Selection for Intramuscular Fat in Duroc Pigs Using Real-time Ultrasound

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Introduction

Today's U.S. pork industry is experiencing phenomenal growth as it continues to meet consumer demand and pork is the most widely eaten meat worldwide. Pork has proven to be a valuable protein source as Americans consume 66 lbs/person/year on a carcass disappearance basis (USDA, 2002 Agricultural Statistics). Pork production in the United States is also a vital part of the economy. Nearly 19 billion pounds of pork, with a retail value of $38 billion, was processed from about 97 million hogs in 2001. The U.S. pork industry is responsible for over $72 billion in total domestic economic activity. In addition, the pork industry adds over $27 billion of value to basic production inputs such as corn and soybeans (NPPC, 2003).

Emphasis placed on lean, fast growing pigs over the past decade has contributed to a general decline in pork quality. Inferior quality problems cost the industry an estimated $90 million annually (Stetzer and McKeith, 2003), and the incidence of pale, soft, and exudative (PSE) pork has risen from 10% to 15.5% between 1996 and 2003 (Cannon et al., 1996; Stetzer and McKeith, 2003). Fresh pork quality has become important and has received more attention as producers and processors try to meet consumer demand for high quality, nutritious products. Many different traits have been identified as indicators of consumer acceptance of fresh pork. These include color, firmness, pH, intramuscular fat percentage (marbling), water-holding capacity, tenderness, juiciness, and flavor. Each of these has been shown to be low to moderately heritable (Sonesson et al., 1998; Knapp et al., 1997) and to impact consumer acceptance of fresh pork products. However, measuring these traits in the live animal has been difficult.

Intramuscular fat percentage (IMF) is one of the meat quality traits which has the potential to be measured in the live animal (Ragland, 1998; Newcom et al., 2001, Newcom et al., 2002), and has favorable genetic correlations with many other meat quality traits. Greater amounts of IMF have been shown to positively impact sensory panel traits such as tenderness, juiciness, and flavor, along with mechanical measures of tenderness (Hiner et al., 1965; De Vol et al., 1988; Hodgson et al., 1991; NPPC, 1995; Huff-Lonergan et al., 2002).

Prediction of IMF

Purebred Durocs (n=207) were used to develop a model to predict loin intramuscular fat percentage (PIMF) of the longissimus muscle in live pigs. Purebred Durocs were utilized in this study because they are known to offer the unique combination of positive attributes for not only growth and performance, but IMF as well. Additionally, it has been shown that variation exists in IMF measures within the Duroc breed. A minimum of four longitudinal, real-time ultrasound images were collected 7 cm off-midline across the 10th - 13th ribs on the live animal using an Aloka 500V SSD ultrasound machine fitted with a 3.5 MHz, 12.5 cm linear-array transducer (Corometrics Medical Systems, Inc., Wallingford, CT). A trained technician used texture analysis software to interpret the images and produce 10 image parameters. Backfat and loin muscle area were measured from a cross-sectional image at the 10th rib. After harvest, a slice from the 10th-11th rib loin interface was used to determine carcass loin intramuscular fat percentage (CIMF) using the method of Bligh and Dyer (1959).

The model to predict loin intramuscular fat percentage was developed using linear regression analysis with CIMF as the dependent variable. Initial independent variables were off-test weight, live animal ultrasonic 10th rib backfat and loin muscle area, and the 10 image parameters. Independent variables were removed individually until all variables remaining were significant ($P<0.05$). The final prediction model included live animal ultrasound backfat and five image parameters.

Multiple coefficient of determination (R^2) and root mean square error (RMSE) for the prediction model were 0.32 and 1.02%, respectively. An independent data set of Duroc (n=331) and Yorkshire (n=288) pigs from two replications of the National Pork Board's Genetics of Lean Efficiency Project (1999) were used for model validation. The product moment correlation and rank correlation coefficients between PIMF and CIMF were 0.60 and 0.56, respectively, in the Duroc population. Duroc pigs provided the best validation of the model. This demonstrates that real-time ultrasound image analysis can be used to predict intramuscular fat percentage in live swine.

Selection for Increased IMF

A selection project to increase intramuscular fat percentage using real-time ultrasound was initiated at the Bilsland Memorial Swine Breeding Farm at Iowa State University in 1998. The project was started by purchasing 40 Duroc gilts from Midwest breeders. Two generations of random mating using Duroc boars available at regional boar studs were used to expand the population, and to ensure that the population represented the genetic variability that was currently available in the Duroc breed. A base population of 56 litters was produced in 2000. At weaning, two boars in each litter were randomly selected to remain boars and all other boars in the litter were castrated. At an average weight of 250 lbs., pigs were ultrasonically evaluated with an Aloka 500V SSD ultrasound machine for measurement of 10th rib off-midline backfat depth and loin muscle area. A minimum of four longitudinal images were collected 7 cm off-midline across the 10th-13th ribs. Predicted IMF was determined by the method described in Newcom et al. (2002).

All barrows within each litter meeting the minimum weight requirement (> 215 lbs.) were harvested 5 d after scanning. If no barrows were available, a randomly chosen gilt was harvested. After harvest, a slice of the longissimus muscle from the 10th – 11th rib interface was analyzed for carcass IMF as previously described (Bligh and Dyer, 1959). In total, 379 pigs were scanned and 141 pigs harvested in the base population.

From the litters produced, littermate pairs of gilts were randomly chosen to produce the next generation. One gilt in each littermate pair was assigned to the select line and the remaining littermate was assigned to the control line. Littermate gilts across both lines were mated to the same boar (via natural mating or artificial insemination) to maintain genetic ties between the lines for production of Generation 1. A total of 24 sires from 14 sire families were used to produce 50 control and 45 select line litters. At weaning, two boars in each litter were randomly selected to remain boars and all other boars in the litter were castrated. When Generation 1 animals reached an average of 250 lbs., pigs were scanned and harvested according to the protocol previously described. In total, 324 and 283 pigs from the control and select lines, respectively, were scanned. A total of 148 pigs (87 control and 64 select) from Generation 1 were harvested.

Breeding values were estimated for predicted and carcass IMF by fitting a two-trait animal model and the full relationship matrix in MATVEC (Wang et al., 2003). Genetic and environmental variances were estimated using predicted and carcass IMF values from the 289 pigs harvested using the following model: $\mathbf{y} = \mathbf{Xb} + \mathbf{Za} + \mathbf{Hd} + \beta + \mathbf{e}$, where $\mathbf{y}$ = the vector of observations; $\mathbf{b}$ = the vector of fixed effects (scan contemporary group, harvest contemporary group, and sex), $\mathbf{a}$ = the vector of random additive genetic effect, which includes the numerator relationship matrix among animals; $\mathbf{d}$ = the vector of common litter effects, which is assumed to be uncorrelated with the random animal effects, β = covariate of off-test weight, and $\mathbf{e}$ = the vector of residuals. The incidence matrices relating observations to fixed, random animal, and common litter effects are $\mathbf{X}$, $\mathbf{Z}$, and $\mathbf{H}$, respectively.

Selection was based on EBV for carcass IMF. In the select line, the 10 boars and 75 gilts with the highest EBV were selected. To minimize inbreeding, no more than two boars per sire family were selected, selection of full-sib boars was not permitted, and no more than four gilts per litter were selected. In the control line, one boar from each of the 14 sire families and 50 gilts representing all 14 sire families were randomly selected. Animals within each line were randomly mated to produce Generation 2, but matings were designed to control inbreeding and ensure several litters from each selected boar.

In Generation 2, 56 select and 36 control line litters were produced. At weaning, three boars in each select litter and two boars in each control litter were randomly selected to remain boars and all other boars in the litter were castrated. When Generation 2 animals reached an average of 250 lbs., pigs were scanned and harvested according to the protocol previously described. A total of 614 pigs were scanned and 103 pigs from Generation 2 were harvested. The genetic evaluation described above was performed to make selections.

In Generation 3, 54 select and 38 control line litters were produced. At weaning, three boars in each select litter and a minimum of six boars in each control sire group were randomly selected to remain boars and all other boars were castrated. Pigs were again scanned and harvested according to the protocol previously described. From Generation 3, a total of 626 pigs were scanned and 145 pigs were harvested for carcass evaluation.

After three generations of selection, a total of 217 control line and 182 select line pigs have been harvested. Least squares means for carcass and quality traits were estimated using PROC MIXED in SAS with a model that included fixed effects of line, generation, harvest group within generation, sex, and a linear covariate for carcass weight. Sire and dam within line were random effects in the model. Results from this analysis are presented in Table 1. Pigs in the select line had significantly more ($P < 0.01$) IMF (3.94% vs. 3.40%) than pigs evaluated from the control line. Differences between the lines for Hunter L color, Minolta reflectance, and ultimate pH were not significant. Control pigs had significantly less tenth rib backfat (0.79 in. vs. 0.87 in.) and significantly more loin muscle area (6.72 in.^{2} vs. 6.39 in.^{2}). There was a trend for control line pigs to have less last rib backfat but the difference was not significant.

Table 2 gives the results for the 626 pigs scanned in Generation 3. The average breeding value for IMF for select line pigs after three generations of selection was 0.81% compared to -0.02% for control line pigs. Line comparisons for STAGES backfat, loin muscle area, and terminal sire index (STAGES, 2004) indicated a significant advantage for control line pigs compared to pigs in the select line. Control line pigs also had an advantage in days to 250 lbs. (176.5 vs. 180.9), but the difference was not significant.

Conclusions

After three generations of selection for IMF using real-time ultrasound, the average EBV for select line pigs is 0.83% greater than for control line pigs. Selection for IMF has, however, resulted in slightly more backfat and less loin muscle area, and a trend toward more days to 250 lbs. in the select line compared to the control line. Carcass evaluation of a sample of pigs from each litter indicated a similar increase in IMF, increase in backfat, and reduction in loin muscle area for select line pigs. No differences were found for Hunter L color, Minolta reflectance, and ultimate pH. Ultrasound technology will offer seedstock producers the opportunity to select for improved IMF in live animals and hence speed genetic progress for the improvement of this trait.

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Table 1. Carcass and quality data from pigs harvested in three generations from a selection project for intramuscular fat in Duroc swine (n=399).

Trait	Control	Select	P > F
Tenth rib backfat, in.	0.79	0.87	< 0.001
Last rib backfat, in.	0.93	0.98	N.S
Loin muscle area, in.^{2}	6.72	6.39	< 0.001
Intramuscular fat, %	3.40	3.94	< 0.01
Hunter L color	48.7	49.4	N.S
Minolta reflectance	23.9	24.5	N.S
Ultimate pH	5.82	5.82	N.S

Table 2. EBV for intramuscular fat and STAGES[a] data for Generation 3 pigs from a selection project for intramuscular fat in Duroc swine (n=626).

Trait	Control	Select	P > F
EBV for intramuscular fat, %	-0.024	0.806	<0.0001
STAGES Data			
Days to 250 lbs.	176.5	180.9	N.S.
Backfat, in.	0.72	0.81	< 0.001
Loin muscle area, in.^{2}	6.67	6.34	< 0.05
Terminal Sire Index	111.3	101.2	<0.0001

[a]http://www.ansc.purdue.edu/stages/