied females represented two commercial genetic lines, parental and grandparental line. To our knowledge, this is the first study of this size evaluating longevity of commercial females with known parents in the U.S.

The total proportion culled or died before reaching fourth parity was 56%. Reproductive failure and feet and leg problems were the most frequent culling reasons across the first three parities, causing the loss of 16.0% and 7.4% of the research females. Poor body condition and litter performance had frequencies of 4.6% and 4.5%, respectively. The median survival times were 529 herd days or 721 days of age, which were equal to a

mean removal parity of 2.5. No statistically significant difference was observed in survival times between the studied genetic lines. In the genetic analyses, relatively low heritability estimates were obtained for longevity traits.

By the time of second farrowing, the females averaged 520 days of age and had been in the herd for 341 days. The third farrowing occurred on average at the age of 672 days when the females had been for 492 days in the herd. The litter sizes both in birth and at weaning were very similar in parities two and three. Parental line females were significantly younger both at second and third farrowing with less non-productive days and they farrowed more piglets than females of grandparental line ($P < 0.05$). From arrival to the farm throughout the first three parities, the backfat of parental line females was significantly thicker and loin muscle area smaller than corresponding measurements of grandparental line females ($P \leq 0.001$). During lactation parental line lost more backfat and loin muscle area than grandparental sows. At the time of removal females had farrowed on average 28.2 piglets of which 26.4 were born alive and they had weaned 21.3 piglets. Since large censoring percentage biases the means downward, these figures are expected to increase as further parities will be added into the analyses. Cumulative litter sizes across three parities did not differ significantly between the genetic lines and were lowly to moderately heritable.

Body weight was significantly associated with all longevity traits ($P \leq 0.05$), but not with cumulative reproductive traits. Backfat measurements were highly significantly associated with removal parity and cumulative reproductive traits ($P < 0.001$) and loin muscle area was associated with herd days ($P = 0.02$). Longevity and/or reproductive performance improved with lower gilt weight, greater backfat and greater loin muscle area. Gilt backfat depth between 1.5 cm and 2.0 cm was found favorable to litter size at birth. However, cumulative number weaned was largest for gilts with tenth rib backfat greater than 2.5 cm. Also, parity at removal increased with increasing backfat depth. Slower growth rate, greater backfat and larger loin muscle area were also genetically associated with improved reproductive performance and longevity. However, only adjusted days to 113.5 kg and loin muscle area had significant genetic correlations with these traits.

From structural traits, body length, rib shape, buck knees, front foot size, weak / upright rear legs and overall leg action had significant phenotypic associations ($P \leq 0.05$) across reproductive performance and longevity traits. Slightly shorter body than average and more shaped ribs appeared favorable across most longevity and reproduction variables. For leg structure traits, usually the most extreme inferior scores seemed detrimental regarding longevity and reproductive performance. Weak rear legs seemed to phenotypically affect the longevity and reproductive performance more than upright rear legs. Surprisingly the category of smallest front foot size had the greatest expected values for reproductive and longevity variables. However, the gilts were pre-selected by the genetic supplier before shipping to the farm, which means that the foot size was unlikely the smallest in the entire population. A favorable genetic trend was observed in the associations of body structure with reproductive and longevity traits. As in the phenotypic analyses, also genetically body length and rib shape had significant associations with reproduction and longevity; females with shorter body and more shaped ribs farrowed and weaned more piglets during the first three parities and remained longer in the herd. Furthermore, greater body width was significantly associated with improved longevity. The only leg trait showing significant genetic associations with reproductive performance and longevity was upright rear legs. Structural improvements were associated with improved longevity and reproductive performance. Only 1.7% of the pedigree females had the two most extreme scores for weak rear legs, which is likely to explain why genetic analyses failed to recognize the unfavorable association with reproductive and longevity traits seen on phenotypic results.

The genetic results reported are preliminary as the method used for variance component estimation could not take censoring into account. We are currently in a process of searching for more optimal method for analyzing censored data. Adding the consecutive parities into the data and analyzing the data with a more suitable method may increase the reliability of the genetic estimates. Nevertheless, on the basis of these findings, all these trait groups – compositional, structural soundness, reproductive performance and longevity – are at least to some extent both phenotypically and genetically associated with each other. According to these analyses, more favorable scores for at least body length, body width, rib shape, buck knees, weak / upright rear legs and overall leg action are associated with improvements in productive lifetime and reproductive performance. Thus, replacement gilt selection should target females with sufficient body composition and good

structural soundness, as this would likely improve reproductive performance as well as sow longevity and hence the profitability for pork producers.

Results of immediate or future benefit to pork producers

The unique experimental setting of conducting this study at a typical U.S. commercial farm offers the pork producers results that are obtained at a comparable environment to theirs. This allows the producers to utilize the information gleaned from this study to improve sow longevity in their herds by focusing on improving factors related to gilt composition and structural soundness within their own operations. The current study will also provide future benefit to the swine industry, as it consists of three parts and the last part investigates all the data collected from the entry of the females to the farm until culling or at least through five parities, providing further information on aspects related to superior sow longevity.

When looking at the removal reasons and their frequencies across parities, it becomes obvious that genetic improvements in both reproduction and structural soundness traits are needed to increase the profits of the producers. This study gives insight to the phenotypic and genetic associations of gilt compositional and structural soundness traits with reproductive performance and productive lifetime. All the aforementioned trait groups are to some extent both phenotypically and genetically associated with each other. More favorable scores for at least body length, body width, rib shape, buck knees, weak / upright rear legs and overall leg action are associated with improvements in productive lifetime and reproductive performance. Thus, replacement gilt selection should target females with sufficient body composition and good structural soundness, as this would likely improve reproductive performance as well as sow longevity and hence the profitability for pork producers.

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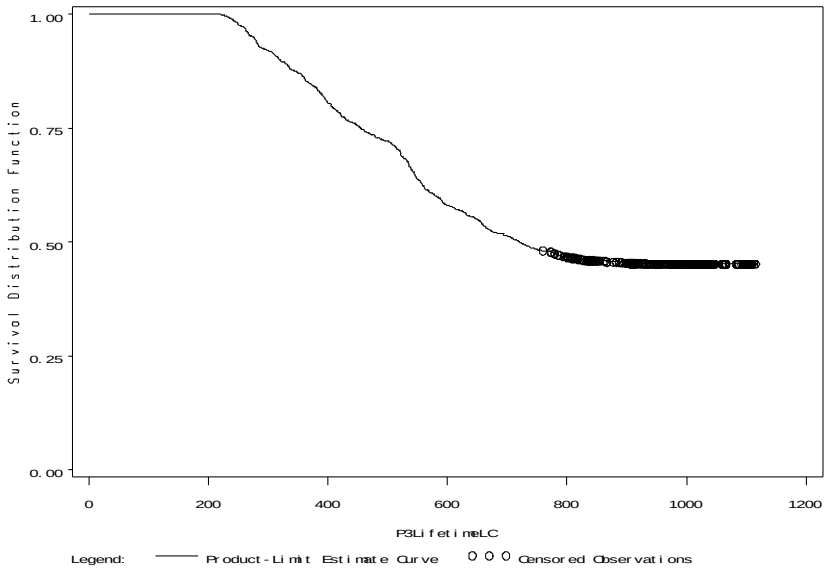
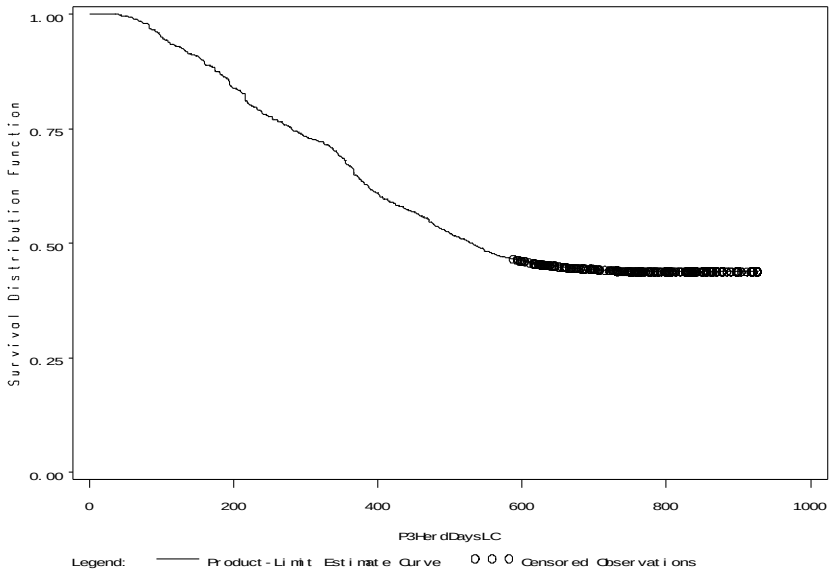
Graphs

Graph 1. Survival distribution measured in days of age in study evaluating the relationship between compositional, structural soundness, reproductive performance and productive lifetime in commercial lines of sows.



Graph 2. Survival distribution measured in herd days in study evaluating the relationship between compositional, structural soundness, reproductive performance and productive lifetime in commercial lines of sows.



Tables

Table 1. Removal and mortality frequencies across three parities in study evaluating the relationship between compositional, structural soundness, reproductive performance and productive lifetime in commercial lines of sows (n = 2064).

Removals and mortalities in the first three parities					
	P0[a]	**P1**	**P2**	**P3**	**P0 - P3**
Reproductive problems	5.8 %	4.7 %	2.9 %	2.6 %	16.0 %
Feet and leg problems	3.1 %	1.9 %	1.7 %	0.7 %	7.4 %
Body condition	0.5 %	1.1 %	2.0 %	1.0 %	4.6 %
Litter performance	-	0.3 %	1.6 %	2.5 %	4.5 %
Miscellaneous total	5.1 %	1.1 %	0.9 %	0.7 %	7.8 %
Total culled	14.5 %	9.2 %	9.1 %	7.5 %	40.3 %
Mortality percentage	1.5 %	7.5 %	5.8 %	1.1 %	15.8 %
Total percentage lost	15.9 %	16.7 %	14.8 %	8.6 %	56.1 %

[a]P0 indicates that the female did not succeed to farrow even once.

Table 2. Removal reason frequencies among the removed ***second parity*** females in study evaluating the relationship between compositional, structural soundness, reproductive performance and productive lifetime in commercial lines of sows. Both total percentages and within line percentages (GrandParental or Parental) are presented for each removal reason. The corresponding number of animals is in parenthesis.

Primary removal reason	**Culled GP-line females**	**Culled P-line females**	**Total**
Open, repeat estrus	12.2 % (19)	6.7 % (10)	9.5 % (29)
Non-cycle	5.1 % (8)	6.0 % (9)	5.6 % (17)
Vaginal or uterine prolapsed		2.7 % (4)	1.3 % (4)
Discharge	1.9 % (3)		1.0 % (3)
Aborted	1.9 % (3)		1.0 % (3)
Farrowing difficulty	0.6 % (1)	1.3 % (2)	1.0 % (3)
Reproductive problem total	21.8 % (34)	16.7 % (25)	19.3 % (59)
Poor farrowing performance	5.8 % (9)	7.3 % (11)	6.5 % (20)
Poor weaning performance	3.9 % (6)	2.7 % (4)	3.3 % (10)
Bad udder	0.6 % (1)	0.7 % (1)	0.7 % (2)
Poor mother	0.6 % (1)		0.3 % (1)
Litter performance total	10.9 % (17)	10.7 % (16)	10.8 % (33)
Lameness	8.3 % (13)	14.0 % (21)	11.1 % (34)
Spraddle (rear legs spread)		0.7 % (1)	0.3 % (1)
Feet and leg problems total	8.3 % (13)	14.7 % (22)	11.4 % (35)
Thin, unthrifty	10.9 % (17)	16.0 % (24)	13.4 % (41)
Behavior	0.6 % (1)		0.3 % (1)
Unknown	1.3 % (2)		0.7 % (2)
Culled census / delinquent	3.9 % (6)	6.7 % (10)	5.2 % (16)
Miscellaneous total	16.7 % (26)	22.7 % (34)	19.6 % (60)
Sow mortalities	42.3 % (66)	35.3 % (53)	38.9 % (119)
Grand total	156	150	306

Table 3. Removal reason frequencies among the removed ***third parity*** females in study evaluating the relationship between compositional, structural soundness, reproductive performance and productive lifetime in commercial lines of sows. Both total percentages and within line percentages (GrandParental or Parental) are presented for each removal reason. The corresponding number of animals is in parenthesis.

Primary removal reason	**Culled GP-line females**	**Culled P-line females**	**Total**
Non-cycle	13.7 % (14)	14.5 % (11)	14.0 % (25)
Open, repeat estrus	12.8 % (13)	10.5 % (8)	11.8 % (21)
Open, no observed cycle	2.0 % (2)		1.1 % (2)
Aborted		2.6 % (2)	1.1 % (2)
Discharge		1.3 % (1)	0.6 % (1)
Open, at farrowing or late gestation		1.3 % (1)	0.6 % (1)
Farrowing difficulty		1.3 % (1)	0.6 % (1)
Vaginal or uterine prolapse		1.3 % (1)	0.6 % (1)
Reproductive problem total	28.4 % (29)	32.9 % (25)	30.3 % (54)
Poor farrowing performance	16.7 % (17)	11.8 % (9)	14.6 % (26)
Poor weaning performance	15.7 % (16)	13.2 % (10)	14.6 % (26)
Litter performance total	32.4 % (33)	25.0 % (19)	29.2 % (52)
Lameness	6.9 % (7)	9.2 % (7)	7.9 % (14)
Feet and leg problems total	6.9 % (7)	9.2 % (7)	7.9 % (14)
Thin, unthrifty	10.8 % (11)	13.2 % (10)	11.8 % (21)
Unknown	1.0 % (1)		0.6 % (1)
Culled census / delinquent	5.9 % (6)	9.2 % (7)	7.3 % (13)
Miscellaneous total	17.6 % (18)	22.4 % (17)	19.7 % (35)
Sow mortalities	14.7 % (15)	10.5 % (8)	12.9 % (23)
Grand total	102	76	178

Table 4. Means from PROC LIFETEST and heritability estimates for productive lifetime traits in study evaluating the relationship between compositional, structural soundness, reproductive performance and productive lifetime in commercial lines of sows.

	Mean ± s.e.	**Mean ± s.e.**	***P*-value[b]**	**h^2 ± s.e.**
Reproductive performance[a]	**Grandparent line**	**Parent line**		**Across lines**
Cumulative total number born	27.39 ± 0.60	28.96 ± 0.58	0.14	0.12 ± 0.05
Cumulative number born alive	25.26 ± 0.55	27.13 ± 0.55	0.11	0.12 ± 0.05
Cumulative number weaned	20.71 ± 0.50	21.79 ± 0.49	0.06	0.20 ± 0.07
Longevity				
Lifetime (d)[c]	679.34 ± 11.20	689.92 ± 8.10	0.63	0.10 ± 0.05
Herd days[c]	501.48 ± 7.37	506.08 ± 7.69	0.91	0.10 ± 0.05
Removal parity	2.44 ± 0.05	2.52 ± 0.05	0.22	0.14 ± 0.06

[a]Cumulative reproductive performance across three parities.
[b]*P*-value for the difference of means between genetic lines.
[c]Cutting point the date of last P3 removal among research females.

Table 5. Descriptive statistics for ***second parity*** reproduction and body composition traits in study evaluating the relationship between compositional, structural soundness, reproductive performance and productive lifetime in commercial lines of sows.

Variable	N of sows	Mean	S.d.	CV	Min	Max	Range
Reproduction information							
Age at conception	1085	407.15	34.75	8.53	340	633	293
Age at farrowing	971	520.38	33.45	6.43	457	701	244
Herd days at farrowing	1391	340.62	33.64	9.88	282	533	251
Cumulative non-productive days[a]	1735	102.15	48.32	47.30	33	407	374
Gestation length	1390	115.47	1.20	1.04	109	119	10
Lactation length[b]	1391	18.15	5.17	28.46	0	32	32
Reproductive performance							
Total number born	1387	11.57	3.40	29.35	0	21	21
Number born alive	1387	10.82	3.33	30.77	0	21	21
Percentage born alive	1386	93.67	11.71	12.50	0	100	100
Stillborn	1387	0.75	1.31	175.60	0	11	11
Mummies	1387	0.13	0.46	340.32	0	7	7
Litter birth weight (kg)	826	14.92	4.40	29.46	1.40	26.80	25.40
Piglet birth weight (kg)[c]	826	1.39	0.29	20.67	0.60	2.40	1.80
Number weaned	1252	9.67	1.71	17.71	0	19	19
Litter weaning weight (kg)	841	56.21	14.03	24.97	12.20	95.30	83.10
Adjusted litter wean weight (kg)[d]	841	60.18	14.56	24.20	11.80	97.40	85.60
Piglet weaning weight (kg)	841	5.85	1.12	19.16	2.50	9.90	7.40
Adjusted piglet wean weight (kg)	841	6.26	1.11	17.75	2.60	9.90	7.30
Number died	570	1.76	1.31	74.45	1	12	11
Body composition							
Body weight at farrowing (kg)	958	243.26	23.11	9.50	158.8	312.1	153.30
Body weight at weaning (kg)	838	219.51	22.24	10.13	156.5	279.0	122.50
Lactation weight loss (kg)[e]	677	-23.32	18.57	-79.63	-111.1	44.5	155.60
Last rib backfat at farrowing (cm)	1002	2.12	0.56	26.60	0.64	4.06	3.42
Last rib backfat at weaning (cm)	932	1.86	0.52	27.99	0.69	3.51	2.82
Last rib backfat loss (cm)	889	-0.26	0.34	-127.91	-1.63	1.42	3.05
10^{th} rib backfat at farrowing (cm)	1002	2.14	0.62	28.83	0.64	4.24	3.60
10^{th} rib backfat at weaning (cm)	932	1.79	0.52	29.28	0.64	3.63	2.99
10^{th} rib backfat loss (cm)	889	-0.37	0.33	-88.56	-1.81	1.58	3.39
LMA[f] at farrowing (cm^2)	1002	51.24	6.05	11.80	31.94	75.10	43.16
LMA at weaning (cm^2)	932	48.69	5.71	11.73	28.65	70.71	42.06
Loin muscle area loss (cm^2)	889	-2.58	5.12	-198.24	-20.90	18.00	38.90

[a]Sum of the non-productive days until second conception or removal if no farrowing occurred. Counting of non-productive days started from entry to the farm.

[b]The entire lactation length including possible nursing of a foster litter.

[c]Piglet birth weight is an average weight of an individual piglet = litter birth weight / number of liveborn piglets.

[d]Litter weaning weight adjusted to 21 days weighing age (NSIF, 1997).

[e]Weight loss = weaning weight – entry weight (negative figure means sow has lost weight). Similarly, body composition losses = weaning measurement – farrowing measurement.

[f]LMA = loin muscle area.

Table 6. Descriptive statistics for ***third parity*** reproduction and body composition traits in study evaluating the relationship between compositional, structural soundness, reproductive performance and productive lifetime in commercial lines of sows.

Variable	N of sows	Mean	S.d.	CV	Min	Max	Range
Reproduction information							
Age at conception	836	557.41	42.37	7.60	480	769	289
Age at first farrowing	767	671.55	41.23	6.14	597	882	285
Herd days at farrowing	1085	492.20	43.54	8.85	425	714	289
Cumulative non-productive days[a]	1391	116.78	50.44	43.19	38	447	409
Gestation length	1083	115.48	1.26	1.09	110	119	9
Lactation length[b]	1085	18.74	4.61	24.59	0	33	33
Reproductive performance							
Total number born	1085	11.83	3.57	30.16	0	22	22
Number born alive	1085	10.98	3.32	30.26	0	19	19
Percentage born alive	1084	93.24	10.04	10.77	0	100	100
Stillborn	1085	0.85	1.25	146.48	0	12	12
Mummies	1085	0.15	0.49	327.24	0	5	5
Litter birth weight (kg)	932	15.43	4.60	29.79	1.40	31.80	30.40
Piglet birth weight (kg)[c]	932	1.44	0.31	21.75	0.60	2.70	2.10
Number weaned	1012	9.71	1.49	15.38	0	14	14
Litter weaning weight (kg)	528	56.39	13.80	24.47	17.20	108.90	91.70
Adjusted litter wean weight (kg)[d]	528	59.58	13.56	22.76	19.90	142.80	122.90
Piglet weaning weight (kg)	528	5.84	1.19	20.30	2.10	9.50	7.40
Adjusted piglet wean weight (kg)	528	6.17	1.12	18.17	2.00	14.30	12.30
Number died	472	1.93	1.52	78.58	1	13	12
Body composition							
Body weight at farrowing (kg)	379	250.27	21.88	8.74	171.5	326.6	155.10
Body weight at weaning (kg)	424	224.58	20.08	8.94	176.9	290.3	113.40
Lactation weight loss (kg)[e]	318	-25.42	17.00	-66.89	-81.6	36.3	117.90
Last rib backfat at farrowing (cm)	698	2.04	0.58	28.61	0.56	4.19	3.63
Last rib backfat at weaning (cm)	681	1.80	0.55	30.47	0.74	3.96	3.22
Last rib backfat loss (cm)	645	-0.24	0.32	-130.82	-1.52	1.04	2.56
10^{th} rib backfat at farrowing (cm)	698	1.98	0.64	32.39	0.64	4.29	3.65
10^{th} rib backfat at weaning (cm)	681	1.68	0.53	31.51	0.56	3.51	2.95
10^{th} rib backfat loss (cm)	645	-0.30	0.31	-101.18	-1.35	1.24	2.59
LMA[f] at farrowing (cm^2)	698	48.80	5.90	12.08	29.42	69.42	40.00
LMA at weaning (cm^2)	681	47.29	5.89	12.46	30.71	66.52	35.81
Loin muscle area loss (cm^2)	645	-1.58	5.48	-347.43	-18.07	27.16	45.23

[a]Sum of the non-productive days until third conception or removal if no farrowing occurred. Counting of non-productive days started from entry to the farm.

[b]The entire lactation length including possible nursing of a foster litter.

[c]Piglet birth weight is an average weight of an individual piglet = litter birth weight / number of liveborn piglets.

[d]Litter weaning weight adjusted to 21 days weighing age (NSIF, 1997).

[e]Weight loss = weaning weight – entry weight (negative figure means sow has lost weight). Similarly, body composition losses = weaning measurement – farrowing measurement.

[f]LMA = loin muscle area.

Table 7. Least squares means for ***second parity*** reproduction and body composition traits in study evaluating the relationship between compositional, structural soundness, reproductive performance and productive lifetime in commercial lines of sows.

Variable	GP-line	P-line	*P*-value
Reproduction information			
Age at conception	412.46 ± 1.89	404.79 ± 1.26	< 0.001
Age at farrowing	526.19 ± 1.89	517.67 ± 1.29	< 0.001
Herd days at farrowing	343.42 ± 1.29	337.98 ± 1.25	0.003
Cumulative non-productive days	105.35 ± 1.68	99.25 ± 1.60	0.009
Gestation length	115.52 ± 0.05	115.43 ± 0.04	0.20
Lactation length	17.81 ± 0.20	18.47 ± 0.19	0.02
Reproductive performance			
Total number born	11.30 ± 0.13	11.82 ± 0.13	0.004
Number born alive	10.53 ± 0.13	11.11 ± 0.12	0.001
Percentage born alive	93.13 ± 0.45	94.19 ± 0.44	0.09
Stillborn	0.78 ± 0.05	0.72 ± 0.05	0.41
Mummies	0.13 ± 0.02	0.14 ± 0.02	0.66
Litter birth weight (kg)	15.13 ± 0.19	14.58 ± 0.25	0.08
Piglet birth weight (kg)	1.44 ± 0.01	1.32 ± 0.02	< 0.001
Number weaned	9.64 ± 0.07	9.70 ± 0.07	0.50
Litter weaning weight (kg)	56.33 ± 0.79	56.14 ± 0.61	0.84
Adjusted litter wean weight (kg)	61.14 ± 0.82	59.61 ± 0.63	0.14
Piglet weaning weight (kg)	5.86 ± 0.06	5.84 ± 0.05	0.82
Adjusted piglet wean weight (kg)	6.36 ± 0.06	6.20 ± 0.05	0.04
Number died	1.79 ± 0.08	1.72 ± 0.08	0.53
Body composition			
Body weight at farrowing (kg)	246.69 ± 1.13	240.64 ± 0.98	< 0.001
Body weight at weaning (kg)	224.36 ± 1.19	216.23 ± 0.98	< 0.001
Lactation weight loss (kg)	-21.45 ± 1.18	-24.40 ± 0.89	0.05
Last rib backfat at farrowing (cm)	2.01 ± 0.03	2.17 ± 0.02	< 0.001
Last rib backfat at weaning (cm)	1.77 ± 0.03	1.91 ± 0.02	< 0.001
Last rib backfat loss (cm)	-0.25 ± 0.02	-0.27 ± 0.01	0.33
10^{th} rib backfat at farrowing (cm)	2.02 ± 0.03	2.21 ± 0.02	< 0.001
10^{th} rib backfat at weaning (cm)	1.69 ± 0.03	1.84 ± 0.02	< 0.001
10^{th} rib backfat loss (cm)	-0.33 ± 0.02	-0.39 ± 0.01	0.007
LMA at farrowing (cm^2)	53.93 ± 0.30	49.74 ± 0.22	< 0.001
LMA at weaning (cm^2)	51.48 ± 0.30	47.19 ± 0.22	< 0.001
Loin muscle area loss (cm^2)	-2.49 ± 0.29	-2.63 ± 0.21	0.70

Table 8. Least squares means for ***third parity*** reproduction and body composition traits in study evaluating the relationship between compositional, structural soundness, reproductive performance and productive lifetime in commercial lines of sows.

Variable	GP-line	P-line	*P*-value
Reproduction information			
Age at conception	561.71 ± 2.59	555.40 ± 1.77	0.04
Age at farrowing	676.45 ± 2.67	669.34 ± 1.79	0.03
Herd days at farrowing	494.78 ± 1.91	489.83 ± 1.83	0.06
Cumulative non-productive days	123.98 ± 1.92	109.99 ± 1.87	< 0.001
Gestation length	115.50 ± 0.06	115.45 ± 0.05	0.48
Lactation length	19.39 ± 0.20	18.13 ± 0.19	< 0.001
Reproductive performance			
Total number born	11.48 ± 0.16	12.15 ± 0.15	0.002
Number born alive	10.58 ± 0.14	11.35 ± 0.14	< 0.001
Percentage born alive	92.71 ± 0.44	93.72 ± 0.42	0.10
Stillborn	0.91 ± 0.05	0.80 ± 0.05	0.18
Mummies	0.12 ± 0.02	0.18 ± 0.02	0.06
Litter birth weight (kg)	14.82 ± 0.22	15.96 ± 0.20	< 0.001
Piglet birth weight (kg)	1.44 ± 0.01	1.43 ± 0.01	0.66
Number weaned	9.46 ± 0.07	9.94 ± 0.06	< 0.001
Litter weaning weight (kg)	57.61 ± 0.81	54.96 ± 0.88	0.03
Adjusted litter wean weight (kg)	59.04 ± 0.80	60.22 ± 0.87	0.32
Piglet weaning weight (kg)	6.08 ± 0.07	5.56 ± 0.07	< 0.001
Adjusted piglet wean weight (kg)	6.23 ± 0.07	6.10 ± 0.07	0.16
Number died	2.00 ± 0.10	1.86 ± 0.10	0.33
Body composition			
Body weight at farrowing (kg)	252.10 ± 1.95	249.36 ± 1.37	0.25
Body weight at weaning (kg)	226.24 ± 1.55	223.50 ± 1.25	0.17
Lactation weight loss (kg)	-26.06 ± 1.65	-25.09 ± 1.17	0.63
Last rib backfat at farrowing (cm)	1.90 ± 0.04	2.10 ± 0.03	< 0.001
Last rib backfat at weaning (cm)	1.70 ± 0.04	1.85 ± 0.02	0.001
Last rib backfat loss (cm)	-0.20 ± 0.02	-0.26 ± 0.01	0.02
10^{th} rib backfat at farrowing (cm)	1.77 ± 0.04	2.06 ± 0.03	< 0.001
10^{th} rib backfat at weaning (cm)	1.51 ± 0.04	1.75 ± 0.02	< 0.001
10^{th} rib backfat loss (cm)	-0.26 ± 0.02	-0.32 ± 0.01	0.02
LMA at farrowing (cm^2)	50.10 ± 0.41	48.26 ± 0.26	< 0.001
LMA at weaning (cm^2)	50.03 ± 0.40	46.14 ± 0.26	< 0.001
Loin muscle area loss (cm^2)	-0.05 ± 0.39	-2.20 ± 0.25	< 0.001

Table 9. Statistical significances (***P*-values**) from PROC LIFETEST for phenotypic associations between productive lifetime traits and compositional or structural soundness traits in study evaluating the relationship between body composition, structural soundness, reproductive performance and productive lifetime in commercial lines of sows.

	Productive lifetime traits					
	Cum-TNB[a]	Cum-NBA[a]	Cum-NW[a]	Removal parity	Lifetime	Herd days
Body composition						
Body weight	0.25[b]	0.16	0.08	**0.05**	**0.02**	**0.04**
Last rib backfat[d]	< **0.001**[c]	< **0.001**	< **0.001**	< **0.001**	0.15	0.21
10th rib backfat[d]	< **0.001**	< **0.001**	< **0.001**	< **0.001**	0.36	0.27
Loin muscle area	0.30	0.40	0.65	0.17	0.08	**0.02**
Body structure						
Body length	**0.004**	**0.002**	< **0.001**	< **0.001**	**0.02**	**0.002**
Body depth	0.10	0.12	0.10	0.07	0.46	0.20
Body width	0.15	0.17	0.23	0.11	0.50	0.17
Rib shape	**0.003**	**0.003**	< **0.001**	**0.003**	**0.03**	**0.002**
Top line	0.31	0.36	0.22	0.28	0.14	0.22
Hip structure	0.29	0.27	0.33	0.31	0.17	0.35
Front leg structure						
Front legs turned	0.79	0.80	0.81	0.80	0.49	0.94
Buck knees	**0.05**	**0.04**	**0.007**	0.06	**0.009**	0.06
Front pastern posture	0.24	0.26	**0.02**	0.13	0.14	0.39
Front foot size	**0.02**	**0.02**	**0.02**	**0.01**	0.08	**0.007**
Uneven front toes	0.72	0.72	0.71	0.68	0.64	0.53
Rear leg structure						
Rear legs turned	0.07	0.06	**0.03**	**0.04**	0.21	0.07
Weak / upright legs	< **0.001**	< **0.001**	< **0.001**	< **0.001**	**0.002**	< **0.001**
Rear pastern posture	0.81	0.85	0.78	0.84	0.75	0.90
Rear foot size	0.31	0.20	0.61	0.16	0.14	0.06
Uneven rear toes	0.07	0.08	0.28	0.10	0.30	0.09
Overall leg action	**0.02**	**0.02**	**0.001**	**0.003**	**0.005**	**0.004**

[a]Cum-TNB = cumulative total number born, Cum-NBA = cumulative number born alive, and Cum-NW = cumulative number weaned.
[b]*P*-values are based on Wilcoxon test statistics which put more weight on early than late event times.
[c]*P*-values less or equal than 0.05 are in bold.
[d]*P*-values for continuous backfat measurements, not class variables as in table 10.

Table 10. Phenotypic associations of backfat depth with productive lifetime traits expressed as mean reproductive performance or removal parity expectations from PROC LIFETEST in study evaluating the relationship between compositional, structural soundness, reproductive performance and productive lifetime in commercial lines of sows.

	Reproductive performance or lifetime expectation for bacfat depth class				
Backfat	BF < 1.0	1.0 ≤ BF < 1.5	1.50 ≤ BF < 2.0	2.0 ≤ BF < 2.5[a]	BF ≥ 2.50
			Cumulative total number born (piglets)		
Last rib backfat[b]	25.70 ± 0.91	28.40 ± 0.55	30.26 ± 0.97	24.72 ± 1.84	
10th rib backfat[c]	24.44 ± 1.29	28.05 ± 0.56	29.12 ± 0.79	27.09 ± 1.50	25.81 ± 1.99
			Cumulative number born alive (piglets)		
Last rib backfat[d]	23.42 ± 0.81	26.54 ± 0.52	28.05 ± 0.89	23.65 ± 1.80	
10th rib backfat[e]	23.23 ± 1.26	26.23 ± 0.53	26.84 ± 0.73	25.20 ± 1.39	21.85 ± 1.66
			Cumulative number weaned (piglets)		
Last rib backfat[f]	18.05 ± 0.69	21.40 ± 0.46	23.21 ± 0.80	19.46 ± 1.55	
10th rib backfat[g]	17.27 ± 1.00	21.11 ± 0.47	21.71 ± 0.64	22.33 ± 1.44	22.52 ± 1.97
			Removal parity		
Last rib backfat[h]	2.28 ± 0.08	2.50 ± 0.04	2.62 ± 0.08	2.67 ± 0.20	
10th rib backfat[i]	2.24 ± 0.11	2.47 ± 0.05	2.53 ± 0.07	2.58 ± 0.14	3.03 ± 0.25

[a]For last rib backfat class 2.0 ≤ BF < 2.5 includes also observations greater than 2.5 as there very few of them.
[b]$P = 0.005$
[c]$P = 0.03$
[d]$P = 0.006$
[e]$P = 0.04$
[f]$P < 0.001$
[g]$P = 0.01$
[h]$P = 0.004$
[i]$P = 0.05$

Table 11. Phenotypic associations of structural soundness traits with longevity traits expressed as mean lifetime expectations from PROC LIFETEST in study evaluating the relationship between compositional, structural soundness, reproductive performance and productive lifetime in commercial lines of sows.

	Lifetime or parity expectation within a structural soundness score							
Soundness traits	1	2	3	4	5	6	7	8
				Lifetime (days)				
Body length			633.9 ± 18.9	686.4 ± 10.6	676.3 ± 9.8	671.3 ± 18.9	589.9 ± 27.1	
Rib shape	615.8 ± 29.4	653.0 ± 16.0	647.9 ± 11.4	663.5 ± 12.9	681.6 ± 14.5	689.0 ± 17.3	615.6 ± 21.1	447.3 ± 26.9
Buck knees	568.2 ± 22.7	659.3 ± 19.7	673.6 ± 15.3	681.6 ± 11.6	695.6 ± 14.7	632.5 ± 17.7	670.6 ± 17.5	558.5 ± 29.2
Weak / upright legs		571.7 ± 49.4	702.1 ± 20.7	656.2 ± 13.4	676.7 ± 10.2	690.2 ± 13.0	588.7 ± 15.1	
Overall leg action	592.0 ± 41.2	640.9 ± 15.7	641.8 ± 12.5	682.8 ± 13.2	698.4 ± 15.3	677.1 ± 17.6	613.7 ± 14.9	591.0 ± 25.5
				Herd days				
Body length			447.1 ± 15.2	507.1 ± 9.0	498.7 ± 8.2	498.3 ± 14.0	423.6 ± 22.4	
Rib shape	413.0 ± 27.7	477.4 ± 13.6	473.1 ± 9.6	509.3 ± 11.1	505.2 ± 11.8	508.9 ± 14.0	420.4 ± 17.6	374.0 ± 32.9
Weak / upright legs		380.6 ± 42.8	516.5 ± 15.8	478.9 ± 11.0	507.7 ± 8.9	519.5 ± 11.3	427.9 ± 13.0	
Overall leg action	497.6 ± 29.0	462.6 ± 12.3	471.9 ± 10.5	503.8 ± 11.6	511.7 ± 12.8	507.1 ± 14.3	478.7 ± 15.3	423.8 ± 21.9
				Removal parity				
Body length			2.69 ± 0.13	2.57 ± 0.06	2.47 ± 0.05	2.40 ± 0.09	1.94 ± 0.15	
Rib shape	2.50 ± 0.29	2.61 ± 0.10	2.56 ± 0.07	2.54 ± 0.07	2.49 ± 0.08	2.45 ± 0.09	2.14 ± 0.13	1.76 ± 0.24
Front foot size			2.54 ± 0.19	2.52 ± 0.09	2.44 ± 0.05	2.40 ± 0.07	2.88 ± 0.11	
Rear legs turned		2.31 ± 0.26	2.31 ± 0.08	2.56 ± 0.05	2.47 ± 0.07			
Weak / upright legs		1.63 ± 0.28	2.55 ± 0.10	2.31 ± 0.07	2.57 ± 0.06	2.64 ± 0.07	2.32 ± 0.10	
Overall leg action	2.72 ± 0.22	2.63 ± 0.10	2.51 ± 0.08	2.54 ± 0.08	2.53 ± 0.08	2.50 ± 0.09	2.33 ± 0.10	1.98 ± 0.14

Table 12. Phenotypic associations of structural soundness traits with cumulative reproductive traits expressed as mean reproductive performance expectations from PROC LIFETEST in study evaluating the relationship between compositional, structural soundness, reproductive performance and productive lifetime in commercial lines of sows.

	Litter size expectation within a structural soundness score							
Soundness traits	1	2	3	4	5	6	7	8
				Cumulative total number born (piglets)				
Body length			27.05 ± 1.29	28.01 ± 0.69	28.21 ± 0.65	27.35 ± 1.07	22.28 ± 1.82	
Rib shape	23.45 ± 2.77	28.76 ± 1.19	28.99 ± 0.87	28.90 ± 0.89	27.07 ± 0.85	27.91 ± 1.11	24.43 ± 1.57	18.65 ± 2.45
Buck knees	29.05 ± 2.34	28.46 ± 1.47	28.46 ± 1.11	28.86 ± 0.82	29.60 ± 0.93	25.19 ± 0.99	26.64 ± 1.16	23.54 ± 2.08
Front foot size			28.11 ± 2.15	28.72 ± 1.08	27.69 ± 0.61	27.33 ± 0.81	30.62 ± 1.22	
Weak / upright legs		17.69 ± 2.99	28.71 ± 1.21	26.32 ± 0.88	29.37 ± 0.73	28.81 ± 0.84	25.63 ± 1.19	
Overall leg action	26.13 ± 1.95	28.90 ± 1.17	28.67 ± 0.96	28.59 ± 0.95	28.87 ± 1.03	28.35 ± 1.08	24.68 ± 1.06	22.56 ± 1.70
				Cumulative number born alive (piglets)				
Body length			24.00 ± 1.12	26.88 ± 0.68	26.33 ± 0.61	25.47 ± 1.00	20.13 ± 1.65	
Rib shape	22.42 ± 2.74	28.20 ± 1.21	26.79 ± 0.80	26.98 ± 0.84	25.95 ± 0.83	25.90 ± 1.02	22.27 ± 1.41	17.39 ± 2.31
Buck knees	25.45 ± 1.92	27.25 ± 1.46	26.27 ± 1.01	26.99 ± 0.77	27.27 ± 0.86	23.81 ± 0.96	24.67 ± 1.08	22.81 ± 2.09
Front foot size			27.01 ± 2.23	26.40 ± 0.99	25.90 ± 0.58	25.30 ± 0.74	27.38 ± 1.07	
Weak / upright legs		16.45 ± 2.78	26.74 ± 1.14	24.57 ± 0.83	27.13 ± 0.67	27.86 ± 0.85	24.66 ± 1.18	
Overall leg action	23.03 ± 1.68	26.46 ± 1.07	26.49 ± 0.88	26.70 ± 0.89	26.59 ± 0.94	26.73 ± 1.04	23.77 ± 1.04	20.32 ± 1.51
				Cumulative number weaned (piglets)				
Body length			21.04 ± 1.21	21.64 ± 0.58	21.22 ± 0.53	19.01 ± 0.84	14.96 ± 1.45	
Rib shape	15.00 ± 2.01	22.37 ± 1.06	21.03 ± 0.69	21.49 ± 0.70	20.84 ± 0.72	20.77 ± 0.92	17.01 ± 1.21	11.53 ± 1.77
Buck knees	20.76 ± 1.90	23.29 ± 1.28	21.15 ± 0.91	20.02 ± 0.61	22.49 ± 0.76	18.88 ± 0.88	20.47 ± 0.98	17.11 ± 1.70
Front pastern posture	20.75 ± 2.32	21.43 ± 1.16	21.75 ± 0.75	21.87 ± 0.71	21.79 ± 0.74	18.64 ± 0.96	18.51 ± 1.02	17.09 ± 1.77
Front foot size			20.59 ± 1.63	21.83 ± 0.89	20.78 ± 0.50	19.74 ± 0.65	22.80 ± 1.00	
Rear legs turned		15.29 ± 2.05	19.69 ± 0.78	22.03 ± 0.47	20.88 ± 0.69			
Weak / upright legs		9.95 ± 2.17	21.12 ± 0.97	19.46 ± 0.73	22.42 ± 0.59	22.02 ± 0.75	18.60 ± 0.95	
Overall leg action	20.14 ± 1.50	22.21 ± 0.98	21.86 ± 0.78	21.44 ± 0.78	20.87 ± 0.79	21.28 ± 0.94	18.04 ± 0.90	15.16 ± 1.28

Table 13. Genetic correlations (± s.e.) between productive lifetime traits (across three parities) and body composition or structural soundness traits in study evaluating the relationship between compositional, structural soundness, reproductive performance and productive lifetime in commercial lines of sows.

	Productive lifetime traits[a]				
	Cum-TNB	Cum-NBA	Cum-NW	Removal parity	Lifetime
Body composition					
Last rib backfat	0.14 ± 0.21	0.13 ± 0.21	0.31 ± 0.19	0.22 ± 0.20	0.11 ± 0.23
Adj. 10th rib backfat	0.07 ± 0.21	0.07 ± 0.21	0.26 ± 0.19	0.15 ± 0.20	0.01 ± 0.23
Adj. loin muscle area	**0.36 ± 0.18**[b]	**0.36 ± 0.18**	0.33 ± 0.17	**0.40 ± 0.17**	**0.47 ± 0.18**
Adj. days to 113.5 kg	0.10 ± 0.24	0.18 ± 0.23	**0.44 ± 0.20**	**0.46 ± 0.21**	**0.54 ± 0.21**
Body structure					
Body length	**-0.70 ± 0.23**	**-0.66 ± 0.23**	**-0.90 ± 0.16**	**-0.79 ± 0.19**	**-0.70 ± 0.21**
Body depth	-0.03 ± 0.27	-0.02 ± 0.27	-0.24 ± 0.23	-0.26 ± 0.24	-0.29 ± 0.27
Body width	0.34 ± 0.25	0.31 ± 0.25	0.40 ± 0.22	**0.46 ± 0.23**	**0.57 ± 0.23**
Rib shape	**-0.62 ± 0.25**	**-0.61 ± 0.25**	**-0.62 ± 0.22**	**-0.75 ± 0.21**	**-0.61 ± 0.26**
High top line	-0.02 ± 0.38	0.05 ± 0.37	-0.46 ± 0.33	-0.37 ± 0.36	-0.35 ± 0.41
Weak top line	0.32 ± 0.32	0.28 ± 0.32	0.07 ± 0.30	0.19 ± 0.31	0.20 ± 0.35
Hip structure	-0.28 ± 0.27	-0.27 ± 0.26	-0.41 ± 0.23	-0.36 ± 0.25	-0.35 ± 0.29
Front leg structure					
Front legs turned out	0.62 ± 0.33	0.60 ± 0.32	0.39 ± 0.34	0.48 ± 0.33	0.41 ± 0.39
Front legs turned in	-0.71 ± 0.85	-0.64 ± 0.86	-0.54 ± 0.82	-0.45 ± 0.82	-0.07 ± 1.07
Buck knees	0.27 ± 0.34	0.42 ± 0.33	0.13 ± 0.31	0.19 ± 0.32	0.30 ± 0.37
Front pastern posture	0.17 ± 0.26	0.11 ± 0.26	-0.01 ± 0.24	-0.03 ± 0.26	-0.24 ± 0.28
Front foot size	-0.37 ± 0.28	-0.34 ± 0.29	-0.27 ± 0.27	-0.23 ± 0.29	-0.29 ± 0.32
Uneven front toes	-0.06 ± 0.34	-0.02 ± 0.33	0.17 ± 0.30	0.08 ± 0.32	-0.19 ± 0.36
Rear leg structure					
Rear legs turned out	0.21 ± 0.28	0.23 ± 0.28	-0.04 ± 0.28	0.03 ± 0.28	-0.09 ± 0.32
Rear legs turned in	0.22 ± 0.33	0.16 ± 0.33	0.43 ± 0.28	0.39 ± 0.30	0.24 ± 0.35
Weak rear legs	0.50 ± 0.36	0.47 ± 0.36	0.43 ± 0.32	0.41 ± 0.37	0.46 ± 0.42
Upright rear legs	**-0.63 ± 0.23**	**-0.63 ± 0.23**	**-0.58 ± 0.22**	**-0.50 ± 0.26**	-0.44 ± 0.31
Rear pastern posture	-0.26 ± 0.26	-0.18 ± 0.26	-0.18 ± 0.24	-0.04 ± 0.25	-0.06 ± 0.29
Rear foot size	0.11 ± 0.32	0.21 ± 0.31	0.16 ± 0.30	0.30 ± 0.30	0.41 ± 0.32
Uneven rear toes	0.18 ± 0.30	0.17 ± 0.30	0.32 ± 0.26	0.15 ± 0.30	0.12 ± 0.34
Overall leg action	0.43 ± 0.32	0.37 ± 0.32	0.06 ± 0.31	0.23 ± 0.32	0.17 ± 0.37

[a]Cum-TNB = cumulative total number born, Cum-NBA = cumulative number born alive, and Cum-NW = cumulative number weaned.

[c]Genetic correlations differing significantly from zero ($P \leq 0.05$) are in bold.

Appendix 1. Structural scoring sheet.

BODY STRUCTURE EVALUATION

BODY LENGTH

1 = short … 9 = long

BODY DEPTH

1 = deep … 9 = shallow

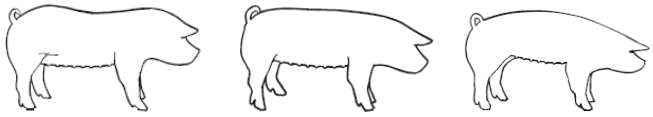
BODY WIDTH

1 = narrow 5 = intermediate 9 = wide

RIB SHAPE

1 = more shape … 9 = flat / less shape

TOP LINE



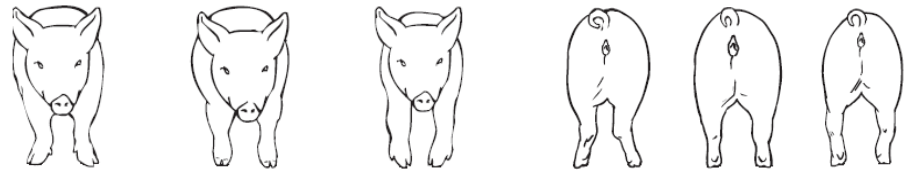
1 = weak 5 = level 9 = high topped

HIP STRUCTURE

1 = level … 9 = steep

LEG STRUCTURE EVALUATION

LEGS TURNED OUT / IN (FRONT & REAR)



1 = turned out 5 = straight 9 = turned in

BUCK KNEES

1 = upright 2 = normal 9 = severe buck knees

WEAK / UPRIGHT REAR LEGS

1 = weak 5 = normal 9 = upright

WEAK / UPRIGHT PASTERNS (FRONT & REAR)

1 = weak / soft 5 = intermediate 9 = upright

FOOT SIZE (FRONT & REAR)

1 = large feet 9 = small feet

UNEVEN TOES (FRONT & REAR)

1 = even toes 9 = severely uneven toes

OVERALL LEG ACTION

1 = excellent movements 9 = severely impaired movements / unable to walk

MTT

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