Modeling, Management and Selection of Genetics for Optimal Commercial Performance

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Introduction

The two primary approaches for improving the efficiency of pork production are through genetic selection and management changes. Swine growth models have been developed which integrate our knowledge of genetics, nutrient metabolism and environmental conditions on pig growth. These models can be used to improve the efficiency of pork production.

In the past 30 years, intense genetic selection in pigs has substantially increased their genetic potential for lean growth and lean efficiency (Schinckel, 1999). Selection for carcass leanness has reduced lipid accretion, altered fat tissue growth and increased carcass muscle growth rates. Genetic populations with different genetic potentials for lean growth and fat accretion are different physiologically. Genetic selection may have changed how pigs respond to environmental stressors.

Current status of compositional growth modeling

Swine growth models require that the genetic population of pigs be parameterized. These parameters quantativilly describe the composition growth of a population of pigs. The four parameters are: 1) daily protein accretion rates, 2) daily energy intakes (estimated directly or from protein and lipid accretion rate), 3) partitioning of energy between protein and lipid accretion, and 4) energy required for maintenance (Schinckel and de Lange, 1996). Selection for increased rate of lean growth and efficiency of lean growth has increased the daily protein accretion rates and the partitioning of energy from lipid to protein accretion (Schinckel, 1999).

The models estimate the dietary concentrations of essential amino-acids needed to produce the carcass muscle growth for the specific genetic potential of the pigs and ractopamine use (Schinckel et al., 2003b, 2008). The dietary concentration of essential amino-acids estimated as the grams of lysine per Mcal energy intake (ME or NE) has substantially increased with genetic selection for increased carcass lean percentage (Schinckel, 1999; Schinckel et al., 2008). At similar growth rates, genetically lean pigs have substantially greater lean growth rates and lean efficiency (kg carcass lean:kg feed intake). However, the genetically lean pigs require diets with greater concentrations of essential amino acids and minerals which causes the cost per kg of feed to be greater (Schinckel et al., 2008).

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Several swine growth models are available that predict the pig's response to different nutrition, management and marketing alternatives. Initially, models were deterministic in that the growth of one pig with mean values for each parameter was modeled. Recently, stochastic models have been developed which predict the nutrient requirements and optimize the management of a population of pigs (Pomar et al., 2003; Schinckel et al., 2003a). Stochastic models can be used to identify the optimal series of diets, marketing strategy, and use of ractopamine which maximize daily returns above feed and variable costs (Li, 2003; Boys et al., 2007).

The optimal age to empty the barn and refill with a new group of pigs can be determined for all-in, all-out management. Carcass value is determined by the pork processor's market grid which gives premiums or discounts based on predicted carcass lean percentage and carcass weight. The direct economic value for increased carcass leanness is dependent on the pork processors payment for pigs with different predicted percent lean and the current mean and distribution of predicted carcass lean percentage. The value of increased carcass growth rate is dependent on the tightness of the building turnover schedule (Li, 2003).

Environmental effects on pig growth

Substantial differences in performance exist between different production environments. Environmental stressors including pathogen exposure, social stress, and less than optimal stocking density limit growth. Pigs managed under commercial conditions do not express their maximum potential protein accretion even when allowed ad libitum access to a high quality, nutrient dense diets.

In a past experiment, pigs with minimal disease via segregated early weaning, which were fed a series of non-limiting diets and reared in pens of three pigs (2.23 m^2/pig), achieved 104 kg at 136 d of age and 120 kg at 151 d of age (Schinckel et al., 1995). Pigs raised on the original commercial farm, conventionally weaned with all-in, all-out production, required 184 d to attain 104 kg live weight. In the following experiment, pigs moved to a research building with 3 pigs per pen and 2.23 m^2 per pig grew 42% faster with 37.3% greater carcass lean gain than pigs reared on a commercial farm.

In general, high lean growth pigs reared under poorer health status and environmental conditions (stocking density and air quality) have reduced feed intakes and growth rates. Relative to their reduced feed intakes, pigs undergoing disease and other stressors have lesser protein accretion rates, carcass muscle accretion and carcass lean percentage (Schinckel et al., 2003c).

Genetic by environmental interaction trials

To quantify genetic by environmental interactions, three genetic by environmental trials were conducted (Schinckel et al., 1999). In each trial, two or three genetic populations of pigs were reared under two health status environments: 1) segregated early weaning, three-site (EW), and 2) conventional weaning, continuous flow grow-finish (CF). In each trial, two feed growth promotant or feed growth promotant/vaccination treatments were assigned to pigs of each genetic population in each environment.

Genotype by environmental interaction trial I

Two-hundred eighty-eight pigs were evaluated from two genetic populations: a European Terminal cross (ETC) with a high potential for lean growth and low to moderate feed intake, and a Yorkshire-Landrance cross (YL) with an average potential for lean growth and feed intake. In this trial, there were significant genetic by environmental interactions for average daily gain, daily feed intake, days to market, backfat thickness, percent lean and death loss. The ETC gilts become leaner in the EW environment than the CF environment (13.2 vs. 15.2 mm backfat). The ETC barrows had no difference in carcass lean percentage between environments (18.8 vs. 19.2 mm backfat). The YL gilts raised in the EW environment had greater tenth rib backfat (22.6 vs. 19.3 mm inch) than the CF environment. The YL barrows became substantially greater backfat depth (29.9 vs. 25.4 mm) in the EW environment.

The ETC pigs had significantly higher death loss (18.5 vs. 5.6%) in the CF environment compared to the YL pigs. No significant differences were observed in death loss between the ETC and YL pigs in the EW environment (3.6 vs. 2.3%).

Genotype by environmental interaction trial II

Three terminal sire lines (L, M, and H), increasing in genetic potential for percent lean were bred to European Landrace x Duroc-Large White sows. Previous data had shown that the L line had the highest live weight growth rate, feed intake, and lipid accretion. The H line had the lowest live weight growth rate, feed intake, and lipid accretion. The M sire was a cross of the L and H lines. All three sire lines had similar lean accretion rates when evaluated in prior trials.

In this trial, the EW pigs converted for PRRS and mycoplasma during the finisher period between 112 to 133 d of age. There were no differences in days to 113 kg between the EW and CF environments. There were significant sire line by environment interactions for average daily gain, days to 113 kg, feed efficiency and morbidity. In the CF environment, pigs sired by the L sires grew 100 g/d faster and required 12.3 d less to market than the H-sired pigs. In the EW environment, the L-sired pigs required 3.7 d less days than the H-sired pigs.

Genotype by environmental interaction trial III

Two hundred eighty-eight pigs of two genetic populations were evaluated. Yorkshire-Landrace sows were bred to US Duroc sires (YL/Dur), and European Landrace-Large White/Duroc sows were mated to European Duroc-Hampshire F_1 sires (EUR). The EUR pigs performed substantially better in the EW (894 g/d ADG, 2.14 kg/d ADFI) than the CF environment (785 g/d ADG, 1.83 kg/d ADFI), while the YL/Dur pigs had similar performance in the EW (866 g/d ADG, 2.20 kg/d ADFI) and CF environment (857 g/d ADG, 2.10 kg/d ADFI).

A genetic by environment interaction existed ($P < 0.01$) for days to market. The EUR pigs took 1 d less to 113 kg than the YL/Dur pigs in the EW environment, but were 10 d slower in the CF environment. The days to 113 kg BW data were then analyzed via regression to evaluate the environmental sensitivity of each genetic population-sex group. The performance of each genetic population-sex group was regressed on the overall mean performance of each health environment-treatment (Figure 1). The regression coefficients (b) were significantly greater (P = 0.003) for the EUR barrows (b = 1.58) and gilts (b = 1.31) than for the YL/Dur barrows (b = 0.60) and gilts (b = 0.51). Thus overall, the EUR pigs were 2.6 times more sensitive to the environmental stressors of the lower performing CF environment.

Competition among pigs

A number of experiments investigating the implications of selection of high lean growth swine on the behavior and welfare of these animals have been conducted. Research results include the following:

- Low lean pigs were found to be more active and less anxious than high lean swine in an open field test (Shea-Moore, 1998).
- High lean gain pigs were more aggressive than low lean gain pigs with an almost three times greater number of aggressive attacks (Busse and Shea-Moore, 1999).
- Whole blood serotonin levels (which may be related to aggression) were significantly higher in high lean gain pigs than in control pigs (Torre et al. 2001).

One alternative method to reduce the impact of competition among pigs is to separate the effects on performance due to the individuals' own genes (direct effects) and those from competing individuals (associative effects, Muir, 2005; Bijma et al., 2006a, b). Associative effects are defined as interactions among animals including: competition for limited resources, social dominance and pecking order (Muir, 2005). Mixed model methodology (BLUP) are utilized to predict breeding values for direct and associative effects and selection is placed on an optimum index of the direct and associative effects. One study found that social effects contribute the majority of heritable variance in growth rate and feed intake in pigs (Bergsma et al., 2008).

Joint selection of direct and associative effects has been evaluated using Japanese quail selected for 6-week weight. One line was selected only for direct effects (D-BLUP) and the other line selected for both direct and associative effects (C-BLUP, Muir, 2005). After 23 cycles of selection G-BLUP produced a significant response to selection (b = 0.52 $\underline{+}$ 0.25 g/hatch) while D-BLUP resulted in a nonsignificant negative response (b = -0.10 $\underline{+}$ 0.25 g/hatch). The genetic antagonism between direct and associative effects is likely greater in poultry than pigs. Response to selection based on C-BLUP in pigs has to be completed.

The alternative approach is to measure select against aggressive behavior (Turner et al., 2006, 2009). Behavioral traits such as duration of involvement in reciprocal fighting (h^2 = 0.43 $\underline{+}$ 0.04) and delivery of non-reciprocated aggression were heritable (h^2 = 0.31 $\underline{+}$ 0.04, Turner et al., 2009). A count of skin lesions recorded at 24 h and 3 wk postmixing were moderately heritable (h^2 = 0.19 – 0.43). Anterior lesion counts were associated with reciprocal fighting (r_G = 0.67) and receipt of non-reciprocated aggression (r_G = 0.70, Turner et al., 2009). Selection for lesion counts should allow selection for reduced aggressive behavior.

The best alternative may be to combine C-BLUP (direct and associative effects for grow rate) and the lesion counts. The lesion counts, if genetically correlated with the associative effects, would allow more precise estimation of the associative effects.

Heat stress

Selection for increased carcass lean growth rates and carcass leanness has increased pigs' total heat production and sensitivity to heat stress (Nienaber et al., 1997; Brown-Brandl et al., 2001). Relative humidity combined with high temperature affects pig growth (Huynh et al., 2005) Elevated temperatures reduce feed intakes and after the partitioning of energy from protein accretion to lipid accretion (Brown-Brandl et al., 2000). Commercial stocking densities (0.66 m^2/pig) for the late finishing period further accentuate the impact of heat stress (White et al., 2008).

Alternative genetic evaluation procedures that account for heat stress have been evaluated (Zumbach et al., 2008). Genetic parameters for carcass weight were estimated with univariate, 2-trait (periods with and without heat stress), and random regression of heat index. In the bivariate model, the estimates of heritability were 0.14 ± 0.01 for "cold" and 0.28 ± 0.01 for hot periods with a genetic correlation of 0.42 ± 0.13. Selection for crossbred performance reared under commercial stocking density and periods of heat stress was increased when growth data was included for periods of heat stress (Zumbach et al., 2008). The challenge is to increase carcass lean growth and carcass leanness which produce increased heat output during periods of heat stress (Brown-Brandl et al., 2001).

Reducing the dietary heat increment by reducing dietary crude protein concentrations (while maintaining essential amino-acid concentrations) and increasing fat content can improve pig performance (Spencer et al., 2005). However, these diets are more expensive per kilogram then more typical diets. The cost effectiveness of high energy, low heat increment diets should be greater for pigs with greater lean growth potentials.

Selection for commercial performance and reduced environmental sensitivity

The rates of genetic improvement body weight and lean growth rates predicted by selection under high health nucleus herd environments are not being realized in commercial production environments. Environmental sensitivity is the change in performance of a specific genetic population or family (half-sib, full-sib) across production environments with difference levels of environmental effects (Kolmodin and Bijma, 2004). There are two alternative methods of selection for reduced environmental sensitivity. The first method to select for reduced environmental sensitivity is to estimate and select for commercial breeding values (Knap, 2005; Casey et al., 2006). In pigs, this requires specific procedures including: 1) selection of commercial herds which represent the average commercial environmental conditions, 2) estimation of genetic parameters (heritability and genetic correlations) for performance traits, 3) produce and measure performance of commercial progeny with semen from nucleus AI boars or other close relatives to current generation nucleus animals, and 4) submit commercial records in time for indexing and selection of the nucleus animals (half-sibs, primarily). The organization effects are considerable but worthwhile if commercial performance is increased (Knap, 2005; Casey et al., 2006). The usefulness of including commercial-crossbred data is dependent on the genetic correlations purebred-nucleus to commercial-crossbred performance and their relative heritabilities (Zumbach et al., 2007).

Casey et al. (2006) estimated that the rates of economic response of commercial offspring over five generations would be increased 25.6% in sire lines and 18.6% in dam lines by including the commercial-crossbred performance data and selection based on commercial-crossbred breeding values versus purebred-nucleus breeding values. Selection based on the commercial-crossbred breeding values should result in pigs which as less environmentally sensitive.

The second alternative is to select on a combination of purebred-nucleus herd breeding values and breeding values for linear reaction norm (Knap, 2005; Knap and Su, 2008). The reaction norm, the regression of commercial performance on environmental values, is a measure of environmental sensitivity. This selection scheme would require: 1) the estimation of the genetic parameters for the reaction norm and nucleus performance, 2) ongoing production of families (half-sibs) in several commercial herds which differ in environmental values, and 3) the timely estimation of breeding values for the reaction norm and the nucleus performance estimated breeding value for selection. The advantage of the use of reaction norms is more precise weighting of the breeding values for the reaction norm and the purebred performance (Knap, 2005). Expected performance and economic merit of different sires could be estimated for commercial herds with difference performance levels. Herds with less than average commercial performance would place greater relative emphasis on the reaction norm breeding values than herds with average commercial performance (Knap, 2005).

The disadvantage of reaction norm analysis is the massive number of observations needed for each sire family over a broad range of environmental levels (Knap and Su, 2008) for accurate estimates of the reaction norm slopes. For litter size, even with a large dataset of 113,961 records of 52,120 daughters of 1091 sires recorded on 93 farms, the accuracy of the reaction norm slopes was too low to be useful in the estimation of reaction norm breeding values.

One alternative approach to evaluate the sensitivity of pig growth would be to create two grow-finish environments (i.e. high health, low stocking density, good air quality versus lower health, high stocking density, poorer air quality). Based on previous research, it could be possible to create facilities with 200-250 g/d (2 to 2.5 phenotypic SD) differences in postweaning growth rates. At weaning, commercial crossbred pigs could randomly be assigned within litter to be placed in each environment.

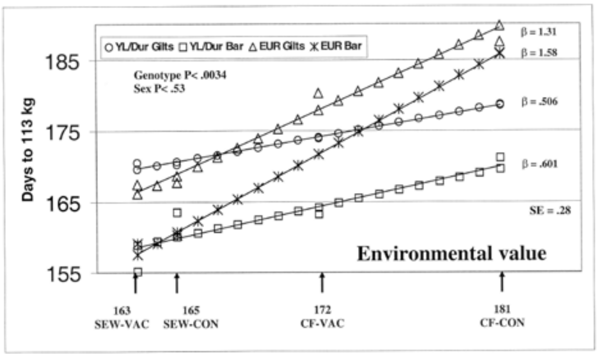

Figure 5. Environmental sensitivity of Yorkshire/Landrace-Duroc gilts (YL/DUR Gilts) or barrows (YL/DUR Bar) and European terminal gilts (EUR Gilts) or barrows (EUR Bar). Environmental value is the mean performance of all pigs in each environment (all-in/all-out (SEW), continuous flow (CF)) and treatment (vaccinated and medicated (VAC), non-vaccinated and no medication (CON) group. (β = regression coefficient of genotype and sex on environmental value.)

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