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EVALUATION OF DUROC VERSUS PIETRAIN SIRED PROGENY
FOR GROWTH, COMPOSITION, AND MEAT QUALITY

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DAVID BOWEN EDWARDS

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Ronald O. Bates
Major professor

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EVALUATION OF DUROC VERSUS PIETRAIN SIRED PROGENY FOR GROWTH, COMPOSITION, AND MEAT QUALITY

By

David Bowen Edwards

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ABSTRACT

EVALUATION OF DUROC VERSUS PIETRAIN SIRED PROGENY FOR GROWTH, COMPOSITION, AND MEAT QUALITY

By

David Bowen Edwards

Crossbred Duroc and Pietrain progeny were evaluated for growth (n = 307 pigs) and carcass merit (n = 162 pigs) traits. Weight and B-mode ultrasound estimates of 10^{th} rib backfat (BF10), loin muscle area (LMA), and last rib back fat (LRF) were serially measured from 10 to 26 wk of age. At 26 wk of age Duroc sired progeny were heavier, had more BF10 and LRF, but had similar LMA to Pietrain sired progeny. Random regression models were generated to model pig weight, BF10, LRF, and LMA, fat free lean tissue (FFTOLN), total fat tissue, empty body protein, and empty body lipid on week on test. Faster growth rate of Duroc progeny and higher percent lean of Pietrain progeny counterbalanced each other to create similar rates of FFTOLN. For carcass measurements at similar ages, Duroc progeny had higher carcass weights and were longer, while Pietrain progeny had less back fat at first rib, last lumbar vertebrae, and tenth rib. No difference was seen for LRF. Pietrain progeny had a higher percent lean at slaughter, higher dressing percentage, larger percentage of the carcass as ham and loin, while Duroc progeny had a larger percentage as belly. Meat quality measures were either not different or favored Duroc sired progeny. Loin chops from Duroc progeny were darker, more marbled, and firmer with a higher 24-h pH and lower percent 24-h drip loss. No differences were seen in shear force. Both sire breeds have traits that can be utilized in commercial pork production and merit further study.

This thesis is dedicated to my entire family, whose love of learning was instilled in me early in my life. Their encouragement has kept me motivated and focused.

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LIST OF ABBREVIATIONS

ADG = average daily gain

ADG1026 = average daily gain from 10 to 26 wk of age

ADJDAYS = covariate to adjust for age at measurement

BF10 = 10^{th} rib backfat

FFL% = percent fat-free lean

FFTOLN = fat free lean tissue

LMA = loin muscle area

LRF = last rib back fat

MTPRO = empty body protein

MTFAT = empty body lipid

SEM = standard error of mean

TOFAT = total fat tissue

W-B = Warner-Bratzler

INTRODUCTION

The ability of pork producers to make correct decisions about breeding schemes hinges on their access to accurate and current information about breeds and lines available. Breeds and lines used greatly impact carcass merit and meat quality attributes of offspring. Certain propensities towards differing rates and shapes of the growth curve are characteristics to be considered in making decisions that will affect the economic outcome of an operation. Using this information about expected growth, composition, and meat quality allows nutrition, production schedules, and marketing schemes to be customized to fit specific genotypes and market demands. Knowledge of performance expectations for different genetic types allows producers to make choices to benefit their production systems and the product available to consumers.

Several domestic breeds have been characterized in studies for traits of economic performance within current U.S. production systems. Unique swine populations have been developed in genetic improvement systems around the world that differ from those seen in the United States. Some of these populations have been imported to the United States and may be untapped resources of beneficial genes for growth, composition, and meat quality. Quantification of these traits relative to current populations used in U.S. production would allow producers to make decisions that would positively impact their operations.

The Pietrain breed is a European population that is now available within the United States, but little comparative information is available to determine its usefulness within U.S. production systems. Duroc pigs and their offspring have been studied and used extensively within U.S. production systems. A comparison of these two breeds as terminal sires would elucidate the differences and possible advantages of including them in commercial breeding programs. The purpose of this study was to evaluate Duroc versus Pietrain progeny for growth, composition, and meat quality traits in systems that emulate those seen in U.S. production.

CHAPTER I

LITERATURE REVIEW

Growth Prediction

Breeds and lines used in commercial pork production each have their unique patterns of growth. "Growth may be considered from at least two different aspects: 1) an increase in body mass with time and 2) changes in form or composition resulting from different growth rates of component parts," (Robison, 1976). Robison (1976) further stated that efforts in the past to change the growth curve have been directed at simply changing rate of body mass growth.

Change in body mass can be partitioned into its component parts. This partitioning provides more information concerning biological differences between different animals within populations as well as further description of different populations. In order to study these compositional changes, animals have been dissected or chemically analyzed at different slaughter weights (Siemens et al., 1989; Schinckel and de Lange, 1996; Wagner et al., 1999). The high cost of these procedures makes them prohibitive to be routinely conducted on a large number of pigs (Schinckel and de Lange, 1996). In addition, animals slaughtered would not be available for breeding purposes, which allows only information on relatives to be used for predicting genetic merit.

Methods to predict these components of growth on live animals are desirable and have been developed. One method is ultrasound technology. Terry et al. (1989) used ultrasound estimates of backfat and loin muscle area to attempt to predict the four lean cuts as a percent of side weight. McLaren et al. (1989) reported preslaughter ultrasound estimates compared to carcass measurements to have partial correlations of .55, .62, and

.55 for backfat measures at the last rib, average backfat and tenth rib backfat, respectively and .61 for loin eye area. McLaren et al. (1989) stated, "Use of real-time ultrasonography to monitor protein and fat accretion in growing-finishing pigs appears promising, and might prove to be a powerful, cost-effective research tool." Targeting protein accretion specifically with attention paid to an adequate amount of fat within pork is a production goal that can be achieved. Several studies have reported non-invasive measures to predict protein and fat composition at various stages of the growth phase (McLaren et al., 1989; Siemens et al., 1989; Houghton and Turlington, 1992; Schinckel and de Lange, 1996; NPPC, 2000). The ability to estimate composition on breeding animals allows optimization of breeding schemes and production practices for desired end products.

A review by Houghton and Turlington (1992) showed that ultrasound could accurately assess body measurements of swine. Overall accuracy of body measures (e.g., backfat at first rib, tenth rib, last rib, and last lumbar and loin muscle depth, width, and area), as assessed by correlation coefficients, was approximately .9. These high correlations to carcass measures allow for non-invasive measures of an animal's phenotype.

The use of ultrasound technology has been used to characterize growth and composition throughout the life of the pig. Serial real-time ultrasound measures have been taken on pigs at regular intervals to predict measures at market weight and to model growth. McLaren et al. (1989) took ultrasound measures starting at 42 d of age and every 2 wk after that until slaughter (mean of 98.5 kg, 170 d). Both measures of backfat and loin muscle area were obtained and used to predict lean gain per day. They reported that serial measures appeared promising, and cost-effective, as a technique for monitoring composition of growth in the pig.

Growth Modeling

Successful simulation of growth performance of an individual pig depends as much on a correct parameterization of its genotypic parameters as on a detailed description of its environment (Knap, 2000). Growth curves are an effective way to summarize measurement information into only a few parameters (Mignon-Grasteau et al., 1999). Many different approaches have been used to summarize growth parameters in different species. These include changes in body mass as well as changes in composition of body mass. Change in body mass has been an important growth characterization in meat animal species. Estimation of growth curves in chickens (Mignon-Grasteau et al., 1999) has shown that parameters of the growth curve are heritable. Four lines of chickens were selected for change of body weight at 8 or 36 weeks of age. One line was selected for high body weight at both ages. Another was selected for low body weight at both ages. A third was selected for high body weight at 8 weeks and low body weight at the 36 weeks. The fourth was selected for low body weight at 8 weeks and high body weight at 36 weeks. Offspring from these selected animals were measured for body weight growth and had growth patterns similar to their parents. Thus, patterns of growth as described by parameters of the functions, not just overall growth, are heritable (Mignon-Grasteau et al., 1999).

VanLunen and Cole (1998) stated that it is generally recognized that growth of animals from conception to maturity occurs in a sigmoidal response of size over time. McKay (1994) reported that growth curves in Yorkshire, Hampshire, and Landrace pigs were linear from 1 to 35 d of age. After 35 d of age, different methods have been used to model body weight gain because of the changes (i.e., other than linear) in the shape of the growth curve. Robison (1976) reported that a quadratic regression term was significant, but probably of little biological importance for postweaning gain to about 130 kg since it only accounted for 1% more variation than a linear model. In chickens, Tzeng and Becker (1981) also found a significant quadratic term for body weight gain, but did not elucidate on its biological importance.

A number of nonlinear models have been applied to growth modeling. One function that has been used to model growth was proposed by Gompertz (1825) and further refined by Laird et al. (1965). This function uses an estimate of initial weight, initial specific growth rate, and rate of decline in growth rate to estimate the body weight or compositional component weight of an animal. This function has been used to model growth both in chickens (Tzeng and Becker, 1981; Mignon-Grasteau et al., 1999) and in pigs (Ferguson and Gous, 1993a,b; Emmans and Kyriazakis, 1997; Knap, 2000). Tzeng and Becker (1981) used a Gompertz function to describe body weight growth in male broilers from 1 to 69 d of age and found predicted curves closely fitted weight data points. This study also fitted a cubic regression model and found it also fitted the data adequately. Mignon-Grasteau et al. (1999) described individual growth curves for 7143 chickens and found, as had Laird et al. (1965), that Gompertz functions fit the sigmoid part of growth well, but did not accurately describe weight changes after this phase of growth.

A further refinement of growth is to measure the change in mass of its components. In meat animals the relationship of lean growth (protein) to fat is especially important. Ferguson and Gous (1993a,b) proposed and tested a method using the Gompertz function to predict genetic merit of pigs by means of body components of mature body protein weight, rate of maturing, and inherent fat content, defined in terms of a lipid to protein ratio at maturity. Emmans and Kyriazakis (1997) also came to the conclusion that a Gompertz function adequately described protein retention rate. Gompertz functions were fitted to body protein and lipid mass by Knap (2000) to estimate mature protein and lipid mass. It was assumed that the rate parameter would be the same for both components in this study. Knap concluded that selection between 'meat-type' pig populations has greatly reduced mature body lipid mass while leaving mature body protein mass practically unchanged. Also, the growth rate of both body fractions had substantially increased and the peak of the protein accretion curve had shifted towards more mature stages of development.

Limitations exist in the use of fixed inflection point nonlinear functions, such as the Gompertz function. They may result in biased estimates of asymptotic values (mature masses) because the fit of the observations is forced to accommodate a fixed y-coordinate (as a proportion of the asymptote) of the point of inflexion (Knap, 2000). Points of inflexion of protein and lean tissue growth pattern in pigs of different genotypes have been estimated to occur at different body weights (Schinckel and de Lange, 1996).

Allometric equations ($Y = aX^b$, with Y as mass of some component and X as live weight) have been discussed and discarded as possibilities to model growth data (Schinckel and de Lange, 1996). The allometric function assumes that for every 1% change in X, Y changes b%, thus body component mass as a percentage of live weight uniformly decreases ($b < 1$), remains constant ($b = 1$), or increases ($b > 1$) as live weight increases. This is not true since rate of accretion of these masses may change during an animal's growth period. Alternatively, augmented allometric equations ($Y = aX^b(c - X)^d$) have been developed that have an increased R^2, and addition of the $(c - X)^d$ term is consistently significant for data from pigs with backfat depths greater than 22 mm at 115 kg live weight (Schinckel and de Lange, 1996). The augmented allometric is a diminishing return function in which the component mass per unit of empty body weight gain decreases and becomes zero as a mature component mass is achieved (Wagner et al., 1995). Negatively, augmented allometric functions are more difficult to fit and less stable than allometric equations in small data sets (Wagner et al., 1999). A difficulty encountered with allometric equations is that they may not be applicable at the earliest and latest stages of growth (Evans and Kempster, 1979). Use of allometric equations to describe the relationship of protein or fat-free lean mass to live weight or empty body mass will result in daily protein accretion and fat-free lean growth rates to be underestimated at empty body weights less than 50 kg and overestimated at empty body weights greater than 80 kg (Wagner et al., 1999). Wagner et al. (1999) also reported that augmented allometric equations may better describe empty body protein, carcass fat-free lean, and moisture mass since these components would be expected to reach mature mass at an empty body mass less than ultimate mature empty body mass.

Nonlinear mixed effects models have been used to describe lactation patterns and growth. Rodriguez-Zas et al. (2000) used four nonlinear and two linear functions to describe somatic cell score in milk. A random term of cow was used in these models, but an assumption of unrelated cows was also used. Koenen and Groen (1996) used sire as a random effect in estimating monthly body weight and weight at first calving measures of heifers. They stated, "Because mature body weight is hard to record directly, mature body weight of an individual animal was estimated by extrapolating longitudinal data." Both Koenen and Groen (1996) and Rodriguez-Zas et al. (2000) mentioned estimating asymptotic values as a difficulty in using nonlinear models. In fact, Koenen and Groen (1996) had to delete animals with estimated mature body weights greater than 1000 kg. Not many studies have been reported that use mixed effect nonlinear modeling.

Random Regression

An alternative to fitting a 'standard' growth function, such as a Gompertz function, for longitudinal data is random regression analysis. Weights of animals are a typical example of longitudinal data, where the trait of interest is changing, gradually but continually, over time. Random regression allows regression of a trait on age to model growth and allows separation of between and within animal variation. Henderson Jr. (1982) first considered random regression coefficients in a linear mixed model context. Recent applications include evaluation of dairy cattle using test day records (Jamrozik and Schaeffer, 1997; Jamrozik et al., 1997), and description of growth curves in beef cattle (Varona et al., 1997) and pigs (Andersen and Pedersen, 1996).

Random regression can be used as an effective tool to reduce the number of traits handled, such as body weight or body component weights, for those traits measured over time. Traits can be described by parameters of a function, instead of by many measures taken over a time period. The fixed regression part of the function can model population trajectory, while the random regression coefficients for each animal represent individuals' deviation from this curve (Meyer, 1998). Random coefficients allow a (co)variance structure to be specified for related factors. Some problems have been encountered when fitting random regression models, giving rise to implausible values of variance or covariance components at the 'edges' or endpoints of the data. This is likely caused by the large effect that values furthest from the mean have in a regression analysis (Meyer, 1999). Schinckel et al. (1996) also found greater error at the endpoints of the data. Data for this study (Schinckel et al., 1996) were collected on pigs between 20 to 120 kg live weight with genotype-environment specific daily protein accretion compared to the generalized predicted daily protein rates. Mean percentage absolute values of the errors were 3.5% for gilts and 6.1% for barrows. From 20 to 110 kg live weight, mean percentage errors were 2.7% for gilts and 4.8% for barrows, therefore, errors were largest between 110 to 120 kg. Schinckel and de Lange (1996) suggest collection of weights before, during, and after the weight interval of interest to properly model traits of interest. "Inclusion of random genetic components of regressions in animal models may be applicable to any situation in which repeated time-dependent observations are taken on a given animal, and when the time-dependent response function exhibits genetic variation," (Schaeffer and Dekkers, 1994).

A study by Andersen and Pedersen (1996) applied random regression technology to growth rate and daily food intake in pigs. Gilts and barrows were on test from 30 to 115 kg live weight. They found that the growth curve of each individual followed a fourth degree polynomial. The (co)variance parameters were estimated using REML, and then fixed effects were estimated and random effects were predicted assuming the estimated (co)variance parameters as the true parameters. The difficulty in introducing random effects or variance components in non-linear functions was the reason that linear models were chosen. When animals are not taken to mature weights, such as growth evaluation to standard or contemporary market weights, it is not necessary to consider curves which approach asymptotic values (Andersen and Pedersen, 1996). This is an advantage of the random regression approach over non-linear models, in which an asymptotic value is estimated by extrapolating from collected data.

Selection and Market Weight on Meat Quality

While growth and composition are major concerns in the swine industry, meat quality of pork products ranks second in concern only to excessive fat (Cannon et al., 1996). The Pork Chain Quality Audit (Cannon et al., 1996) reported that 10.2% of carcasses were classified as having pale, soft, and exudative muscle. It was further reported that a factor affecting pork quality at the packing level in terms of muscle color, firmness, and texture was genetic merit for optimal or acceptable meat quality. Genetic merit may affect other factors of meat quality as well.

Selection for pigs that have a higher proportion of muscle and reduced amounts of fat may negatively affect meat quality characteristics. Genetic correlations of carcass leanness to ultimate pH (-0.13), reflectance (0.16), and drip loss (0.05) (Sellier, 1998) suggest decreased meat quality with leaner pigs. A concern for meat quality is the reduction in average fat thickness levels that has occurred in the same time period as lowered meat quality (Wood, 1985). Wood (1985) reported that work with leaner pigs (below 10 mm P2 fat thickness) suggested increased occurrence of slightly less juicy pork products. Any breed or line introduced into commercial application should improve these meat quality characteristics or at least not detract from current levels of meat quality.

Heavier slaughter-weight pigs can also be a concern for meat quality. Slaughter weights for swine in the United States have been increasing steadily over recent years from a mean of 108 kg in 1977 to 117 kg in 1999 (USDA, 1998; USDA, 2000). Cisneros et al. (1996) reported significant linear regression coefficients on slaughter weight (in kg) for lighter color (-0.006), less firmness (-0.009), a lower 24-h pH (-0.002), higher drip loss (0.029), and decreased tenderness(-0.015) in heavier pigs. All these measures lead to a decrease in overall pork quality as market weight increases. In the same study, non-significant effects of slaughter weight on growth rate and feed efficiency were seen. As breeding scheme choices are made for growth and composition goals, meat quality must also be considered.

Ryanodine Receptor Gene and Meat Quality

Effects of certain genes can significantly alter growth, composition, and meat quality traits. A mutation in the skeletal ryanodine receptor gene has been found to be correlated with malignant hyperthermia, which causes economic losses in the swine industry (Fujii et al., 1991). This mutation has also been called the halothane gene because the test to assess which pigs had this condition was to administer the anesthetic halothane. Those animals whose muscles became rigid in response to the halothane and took a long time before relaxation were identified as positive for the gene. Another name for malignant hyperthermia is porcine stress syndrome, due to the observed response to stress of pigs with this mutation. Pigs may respond to stress by developing blotches on their skin, muscle rigidity, elevated body temperature, labored breathing, and even death (Judge et al., 1992). In addition, pigs with either one or two copies of the mutant allele have leaner carcasses but poorer meat quality (Zhang et al., 1992). This study reported that pigs with two copies of the mutant allele had poorer ($P < 0.05$) subjective (five-point scale) scores for color (3.3 vs. 2.3), firmness (2.8 vs. 1.8), and marbling (2.5 vs. 1.4) than pigs with only one copy of the mutant allele. Leach et al. (1996) compared heterozygous pigs to animals that were homozygous normal. Heterozygous pigs had poorer 45 min pH (6.4 vs. 6.6) and 24-h pH (5.6 vs. 5.7). These pigs also had lower subjective (five-point scale) scores for color (2.2 vs. 2.7), firmness (2.2 vs. 2.9), and marbling (1.2 vs. 1.7). Additionally, drip loss was poorer (5.2% vs. 3.4%), but feed efficiency was better (2.78 vs. 3.03 feed/gain) with no difference reported for fat-free lean percentage of side weight. Murray and Johnson (1998) elucidated another disadvantage of the halothane gene. They reported death rates of the three genotypes of the halothane gene from two packing plants in Western Canada. Frequencies of death within the homozygous mutant, heterozygous, and homozygous normal animals were 9.2, 0.27, and 0.05%, respectively. While the mutation in the ryanodine receptor gene may provide some benefits, it also has economic disadvantages that make it undesirable in commercial pork production.

Duroc and Pietrain Breeds

Throughout the years, the Duroc breed has served as a terminal sire population and as a reference sire in many research evaluations. Duroc animals and their progeny have been compared in nation-wide breed comparisons in different countries (Kennedy et al., 1996; Moeller et al., 1998), as reference sires to newly imported breeds (Young, 1992a,b), and in studies of heterosis and mating schemes (McLaren et al., 1987a,b; Langlois and Minvielle, 1989a,b; Kuhlers et al., 1994; Blanchard et al., 1999). Results of comparisons of growth and composition characteristics to other breeds can be found in Table 1. In general, Duroc pigs and their offspring have been found to grow faster, but also have more backfat than other breeds (Kennedy et al., 1996; Moeller et al., 1998; Blanchard et al., 1999). At the same time, Duroc animals tend to have greater rates of lean gain because of their faster overall rate of gain. Carcass and meat quality characteristics of Durocs versus other breeds appear in Table 2. Durocs tend to have heavier ham and shoulder weight, but similar loin weight compared to other domestic breeds of Hampshire, Landrace, and Yorkshire (Langlois and Minvielle, 1989b). Some studies have shown that Duroc pigs are more efficient converters of feed to gain (McLaren et al., 1987a), while other studies have shown Durocs to be less efficient (Mrode and Kennedy, 1993). One area that Duroc pigs excel in is meat quality. Pork from Duroc and Duroc sired pigs tends to have lower shear force and cooking loss, better color and marbling scores, and higher pH (Langlois and Minvielle, 1989b; Blanchard et al., 1999; Jeremiah et al., 1999). Duroc pigs have been characterized as a fast growing, slightly less lean, but high meat quality population.

A novel population that has been imported to the United States is the Pietrain. These animals have been used in European production systems, but little comparative data has been reported of their merit in U.S. production systems. A summary of characteristics of purebred Pietrains is found in Table 3. Lean et al. (1972) conducted an early study of Pietrains in Europe and found they were lower in fat content, similar in feed efficiency, but had more meat quality defects than Landrace pigs. McKay et al. (1985) reported Pietrains grew slower, but had larger hams than Yorkshire or Minnesota No.1 pigs. Slower body weight growth combined with less backfat allowed Pietrains to have similar lean tissue growth rate as Yorkshire pigs. Fortin et al. (1987) noted that Pietrains demonstrated early maturing characteristics with leaner carcasses compared with Large Whites. Quiniou and Noblet (1995) used Pietrain boars in their study of equations to predict composition because of their propensity towards leanness, and found them to be leaner than either Large White or Meishan pigs ($P < 0.05$), but similar in leanness to a synthetic line used in the study. Pietrains are a novel population that has not been studied under typical U.S. production conditions, but could be of value as leaner animals with a higher proportion of muscle in valuable wholesale cuts.

Duroc vs. Pietrain Studies

Few studies have been undertaken to compare Duroc and Pietrain animals for growth, composition, and meat quality. Those that have been reported do not necessarily have consistent agreement about the traits studied, partially due to differences in ending weights across the studies. Results of some of these studies appear in Table 4 for growth and composition and in Table 5 for carcass and meat quality traits. Kanis et al. (1990) used Duroc and Pietrain animals to study the effects of recombinant porcine somatotropin (rpST). Among control animals, those not receiving rpST, Pietrain animals had better feed efficiency and lean growth rate in early growth, were leaner at all weights, but had similar feed efficiency and lean growth rate over the entire growth period than Durocs. Affentranger et al. (1996) also reported faster growth rate with more backfat, but worse feed efficiency for Duroc animals as compared to Pietrains. Meat quality measures of pH and water holding capacity were better for Duroc pigs in this study. Average daily gain was similar for Duroc and Pietrain influenced animals in a study by Ellis et al. (1996) with Pietrain influenced pigs having less backfat and a larger loin muscle area. Meat quality measures again favored Duroc animals for marbling and Warner-Bratzler shear force. No differences were seen for color score or cooking loss. Garcia-Macias et al.

(1996) also reported less backfat and larger loin muscle area for Pietrain animals as compared to Durocs. Similar weight of ham, loin, and shoulder primal cuts were seen for both Duroc and Pietrain progeny with larger belly cuts in Pietrain progeny in this study. Again, Duroc progeny had better 24-h pH, but no difference was seen for subjective or objective color scores.

Discrepancies seen in these studies may be due to different end weights used. Many studies found Pietrain sired pigs to have favorable characteristics at lighter slaughter weights, but these differences may not be as apparent at heavier weights typically seen in U.S. production systems. These studies also used Pietrain animals that carried the halothane gene, whose effects were described in an earlier section. Pietrain animals that do not carry this gene are now available for use in the U.S. pork industry.

Introduction of novel lines and breeds into breeding schemes requires the accurate evaluation of economically important traits before use by commercial production can be justified. Inconsistent results of previous studies with Pietrains raised in situations different from those in U.S. pork production are difficult to interpret. Evaluation of Duroc versus Pietrain progeny for growth, composition, and meat quality traits will provide pork producers more information so that they can make proper economic decisions and produce an acceptable product for their market chain.

Table 1. Summary of growth and composition characteristics of Durocs.

Investigator and Year	Trait [a]	Duroc	LS means of other breeds [b] Higher	Lower	Similar
McLaren et al., 1987a	ADG	.663 kg/d		L,Y	S
(Duroc sired pigs)	BF, avg	25.0 mm	L,S		Y
	LMA	32.0 cm^2		L,S,Y	
	Length	78.6 mm	L,Y		S
Langlois & Minvielle, 1989a	ADG	699 g/d		L,Y	H
(Duroc sired pigs)	BF	29.5 mm	L,Y	H	
	LMA	40.0 cm^2			H,L,Y
	Length	79.82 cm	L		H,Y
	FE	3.23			H,L,Y
	Birth wt	1.54 kg		L,Y	H
	Wean wt[c]	7.68 kg	L		H,Y
	13 wk wt	33.20 kg		Y	H,L
Kuhlers et al., 1994	ADG	.845 kg/d	L		Y
(Duroc sired pigs)	BF, avg	2.02 cm	L,Y		
	FE	3.17	L,Y		
	Birth wt	1.38 kg	L,Y		
	3 wk wt	5.70 kg	Y		L
	5 wk wt	15.55 kg	L,Y		
Kennedy et al., 1995	BF, avg	16.0 mm		H,Y	L
(purebred Duroc pigs)	Age	173.8 d	H,L,Y		
Moeller et al., 1998	ADG	.835 kg/d		B,C,H,P,S,Y	L
(purebred Duroc pigs)	BF10	27.5 mm		H,L,P,Y	B,C,S
	LRF	23.0 mm		B,H,L,P,Y	C,S
	LLF	26.5 mm	S	H	B,C,L,P,Y
	LMA	35.1 cm2	H,P	B	C,L,S,Y

[a] ADG = average daily gain, BF = backfat, LMA = loin muscle area, FE = feed efficiency (in feed/gain), BF10 = 10^{th} rib backfat, LRF = last rib backfat, LLF = last lumbar backfat

[b] B = Berkshire, C = Chester White, H = Hampshire, L= Landrace, P = Poland China, S = Spotted, Y = Yorkshire

[c] 4-5 wk

Table 2. Summary of carcass and meat quality characteristics of Durocs.

Investigator and Year	Trait	Duroc	—LS means of other breeds [a]— Higher	Lower	Similar
Langlois & Minvielle, 1989b (Duroc sired pigs)	Ham wt	8.66 kg		L	H,Y
	Loin wt	8.08 kg	L		H,Y
	Shoulder wt	8.99 kg		L	H,Y
	45 min pH	6.19		L	H,Y
	24 h pH	5.51			H,L,Y
Jeremiah et al., 1999 at Lacombe, AB (purebred Duroc pigs)	Shear	54.31 N	L,Y	H	
	Cook loss	27.94%	H,L		Y
	Color (1-5)	3.01			H,L,Y
	Marbling (1-5)	3.33		H,L,Y	

[a] H = Hampshire, L= Landrace, Y = Yorkshire

Table 3. Summary of characteristics of purebred Pietrains.

Investigator and Year	Trait [a]	Pietrain	— LS means of other breeds [b]— Higher	Lower	Similar
Lean et al., 1972	ADG	.57 kg/d	L		
	Shoulder fat	37.5 mm	L		
	Loin fat	19.6 mm	L		
	LMA	36.5 cm2		L	
	Length	784 mm	L		
	FE	3.8	L		
McKay et al., 1985	LTGR	.0302 kg/d		M	Y
	FE	2.681	M	Y	

[a] ADG = average daily gain, LMA = loin muscle area, FE = feed efficiency (in feed/gain), LTGR = lean tissue growth rate (gain in boned ham wt/d)
[b] L= Landrace, M = Minnesota No.1, Y = Yorkshire

Table 4. Summary of growth and composition of Durocs vs. Pietrains.

Investigator and Year	Trait [a]	Duroc	Pietrain	Diff.[b]
Kanis et al., 1989 [c]	ADG (22-60 kg)	.628 kg/d	.730 kg/d	*
(purebred pigs)	BF, avg (60 kg)	10.5 mm	8.7 mm	*
	BF, avg (100 kg)	17.5 mm	12.3 mm	*
	FE (60-100 kg)	3.37	3.18	*
	LP (100 kg)	52.7	56.1	*
	LTGR (60-100 kg)	.329 kg/d	.411 kg/d	*
	BF, avg (140 kg)	24.4 mm	17.4 mm	*
	FE (100-140 kg)	4.45	4.71	NS
	LP (140 kg)	50.4	52.2	*
	LTGR (100-140 kg)	.288 kg/d	.278 kg/d	*
Affentranger et al., 1996	ADG	903 g/d	881 g/d	NS
(crossbred pigs)	FE	2.75	2.59	*
	s.c. fat	18.0%	15.0%	*
Ellis et al., 1996	ADG	764 g/d	753 g/d	*
(purebred pigs)	C fat	15.6 mm	14.0 mm	*
	LMA	39.0 cm^2	40.7 cm^2	*
Garcia-Macias et al., 1999	BF, 10^{th} rib	19.84 mm	17.16 mm	*
(crossbred pigs)	LRF	17.82 mm	14.75 mm	*
	LMA	36.77 cm^2	40.51 cm^2	*
	Length	83.34 cm	83.52 cm	NS

[a] ADG = average daily gain, BF = backfat, LMA = loin muscle area, FE = feed efficiency (in feed/gain), LP = lean percentage, LTGR = lean tissue growth rate (gain in boned ham wt/d), s.c. fat = subcutaneous fat percentage, C fat = backfat above deepest part of loin muscle at last rib excluding skin, LRF = last rib fat

[b] Significant difference * = $P < 0.05$, NS = not significant

[c] Weights listed after traits are when traits were measured

Table 5. Summary of carcass and meat quality of Durocs vs. Pietrains.

Investigator and Year	Trait [a]	Duroc	Pietrain	Diff.[b]
Affentranger et al., 1996	Ham %	18.6%	20.3%	*
(crossbred pigs)	45 min pH	5.98	5.70	*
	WHC	74.8 µl	91.7 µl	*
Ellis et al., 1996	Color (1-5)	2.44	2.36	NS
(purebred pigs)	Marbling (1-5)	3.16	2.68	*
	Cook loss	260 g/kg	268 g/kg	NS
	W-B shear force	5.35 kg	5.67 kg	*
Garcia-Macias et al., 1999	Ham %	24.02%	24.06%	NS
(crossbred pigs)	Loin %	11.40%	11.30%	NS
	Shoulder %	14.32%	14.63%	NS
	Belly %	9.31%	9.91%	*
	45 min pH	6.06	6.08	NS
	24 h pH	5.69	5.60	*
	Minolta L	52.13	53.09	NS
	Minolta a	7.63	7.38	NS
	Minolta b	6.30	5.94	NS
	Color (1-6)	2.73	2.58	NS

[a] WHC = water holding capacity (capillar-volumeter method), W-B = Warner-Bratzler
[b] Significant difference * = $P < 0.05$, NS = not significant

CHAPTER II

GROWTH PARAMETERS

Abstract

Terminal sire populations of Duroc and Pietrain animals were evaluated for growth and composition traits. Crossbred progeny that were normal for the ryanodine receptor gene were used. Boars from each breed were mated to either Yorkshire or F_1 Yorkshire-Landrace females with 307 offspring evaluated through 26 wk of age. No significant differences were seen for pig weight from birth through 10 wk of age between progeny sired by either breed. Weight and B-mode ultrasound estimates of tenth rib backfat (BF10), last rib back fat (LRF), and loin muscle area (LMA) were serially measured at 10, 13, 16, 19, 22, 24, and 26 wk of age. At 26 wk of age Duroc sired progeny were heavier (143.2 vs. 133.0 kg, $P < 0.001$), had more BF10 (27.25 vs. 23.67 mm, $P < 0.001$) and LRF (21.59 vs. 19.23 mm, $P < 0.001$), but had similar LMA (45.93 vs. 46.97 cm^2) to Pietrain sired progeny. Mean feed efficiency was not different between either breed of sire in any period of the study. Duroc progeny had a higher ADG (978.7 vs. 893.9 g/d, $P < 0.001$) from 10 to 26 wk of age. Composition traits of total fat tissue (TOFAT), fat free total lean (FFTOLN), empty body protein (MTPRO), and empty body lipid (MTFAT) were calculated. Animal models with polynomial regression on wk on test were fitted to body weight, BF10, LRF, LMA, TOFAT, FFTOLN, MTPRO, and MTFAT from 10 to 26 wk of age for each breed of sire. Quartic polynomial models best fitted body weight, LMA, TOFAT, FFTOLN, and MTPRO, while cubic polynomial models adequately fitted BF10, LRF, and MTFAT. Duroc sired progeny had a greater linear increase in body weight, BF10, LRF, TOFAT, FFTOLN, MTPRO, and MTFAT

while Pietrain sired progeny had a greater linear increase in LMA. Both sire breeds have traits that can be utilized in commercial pork production and merit further study.

Introduction

Breeds and lines used in commercial production systems influence growth, composition, and meat quality. Good definitions of expected outcomes from different breeds and lines are needed by producers to contribute to their decisions regarding genetic programs. Characterization of growth parameters will provide the swine industry better decision tools for optimizing production potential.

While many breeds or lines are available to producers, novel populations that have not been used extensively may contain untapped potential. The Pietrain breed, a fairly new population to the United States, has been used and characterized in European production systems, but Pietrain pigs have yet to be fully evaluated in U.S. production systems. Some studies have compared Pietrain sired pigs with Duroc sired pigs for growth rate, but discrepancies in final weight measured have led to inconsistencies in differences for growth. One study reported faster growth in Pietrain pigs (Kanis et al., 1990), while another reported similar growth rate between these breeds (Ellis et al., 1996), and a third reported faster growth in Duroc pigs (Affentranger et al., 1996). Pietrain based animals tended to have less backfat (Kanis et al., 1990; Garcia-Macias et al., 1996) than Duroc based animals, but it was reported that differences diminished as animals were taken to heavier weights (Ellis et al., 1996). This study evaluated growth differences of Duroc versus Pietrain progeny, using higher ending weights characteristic of current U.S. production systems.

Growth curves can be useful to describe an animal or population genetic potential for the complete time period considered. Random regression models serve as effective tools to reduce the number of traits to be handled for those traits measured over a continuous time (Meyer, 1998). Serial live measurements, such as ultrasound measurements, allow functions of protein and fat accretion to be developed for differing genotypes of pigs. These measurements need to be collected before, during, and after the weight interval of interest to avoid errant predictions at the ends of the test period caused by extreme data points (Schinckel and de Lange, 1996). Application of these models allows separation of between and within animal variation through the introduction of random effects. Accurate evaluations of growth and composition traits allow proper management of genetics, nutrition, and other production decisions.

Materials and Methods

Data Collection

Sires from Duroc or Pietrain populations were used to produce 413 crossbred progeny for this study, born between October 24, 1997 and May 7, 1999. All boars used were homozygous normal for the ryanodine receptor gene. Duroc sires were restricted to rank within the top 40% of the breed, at time of use, for Terminal Sire Index as reported by the National Swine Registry. An effort was made to sample Duroc boars from different genetic families to obtain a cross-section of the breed. Pietrain boars were from a closed herd whose ancestors were imported to the United States from Germany. This population was homozygous normal at the ryanodine receptor locus. A total of 23 litters from 23 Duroc sires and 23 litters from 16 Pietrain sires were evaluated.

Dams for this study were housed at the Michigan State University Swine Teaching & Research Farm. Yorkshire and F_1 Yorkshire-Landrace females within parity and breed classification subgroup were randomly assigned to be single sire mated artificially to either Duroc or Pietrain boars. Four farrowing groups were used to obtain pigs used in this study. Pigs were individually identified at birth. Table 6 shows number of pigs by sire breed, dam breed, and gender subclass. Birth date, birth weight, weaning weight, and lactation length (mean of 24.7 d of age) were recorded.

At weaning, pigs were sorted into sire breed, gender, and weight subgroups and randomly assigned to nursery pens. Pigs were provided diets on an ad libitum basis that met or exceeded nutritional requirements (NRC, 1998) for each production stage. Pig weights were taken at six wk of age and again at 10 wk of age. After 10 wk of age, pigs representative of each litter (Table 6) were taken to a grow-finish facility and randomly assigned to pens in groups of four sorted by sire breed, gender, and weight. Pig weights and B-mode ultrasound estimates of off-midline backfat at the tenth rib (BF10), off-midline last rib fat (LRF), and loin muscle area at the tenth rib (LMA) were measured at 10, 13, 16, 19, 22, 24, and 26 wk of age. Pigs were scanned by a National Swine Improvement Federation certified ultrasound technician. During nursery and grow-finish phases of growth, feed disappearance was measured on a pen basis to calculate gain to feed efficiency.

Table 6. Sire breed, dam breed, and gender subclass numbers for growth.

	Duroc				Pietrain					
	Barrows		Gilts		Barrows		Gilts		Total	
	B	T	B	T	B	T	B	T	B	T
Yorkshire	39	24	41	31	39	23	39	27	158	105
Yorkshire-Landrace	65	46	70	55	67	54	53	47	255	202
Total	104	70	111	86	106	77	92	74	413[a]	307[b]

B = Birth
T = On test
[a, b] total pigs at birth and put on test, respectively

Growth Response Variables

Pig weight at birth, weaning (three wk of age), six wk of age, 10 wk of age, and 26 wk of age were analyzed along with BF10, LRF, and LMA at 26 wk of age. Percent fat-free lean (FFL%) was calculated from weight, gender, BF10, and LMA at 26 wk of age (NPPC, 2000). In addition, average daily gain from 10 to 26 wk of age (ADG1026) was calculated. Least squares means were calculated using the following model:

$$Y_{ijklm} = \mu + bos_i + bod_j + sex_k + rep_l + bos*sex_{ik} + id_m + cov + e_{ijklm}$$

where

Y_{ijklm} = record on the m^{th} pig within the i^{th} sire breed, j^{th} dam breed, k^{th} gender, and l^{th} farrowing group,
μ = overall mean of trait,
bos_i = fixed effect of sire breed i (Duroc or Pietrain),
bod_j = fixed effect of dam breed j (Yorkshire or F_1 Yorkshire-Landrace),
sex_k = fixed effect of gender k (Barrow or Gilt),
rep_l = fixed effect of farrowing group l (1, 2, 3, or 4),
$bos*sex_{jk}$ = interaction of fixed effects of sire breed j and gender k of animal,
id_m = random effect of animal m ~$N(\mathbf{0}, \mathbf{A}\sigma_a^2)$,
cov = covariate(s) appropriate to each trait,
e_{ijklm} = random error ~$N(\mathbf{0}, \mathbf{I}\sigma_e^2)$.

The (co)variance matrix for the random animal effect was $\mathbf{A}\sigma_a^2$, where **A** was the numerator relationship matrix among animals. This matrix included all animals in pedigrees for paternal and maternal grandsires and grandams of boars that sired progeny and sires and dams of females that farrowed litters.

The covariate used for birth weight was number of pigs born in the litter. For many traits a covariate (ADJDAYS) to adjust for age at measurement was used. It was calculated by subtracting an animal's actual age from a pre-set age of measurement. For example, if an animal was 72 d old and the pre-determined measurement age was 70, this covariate was two. For weaning weight, number of pigs weaned from each litter and ADJDAYS were used as covariates. For each measurement of weight and ultrasound estimates ADJDAYS was used as a covariate. The covariate for ADG1026 was ADJDAYS at the 10 wk weighing. Feed efficiency was analyzed on a pen basis using a model with fixed effects of farrowing group, breed of sire, gender, and a term for interaction of breed of sire by gender.

Regression Analysis

Serial weight and ultrasound estimates were used to generate polynomial equations to model pig weight, BF10, LRF, and LMA on age at measurement. Additionally, measures of total fat tissue (TOFAT), fat free lean tissue (FFTOLN), empty body protein (MTPRO), and empty body lipid (MTFAT) at different weight ranges (A. P. Schinkel, unpublished data) were calculated. These measures of fat deposition and protein accretion were modeled on age of measurement by polynomial random regression. Age at measurement was modeled as wk on test to lessen round off error of regression coefficients. Week on test was calculated as age in wk minus nine, which resulted in 1, 4, 7, 10, 13, 15, and 17 wk on test as distinct covariate values used in the analysis.

The model for each trait was tested to determine the proper order of regression on age using a type III sums of squares F-test with terms added consecutively. Models for BF10, LRF, and MTFAT contained linear, quadratic, and cubic regression on age that were significant, while models for pig weight, LMA, TOFAT, FFTOLN, and MTPRO additionally contained a quartic regression on age. Wagner et al. (1999) reported a linear order model best fit tenth rib 3/4 fat depth while a quadratic model best fit loin muscle area, empty body protein, and fat-free lean. This study also found a quadratic effect for last rib backfat and empty body lipid. Andersen and Pedersen (1996) found a quartic order model to best describe weight gain. Different intercepts and linear regression coefficients on age for each sire breed were obtained for the measures with the Pietrain by age factor set to zero to allow design matrices to be full-rank and all parameters to be identifiable. Higher polynomial orders on age were the same for both breeds. A random linear regression on age for animal was included in each model. Higher order terms of animal by age were non-significant. The following model was used:

$$Y_{ijklm} = \mu + bos_i + bod_j + sex_k + rep_l + bos * sex_{ik} + id_m + \sum_{n=1}^{4} \delta_n z_{ijkln} + \beta z_{ijkl} + \alpha_m z_{ijkl} + e_{ijklm}$$

where

Y_{ijklm} = record on the m^{th} pig within the i^{th} sire breed, j^{th} dam breed, k^{th} gender, and l^{th} farrowing group,
μ = overall mean of trait,
bos_i = fixed effect of sire breed i (Duroc or Pietrain),
bod_j = fixed effect of dam breed j (Yorkshire or F_1 Yorkshire-Landrace),
sex_k = fixed effect of gender k (Barrow or Gilt),
rep_l = fixed effect of farrowing group l (1, 2, 3, or 4),
$bos*sex_{jk}$ = interaction of fixed effects of sire breed j and gender k of animal,
id_m = random effect of animal m,
δ_n = fixed regression coefficient for age for n^{th} polynomial term,
β = difference in linear response between Duroc and Pietrain,
α_m = random linear regression coefficient on age for animal m,
e_{ijklm} = random error.

A numerator relationship matrix was used to fit a variance structure for the animal term in the model. A genetic covariance between the animal term and the animal by age term was also fitted in the model. To account for repeated measures from serial measurement, the error (co)variance was fit as a heterogeneous, autoregressive (co)variance structure.

Results and Discussion

Growth Estimates

Least squares means, standard errors of mean (SEM), and significance levels for sire breed for response variables are listed in Table 7. No significant differences were seen between breed of sire for birth, three wk, six wk, or ten wk weights. A significant difference was seen for weight at 26 wk of age, with heavier Duroc sired progeny ($P < 0.001$). Differences between sire breeds for BF10 and LRF were significant ($P < 0.001$) with Duroc sired progeny having more fat at both locations. These results are in agreement with findings by Kanis et al. (1990) that found Duroc animals to have more backfat than Pietrain animals at 60kg (10.5 vs. 8.7 mm), at 100 kg (17.5 vs. 12.3 mm), and at 140 kg (24.4 vs. 17.4 mm). Similar results were also reported by Ellis et al. (1996) with Duroc sired progeny having fatter carcasses than Pietrain progeny from pigs slaughtered at 80, 100, or 120 kg (mean C fat depths of 15.6 vs. 14.0 mm). Garcia-Macias et al. (1996) also reported more backfat measured between third and fourth last ribs (19.84 vs. 17.16 mm) for Duroc progeny versus Pietrain progeny slaughtered at 90 and 120 kg. Pietrain sired progeny tended ($P < 0.10$) to have a larger loin muscle area, differing from reports from other studies of Pietrain progeny having significantly larger LMA, 40.7 vs. 39.0 cm^2 (Ellis et al., 1996) and 40.51 vs. 36.77 cm^2 (Garcia-Macias et al., 1996). The FFL%, calculated at 26 wk of age, was higher for Pietrain sired progeny ($P < 0.001$), as was reported by Kanis et al. (1990) with 56.1% vs. 52.7% at 100 kg and 52.2% vs. 50.4% at 140 kg. A heavier 26 wk weight for Duroc sired progeny, coupled with similar 10 wk weights for pigs from each sire breed, led to Duroc sired progeny with greater ADG1026 ($P < 0.001$), which was in agreement with the study by Affentranger et al. (1996) that reported 20 g/d more weight gain in Duroc progeny compared to Pietrain progeny. These results contrasted with Ellis et al. (1996) (764 g/d for Duroc progeny vs. 753 g/d for Pietrain progeny, but not statistically different) and with results of Kanis et al. (1990) (greater daily gain for Pietrain progeny vs. Duroc progeny, 730 g/d vs. 628 g/d). Least squares means, standard errors of mean (SEM), and significance levels for sire breed for feed efficiency are listed in Table 8. No significant differences were seen for feed efficiency at any of the time periods measured. Kanis et al. (1990) reported a difference in feed efficiency from 60 to 100 kg body weight (3.37 vs. 3.18 feed/gain for Duroc and Pietrain progeny, respectively), but no difference was reported from 100 to 140 kg (4.45 vs. 4.71) or for the entire test from 60 to 140 kg (3.89 vs. 4.00). Affentranger et al. (1996) reported worse feed conversion from 25 to 103 kg (2.75 vs. 2.59) for Duroc progeny.

Table 7. Least squares means of weight, ultrasound estimates, weight gain data, and fat-free lean percentage.

Trait [a]	Duroc	Pietrain	SEM	P-value
Birth weight, kg	1.61	1.72	0.078	0.145
3 wk weight, kg	7.75	7.56	0.303	0.307
6 wk weight, kg	14.75	14.52	0.544	0.362
10 wk weight, kg	31.43	30.95	1.007	0.347
26 wk weight, kg ***	143.21	132.97	1.516	<0.001
26 wk BF10, mm ***	27.26	23.67	0.654	<0.001
26 wk LRF, mm ***	21.59	19.23	0.510	<0.001
26 wk LMA, cm^2 †	45.93	46.97	0.605	0.089
FFL% (26 wk) ***	48.06	50.30	0.349	<0.001
ADG1026, g/d ***	978.97	895.15	11.355	<0.001

[a] Significance: †=P < 0.10, *=P < 0.05, **=P < 0.01, ***=P < 0.001

Table 8. Least squares means of pen feed efficiency (feed/gain).

Trait [a]	Duroc	Pietrain	SEM	P-value
3-6 wk	1.69	1.75	0.067	0.517
6-10 wk	1.86	1.81	0.034	0.268
10-13 wk	2.40	2.49	0.064	0.321
13-16 wk	2.74	2.68	0.051	0.414
16-19 wk	3.14	3.14	0.065	0.945
19-22 wk †	3.48	3.32	0.067	0.096
22-24 wk	3.91	3.66	0.131	0.193
24-26 wk	3.94	4.15	0.152	0.346

[a] Significance: †=P < 0.10, *=P < 0.05, **=P < 0.01, ***=P < 0.001

Regression Analysis

Parameter estimates for each of the eight response variables modeled (body weight, BF10, LRF, LMA, TOFAT, FFTOLN, MTPRO, and MTFAT) appear in Table 9. Initial measures at the beginning of the test period for Duroc sired progeny were greater, but non-significant (P > 0.10), for BF10 and LRF. Pietrain sired progeny had higher, but non-significant (P > 0.10), initial measures of body weight, LMA, TOFAT, FFTOLN, MTPRO, and MTFAT. The intercept and linear term for each breed of sire by age created differences in the growth and composition curves between progeny of each sire breed. Duroc sired progeny had a greater linear increase in body weight, BF10, LRF, TOFAT, FFTOLN, MTPRO, and MTFAT while Pietrain sired progeny had a greater linear increase in LMA.

Graphs of equations for each response variable were plotted by sire breed (Figures 1 through 8). Unlike linear estimates of summary statistics (i.e. average daily gain), these regressions represent changes in the patterns of accretion and deposition curves over time. Figure 1 is the regression of body weight on wk on test. At the beginning of test both sets of progeny were similar in weight, but Duroc sired progeny grew at a faster rate and were heavier at the end of test. Figures 2 and 3 (BF10 and LRF, respectively) indicate that Duroc sired progeny had a greater rate of backfat deposition. Duroc progeny had greater amounts of BF10 and LRF at all time points during the test. Loin muscle area (Figure 4) was greater at all points for Pietrain sired progeny, but was not significant. Rate of LMA accretion slowed near the end of the test period. A sigmodial shape is apparent for TOFAT (Figure 5). Both sets of progeny started with similar amounts of TOFAT, but Duroc sired progeny increased TOFAT at a greater rate than Pietrain sired progeny. At the end of the test Duroc progeny had a larger amount of TOFAT (P < 0.001). The regression of FFTOLN on wk on test in Figure 6 shows that rate of FFTOLN accretion for both sets of progeny slowed near the end of the test period. Pietrain progeny had more FFTOLN at the beginning of the test, but by the end of the test, both sets of progeny were similar for FFTOLN (P > 0.29). Kanis et al. (1990) also reported Pietrain animals had a higher lean tissue growth rate than Duroc animals from 60-100 kg, but no difference was seen from 100-140 kg. Both sets of progeny had similar MTPRO (Figure 7) at the beginning of test, but Duroc progeny had more MTPRO at the end of the test ($P < 0.001$). Rate of fat deposition was again seen to increase during the test period for MTFAT (Figure 8). Both sets of progeny had similar MTFAT at start of test, but Duroc progeny had more MTFAT at end of test ($P < 0.001$). Individual curves could be created for each animal for all of these traits, but were not pursued further in this study.

Implications

Accurate evaluation of growth and composition traits is essential to decision making within breeding programs. Single time point (e.g. backfat at a certain age) and summary estimates (e.g. average daily gain over a time period) of characteristics that occur over time are useful; however, they will not properly distinguish nuances that occur over time. Use of serial measurement and random polynomial modeling can further distinguish subtle differences between breeds and lines that occur during the growth phase. In this study pigs were grown to weights that were larger than those seen within industry to properly capture nuances in growth and composition curves.

Duroc sired progeny grew at a faster rate from 10 to 26 wk of age, but were similar in weight to Pietrain sired progeny from birth to 10 wk of age. Pietrain sired progeny were leaner at the tenth rib and last rib throughout the growth period. Loin muscle area and feed efficiency were similar for progeny of both breeds, which differed from earlier studies reporting Pietrain animals to have larger loin muscle area (Ellis et al., 1996; Garcia-Macias et al. 1996) and better feed efficiency (Affrentranger et al., 1996;

Kanis et al., 1990). These studies all used Pietrain pigs with the mutant ryanodine receptor gene. Since Duroc progeny had a greater rate of backfat deposition, they also had a higher rate of total fat tissue deposition. An important measure of production efficiency, that was nearly identical for both sets of progeny, was rate of fat free total lean accretion. Growth rate of Duroc progeny and leanness of Pietrain progeny counterbalanced each other to create similar curves.

Both breeds can be useful in different breeding schemes. As market weights increase, progeny from both breeds will have similar amounts of fat free total lean; Duroc progeny from faster weight gain, while Pietrain progeny will be leaner. Other factors, including meat quality traits, should also factor into choosing terminal sires. Both breeds merit further study into the genetic control of these economically important traits.

Table 9. Coefficients for regression terms.[a]

Trait	Duroc Intercept	Pietrain Intercept	Age	Age^2	Age^3	Age^4	Duroc * age
Body wt (kg)	23.68**	25.00**	6.268**	-0.1623**	0.02354**	-0.0008115**	0.4905**
BF10 (mm)	6.877**	6.534**	0.1219	0.08526**	-0.001978**	NA	0.1105*
LRF (mm)	5.525**	5.314**	0.1955**	0.04849**	-0.0007664**	NA	0.06453†
LMA (cm^2)	11.91**	13.04**	0.7445**	0.4748**	-0.04214**	0.001098**	-0.07495†
TOFAT (kg)	4.050**	4.625**	3.602**	-0.6217**	0.09518**	-0.003263**	0.3221**
FFTOLN (kg)	17.91**	19.93**	6.722**	-0.2699**	0.02990**	-0.001135**	0.09093
MTPRO (kg)	6.758**	7.261**	2.894**	-0.1968**	0.01857**	-0.0005739**	0.1036**
MTFAT (kg)	5.669**	6.645**	0.4521**	0.3542**	-0.007755**	NA	0.3085**

[a] Significance: †=P < 0.10, *=P < 0.05, **=P < 0.01
Age = weeks on test (1, 4, 7, 10, 13, 15, 17)
NA = term not included in model

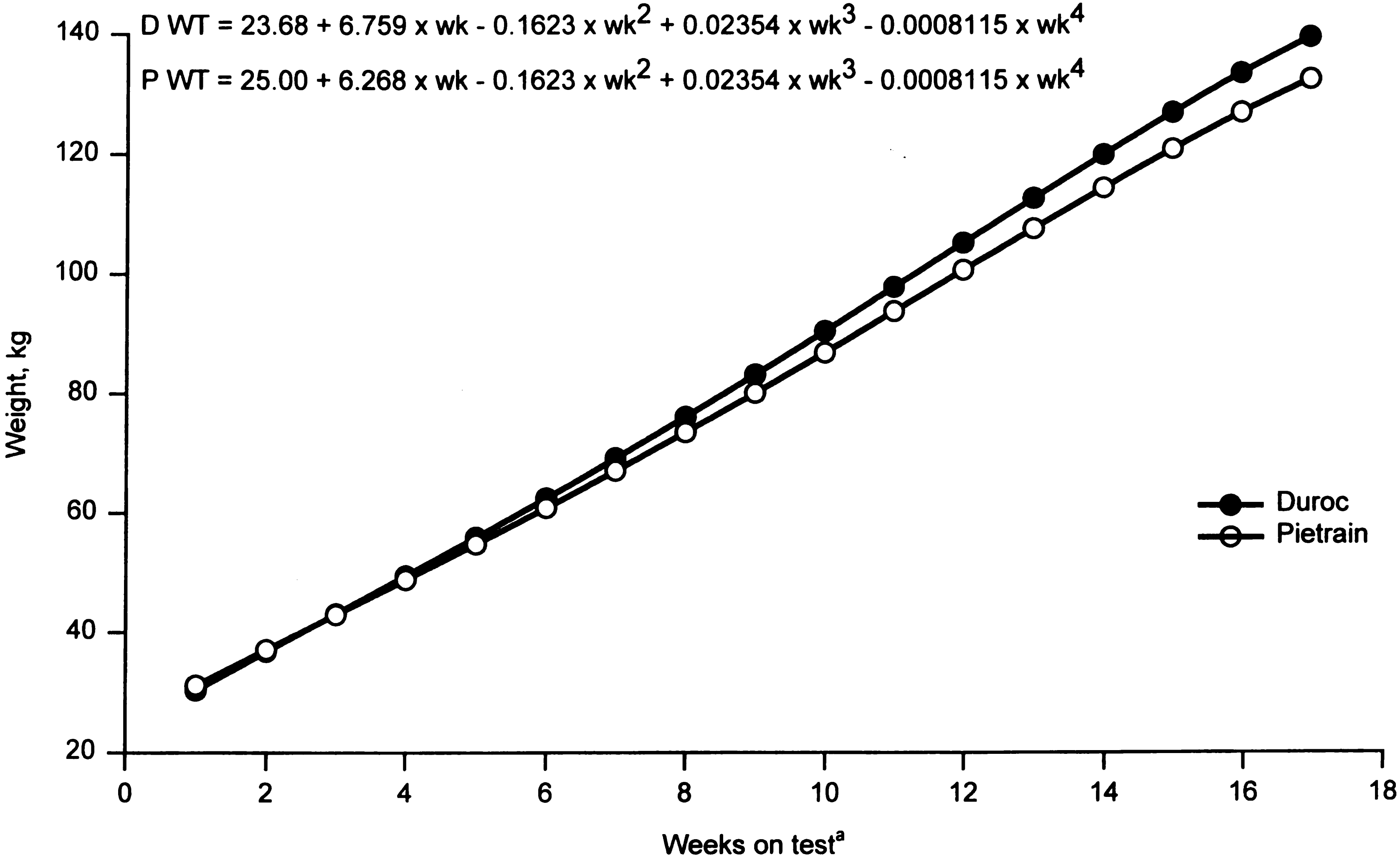

Figure 1. Regression of body weight on weeks on test.
[a]Weeks on test = age (wk) - 9

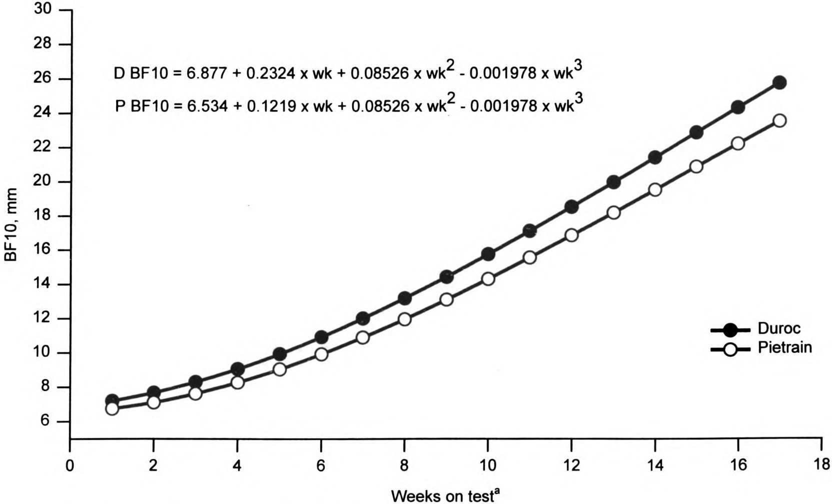

Figure 2. Regression of 10th rib backfat (BF10) on weeks on test.
[a]Weeks on test = age (wk) - 9

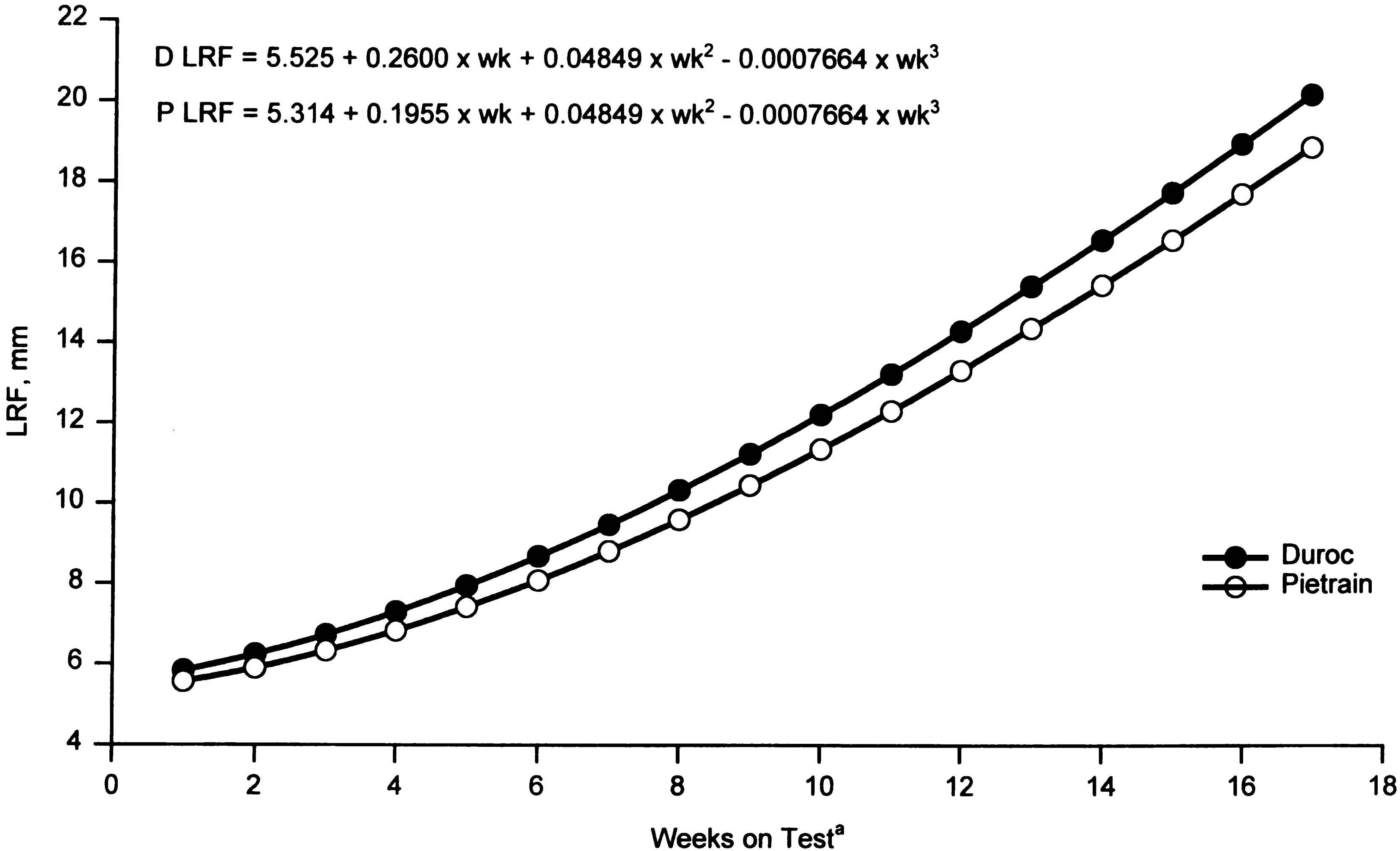

Figure 3. Regression of last rib backfat (LRF) on weeks on test.
[a]Weeks on test = age (wk) - 9

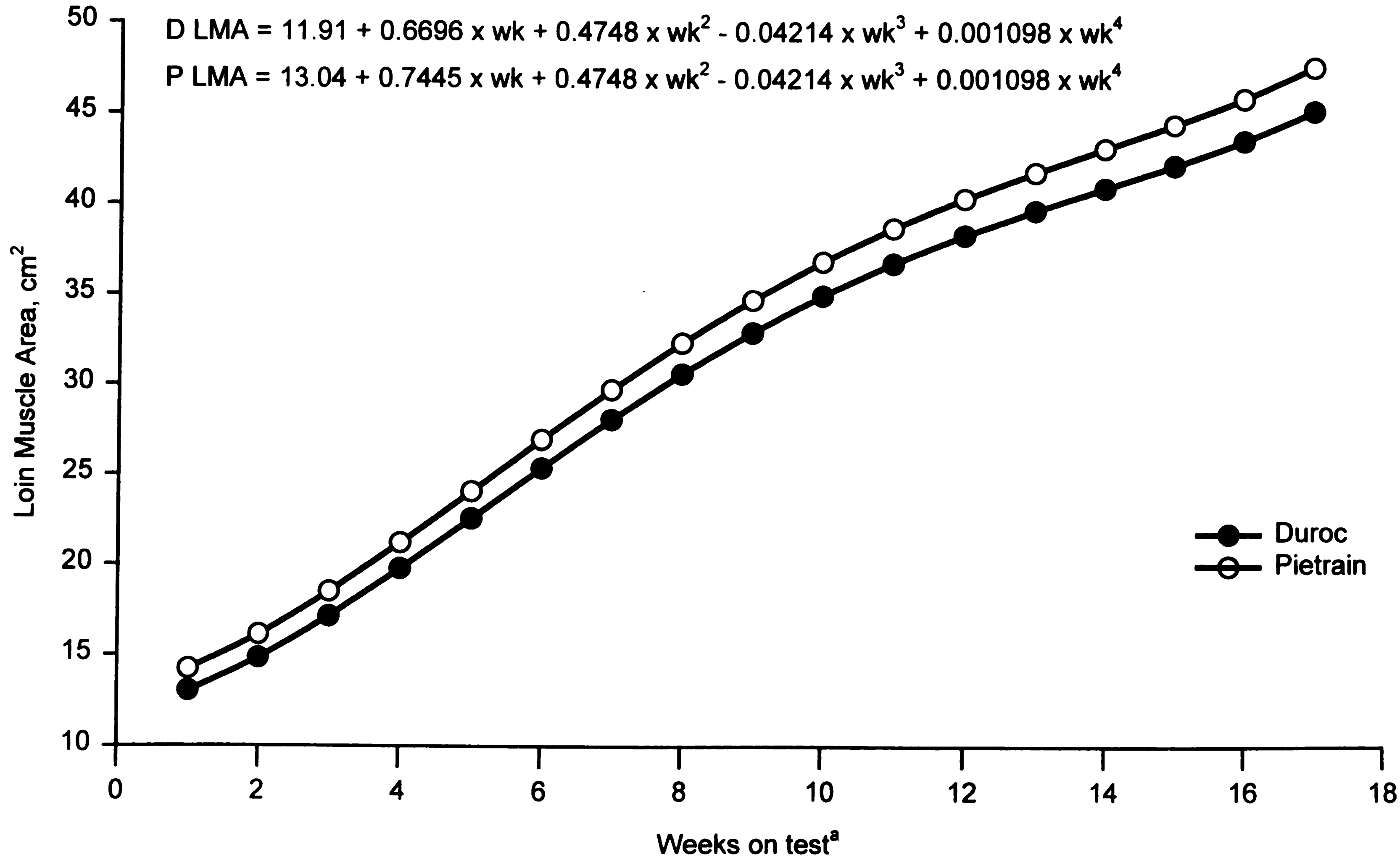

Figure 4. Regression of loin muscle area (LMA) on weeks on test.
[a]Weeks on test = age (wk) - 9

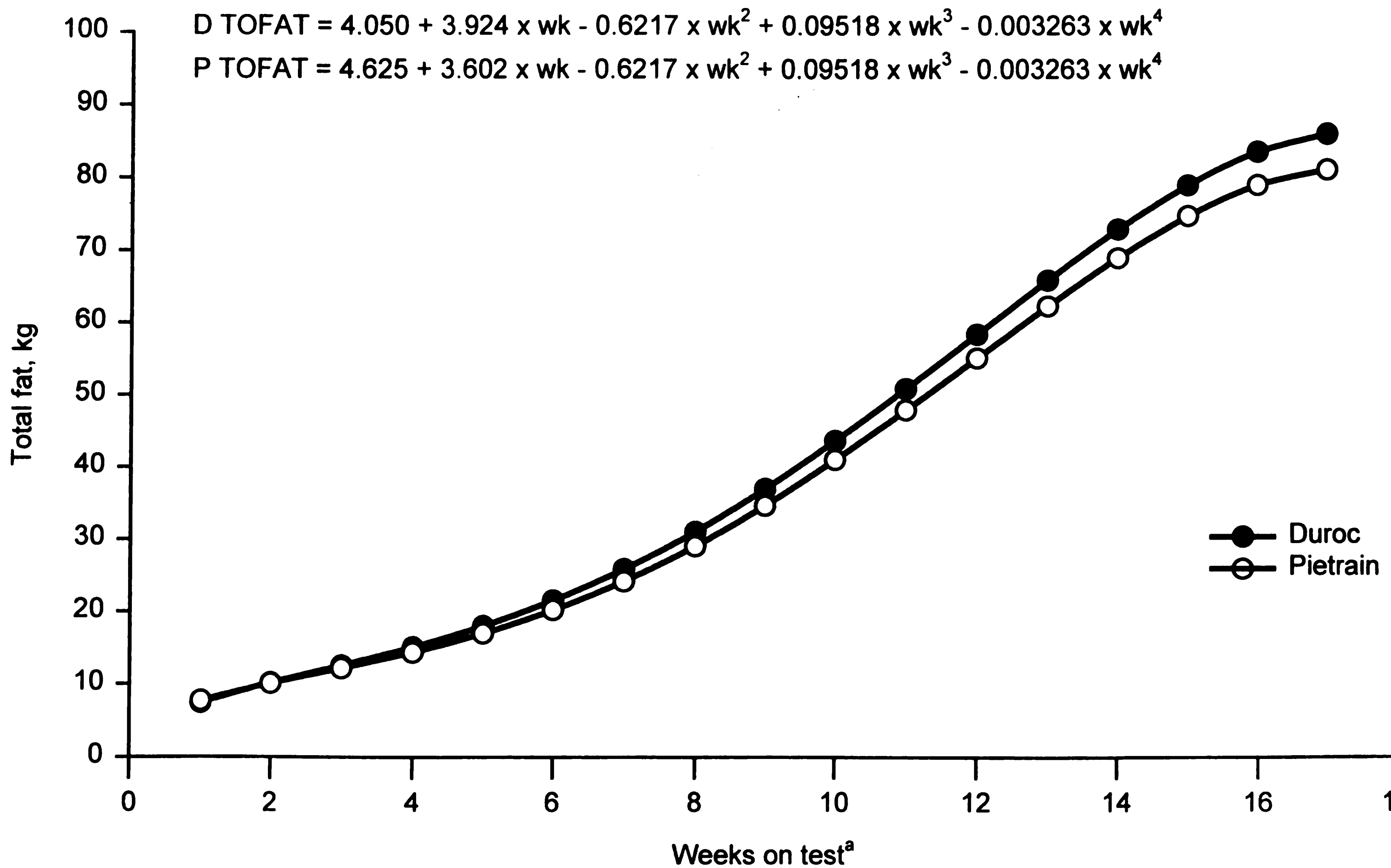

Figure 5. Regression of total fat (TOFAT) on weeks on test.
[a]Weeks on test = age (wk) - 9

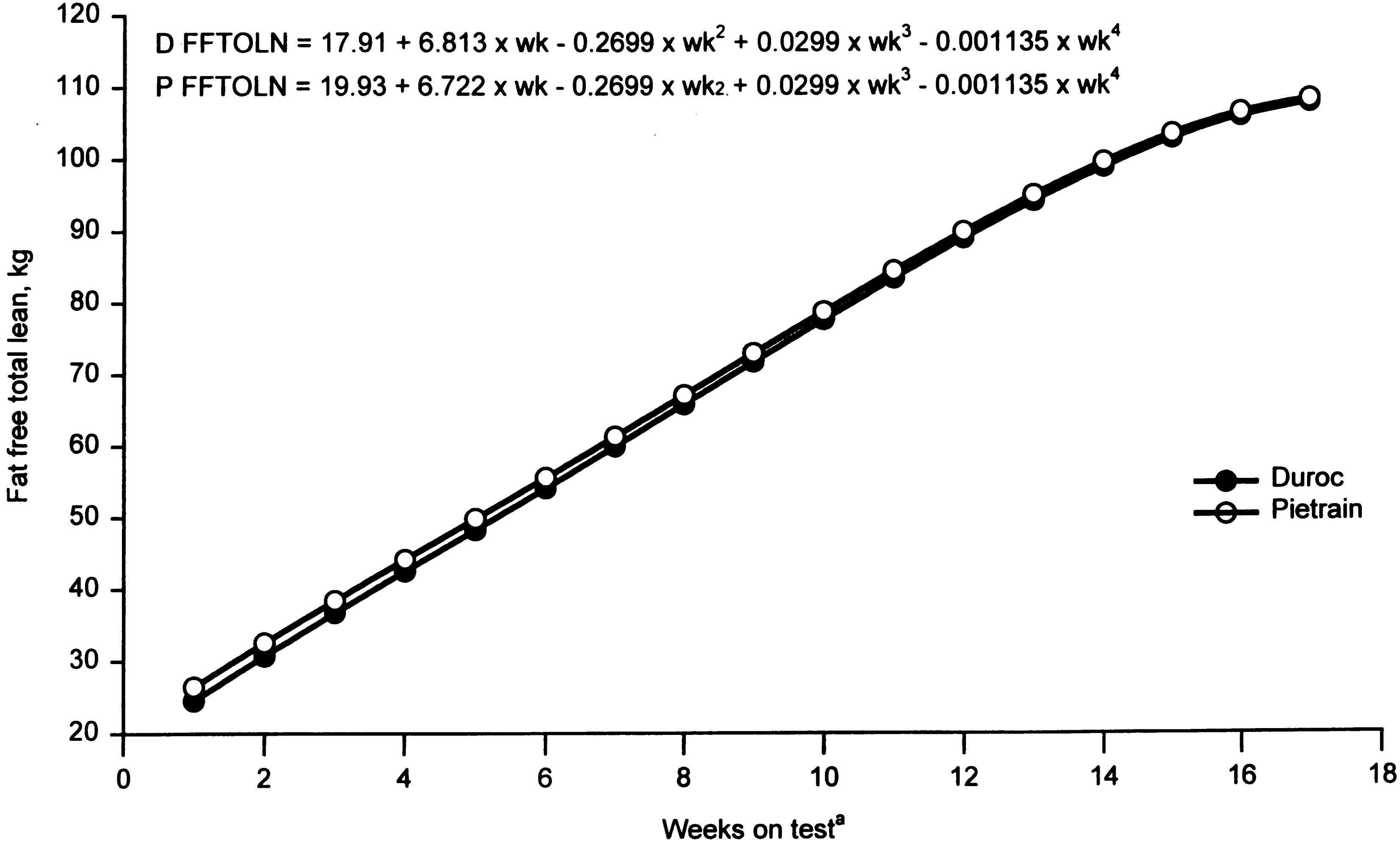

Figure 6. Regression of fat free total lean (FFTOLN) on weeks on test.
[a]Weeks on test - age (wk) - 9

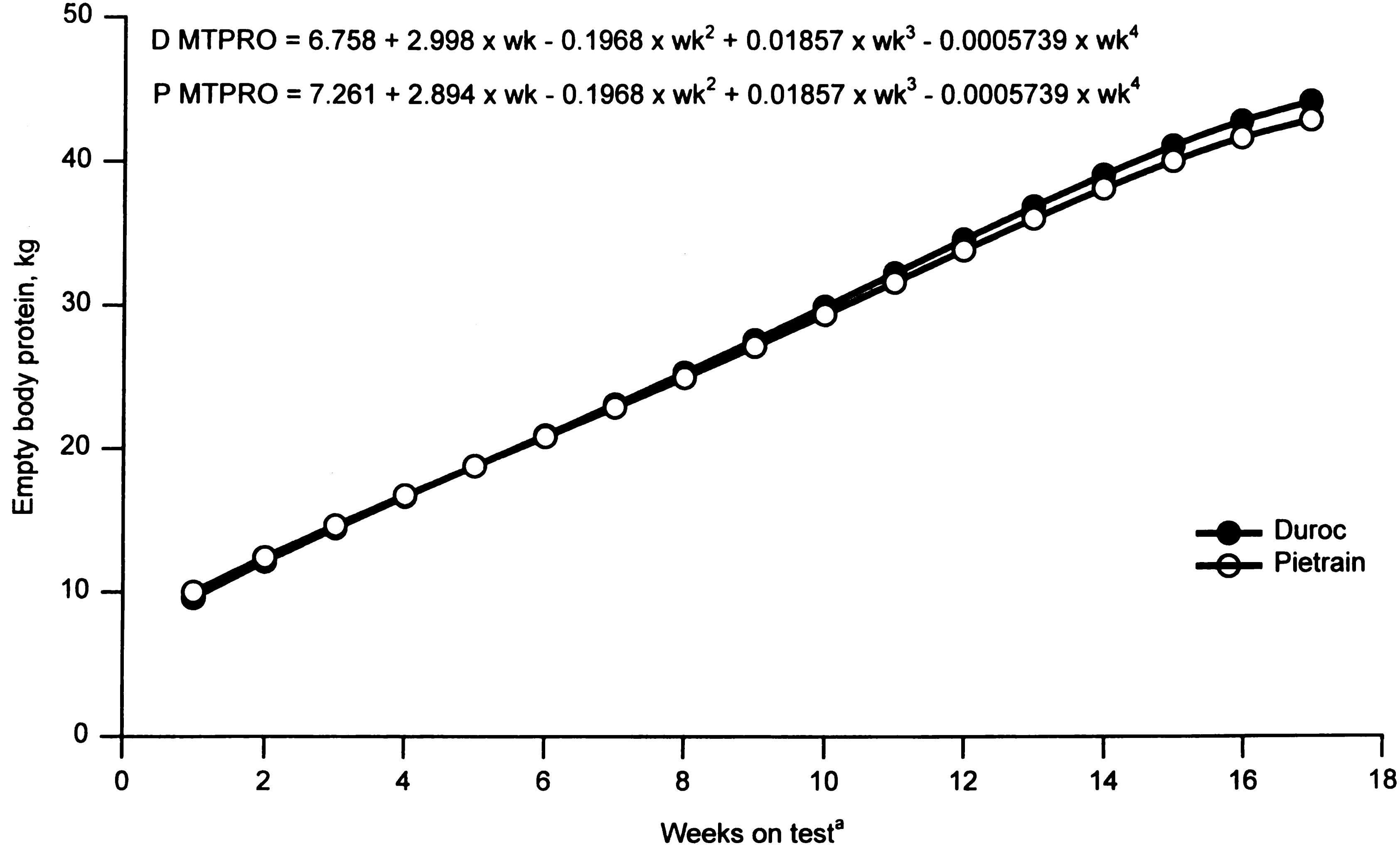

Figure 7. Regression of empty body protein (MTPRO) on weeks on test.
[a]Weeks on test = age (wk) - 9

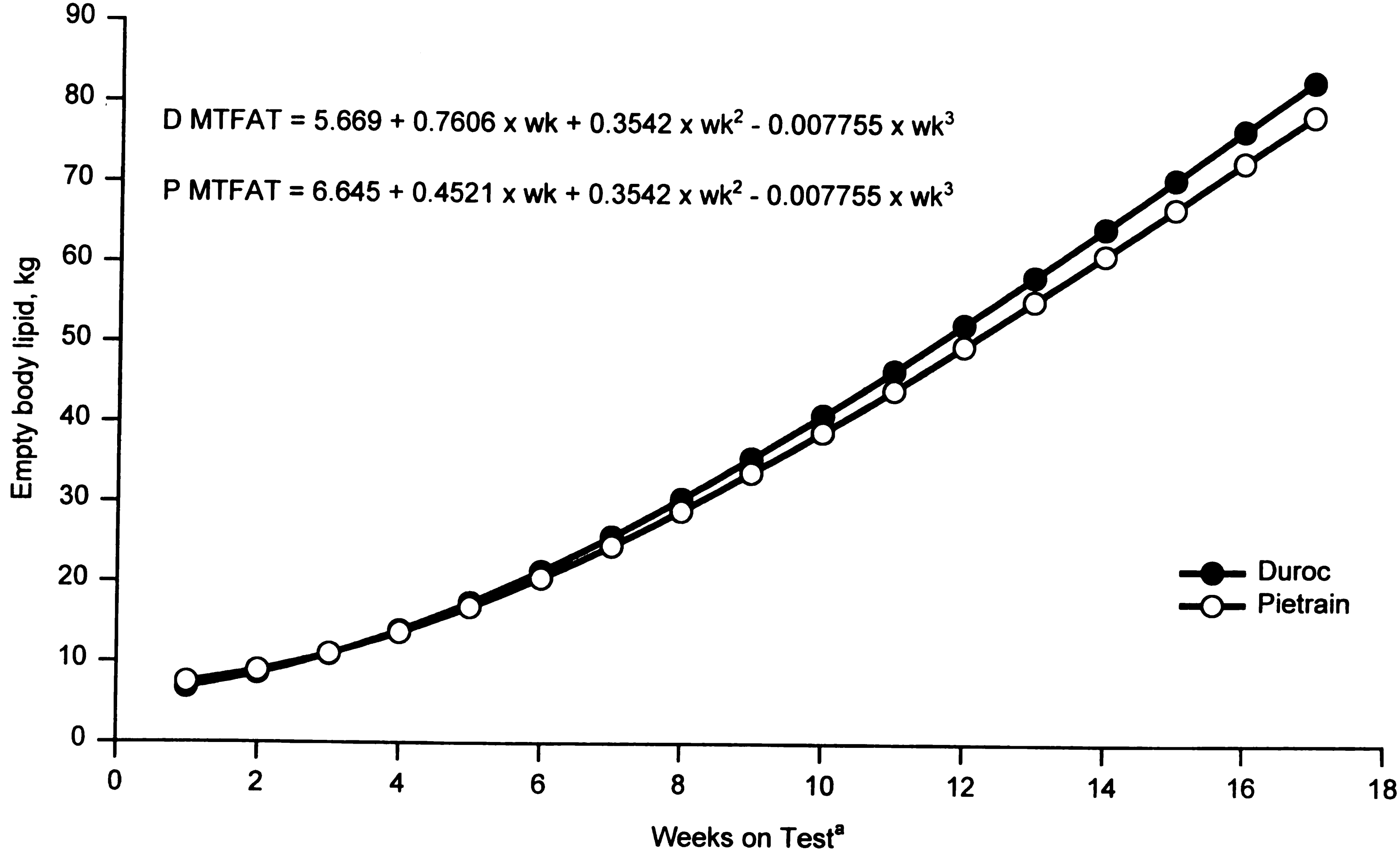

Figure 8. Regression of empty body lipid (MTFAT) on weeks on test.
[a]Weeks on test = age (wk) - 9

CHAPTER III

CARCASS AND MEAT QUALITY MEASURES

Abstract

Crossbred progeny sired by either Duroc or Pietrain boars, normal for the ryanodine receptor gene, were used in this study. Boars from each breed were mated to Yorkshire or F_1 Yorkshire-Landrace females. A total of 162 offspring were evaluated for carcass and meat quality traits. Duroc sired progeny had higher carcass weight (107.95 vs. 102.98 kg, $P < 0.001$) and were longer (86.91 vs. 84.78 cm, $P < 0.01$), while Pietrain sired pigs had less back fat at the first rib (44.55 vs. 47.65 mm, $P < 0.01$), last lumbar vertebrae (20.85 vs. 22.96 mm, $P < 0.05$), and tenth rib (23.04 vs. 25.48 mm, $P < 0.01$). No difference between Pietrain and Duroc progeny was seen for fat depth at the last rib (27.79 vs. 28.75 mm, respectively). Pietrain progeny had a higher percent lean at slaughter (52.60 vs. 50.74, $P < 0.05$) and higher dressing percentage (73.96 vs. 73.08, $P < 0.01$). Primal cut weights were collected with Pietrain progeny having a larger percentage of carcass as ham (23.02 vs. 22.44, $P < 0.01$) and loin (21.59 vs. 21.21, $P < 0.05$), while Duroc progeny had a larger percentage for bellies (11.99 vs. 11.66, $P < 0.05$). Percentages of Boston butt (8.80 vs. 8.96) and picnic shoulder (9.85 vs. 9.91) were similar for Duroc versus Pietrain progeny. Total weight of these five primal cuts, as a percentage of carcass weight, was larger for Pietrain progeny (75.16 vs. 74.25, $P < 0.01$). With higher carcass weight, Duroc progeny had higher primal cut weights as a function of age. Subjective meat quality scores for color, marbling, and firmness (1-5 scale, NPPC, 1991) were more favorable for Duroc sired progeny. Furthermore Duroc progeny had higher 24-h pH (5.526 vs. 5.468, $P < 0.001$) and less percent drip loss (2.892 vs.

3.893, $P < 0.001$). No differences were detected between Duroc and Pietrain sired progeny for Minolta L^* (54.764 vs. 55.307), a^* (17.348 vs. 17.272), or b^* (7.581 vs. 7.441) objective color scores, percent cooking loss (28.629 vs. 29.187), or Warner-Bratzler shear force (6.942 vs. 7.095 kg). Both sire breeds have beneficial traits that can be utilized in commercial pork production and merit further study.

Introduction

Maintaining acceptable meat quality in the pork industry is an important issue. Selection for growth and leanness while maintaining meat quality is a challenge because of the decrease in meat quality with leaner, faster growing pigs at heavier slaughter weights (Cisneros et al., 1996). Different breeds and lines have predetermined propensity towards excellence in certain areas of growth, composition, and meat quality (McLaren et al., 1987a; Ellis et al., 1996; Moeller et al., 1998; and many other studies). Reporting these differences will allow pork producers to make seedstock choices to fit their production and marketing program.

Novel populations may contain untapped potential for improvement in composition and meat quality traits. The Pietrain breed is a novel population that has been used in Europe, but has not been used extensively within the United States. Differences have been reported in meat quality measures of pH at 24 h post-slaughter, marbling, and water holding capacity with Duroc sired progeny having advantages over Pietrain sired progeny in these traits (Affentranger et al., 1996; Ellis et al., 1996; Garcia-Macias et al., 1996). All of these studies have included Pietrain animals that contained at least one copy of the mutant ryanodine receptor gene, which has detrimental effects on pork quality (Judge et al., 1992). Pietrain populations are now available that are homozygous normal at this locus. This study was conducted to evaluate ryanodine receptor gene normal crossbred progeny of Pietrain versus Duroc sires for composition and meat quality traits at weights used in U.S. production systems.

Materials and Methods

Data Collection

Sires from Duroc or Pietrain populations were used to produce 413 crossbred progeny for this study, born between October 24, 1997 and May 7, 1999. All boars used were homozygous normal for the ryanodine receptor gene. Duroc sires ranked within the top 40% of the breed for Terminal Sire Index as reported by the National Swine Registry. An effort was made to select Duroc boars from many distinct genetic families to sample across the breed. Pietrain boars were from a closed herd whose ancestors were imported to the United States from Germany. This herd is homozygous normal at the ryanodine receptor locus. A total of 23 litters from 23 Duroc sires and 23 litters from 16 Pietrain sires were evaluated.

Dams for this study were housed at the Michigan State University Swine Teaching & Research Farm. Yorkshire and F_1 Yorkshire-Landrace females within parity and breed classification subclass were randomly assigned to be single sire mated artificially to either a Duroc or Pietrain boar. Four farrowing groups were used to obtain pigs used in this study. Pigs were individually identified at birth.

At weaning (mean of 24.7 d of age), pigs were sorted into sire breed, gender, and weight subgroups and randomly assigned to nursery pens. Pigs were provided diets on an ad libitum basis that met or exceeded nutritional requirements (NRC, 1998) for each production stage. After 10 wk of age, pigs within two standard deviations of the mean weight (307 total) were taken to a grow-finish facility and randomly assigned to pens in groups of four sorted by sire breed, gender, and weight. After 26 wk of age, pigs near the mean weight within gender representative of each litter (162 total, Table 10) were slaughtered and carcass measurements and meat quality assessment completed.

Table 10. Sire breed, dam breed, and gender subclass numbers for carcass merit.

	Duroc		Pietrain		
	Barrows	Gilts	Barrows	Gilts	Total
Yorkshire	9	12	12	20	53
Yorkshire-Landrace	26	32	27	24	109
Total	35	44	39	44	162[a]

[a] total pigs used in carcass measurements

Pigs were fasted overnight and weighed prior to shipment of 150 km to slaughter. Pigs (n = 130) were slaughtered at a small federally inspected plant in western Michigan (DeVries Meats, Coopersville, MI). The remaining animals (n = 32) were slaughtered at the Michigan State University Meats Laboratory. Carcass weights were obtained prior to chilling. Carcasses were allowed to chill approximately 24 h, and measurements were taken from one side. Data collected included carcass length, midline backfat at the first rib, last rib, and last lumbar vertebrae. During breakdown of the carcass into primal cuts, off-midline backfat at the tenth rib (BF10) and loin muscle area (LMA) was measured. From weight and carcass measures, dressing percentage and fat free lean percentage (FFL%) were calculated (NPPC, 2000).

Primal cut weights of the ham, closely trimmed loin, boston shoulder, picnic shoulder, and belly were obtained from one side. Percentage of each primal versus carcass weight was calculated. A ham-loin weight and percentage were also calculated.

A loin section (tenth to last rib) from each carcass was harvested, placed in an insulated cooler, packed with ice, and returned to the Michigan State University meats laboratory for fresh meat quality analysis. Immediately upon return, a small piece of each section was retained and frozen for 24-h pH analysis. Then the section was cut into 2.54 cm boneless chops. Two chops were allowed to bloom for 10 minutes and subjective scores (1-5) were assessed for each chop for color, marbling, and firmness (NPPC, 1991). Color scores ranged from 1 (pale pinkish gray) to 5 (dark purplish red). Marbling scores were 1 (devoid to practically devoid of marbling, < 2% intramuscular lipid) to 5 (moderately abundant, > 8% intramuscular lipid). Firmness scores were 1 (very soft and watery) to 5 (very firm and dry). Light reflectance scores for L^*, a^*, and b^* were obtained using a Minolta CR-310 colorimeter using a D65 light source with a 2-degree standard observer. Chops were then weighed and hung in sealed plastic bags for 24 hours at 4°C, then weighed again, for drip loss measurement. Two additional chops were vacuum packaged and frozen for later analysis of cooking loss and Warner-Bratzler (W-B) shear force. For cook loss measurements, each chop was thawed, weighed, cooked to 71°C internal temperature on Farberware open hearth electric broilers, cooled to room temperature, and weighed again. From these chops six cores (three cores from each chop) were taken parallel to the muscle fiber direction and W-B shear force measured.

Data Analysis

Least squares means by breed of sire for carcass weight, length, BF10, LRF, LMA, FFL%, dressing percent, and primal cut weights were estimated using the following model:

$$Y_{ijklm} = \mu + bos_i + bod_j + sex_k + slggrp_l + bos*sex_{ik} + id_m + agecov + e_{ijklm}$$

where

Y_{ijklm} = record on the m^{th} subject within the i^{th} breed of sire, j^{th} breed of dam, k^{th} gender, and l^{th} slaughter group,
μ = overall mean of trait,
bos_i = fixed effect of sire breed i (Duroc or Pietrain),
bod_j = fixed effect of dam breed j (Yorkshire or F1 Yorkshire-Landrace),
sex_k = fixed effect of animal's gender k (Barrow or Gilt),
$slggrp_l$ = fixed effect of slaughter group l (1, 2, 3, 4, or 5),
$bos*sex_{jk}$ = interaction of fixed effects of sire breed j and gender k of animal,
id_m = random effect of animal m $\sim N(\mathbf{0}, \mathbf{A}\sigma_a^2)$,
agecov = recentered covariate of age of animal,
e_{ijklm} = random error $\sim N(\mathbf{0}, \mathbf{I}\sigma_e^2)$.

The (co)variance matrix for the animal effect was $\mathbf{A}\sigma_a^2$, where **A** was the numerator relationship matrix among animals. It included all animals in pedigrees for paternal and maternal grandsires and grandams of boars that sired progeny and sires and dams of females that farrowed litters. A normalized covariate of age of animal minus mean age (193.8) and divided by standard deviation (3.39) was used in the model for all of these traits to account for age differences between animals at slaughter.

Least squares means for meat quality traits, including subjective color, marbling, and firmness scores, Minolta L*, a*, and b* readings, 24-h pH, drip loss, cook loss, and shear force were estimated using the same model as for carcass measurements but without the agecov variable. An additional term of pig was included in the model to fit the within pig variation from sample to sample. Shear force measurements had six samples per pig, while other meat quality measures had two samples per pig.

Results and Discussion

Carcass Traits

Least squares means, standard errors of mean (SEM), and significance levels for sire breed for carcass response variables are listed in Table 11. Duroc progeny were longer ($P < 0.01$), had more midline backfat at the first rib ($P < 0.01$), and more off-midline tenth rib backfat ($P < 0.01$). Midline backfat at the last lumbar was greater for Duroc progeny ($P < 0.05$). These results are in agreement with findings by Kanis et al. (1990) that found Duroc animals to have more backfat than Pietrain animals at 60kg (10.5 vs. 8.7 mm), at 100 kg (17.5 vs. 12.3 mm), and at 140 kg (24.4 vs. 17.4 mm). Similar results were also reported by Ellis et al. (1996) with Duroc sired progeny having fatter carcasses than Pietrain progeny from pigs slaughtered at 80, 100, or 120 kg (mean C fat depths of 15.6 vs. 14.0 mm). Garcia-Macias et al. (1996) also reported more backfat measured between third and fourth last ribs (19.84 vs. 17.16 mm) for Duroc progeny versus Pietrain progeny slaughtered at 90 and 120 kg. Pietrain progeny had larger loin muscle area ($P < 0.01$), similar to results from Ellis et al. (1996) of 40.7 vs. 39.0 cm^2 and Garcia-Macias et al. (1996) of 40.51 vs. 36.77 cm^2. Furthermore, Pietrain had higher dressing percentage ($P < 0.01$), which differed from results reported by Garcia-Macias et al. (1996), in which no difference was seen (811.8 g/kg for Pietrain progeny vs. 816.9 g/kg for Duroc progeny). Fat free lean percentage was also higher for Pietrain progeny ($P < 0.001$), as was reported by Kanis et al. (1990) with 56.1% vs. 52.7% at 100 kg and 52.2% vs. 50.4% at 140 kg. No significant difference between progeny of the two sire breeds was seen for midline backfat at the last rib, differing from that reported by Garcia-Macias et al. (1996) at the last rib (17.82 mm for Duroc progeny vs. 14.75 mm for Pietrain progeny).

Table 11. Least squares means of carcass measurements.

Trait [a]	Duroc	Pietrain	SEM	P-value
Length (cm) **	86.91	84.78	0.5508	0.001
First rib fat (mm) **	47.65	44.55	0.8428	0.003
Last rib fat (mm)	28.75	27.79	0.9059	0.199
Last lumbar fat (mm) *	22.96	20.85	0.7516	0.015
BF10 (mm) **	25.48	23.04	0.6594	0.003
LMA (cm^2) **	50.19	53.21	0.8892	0.004
FFL (%) ***	50.74	52.60	0.3868	<0.001
Dressing (%)**	73.08	73.96	0.0025	0.004

[a] Significance: †=P < 0.10, *=P < 0.05, **=P < 0.01, ***=P < 0.001

Table 12 contains least squares means, standard errors of mean (SEM), and significance levels by sire breed for primal cut response variables. Each of the primal cuts was reported as the weight from one side of the carcass. Percentage measurements were obtained by doubling primal cut weight and taking it as a percentage of hot carcass weight. Duroc sired progeny had a heavier (P < 0.001) carcass, which led to higher weights of primal cuts. However, as a percentage of carcass weight Pietrain sired progeny had larger hams (P < 0.01), similar to what Affentranger et al. (1996) reported (20.3% vs. 18.6%), but Garcia-Macias et al. (1996) reported no difference between ham percentage of progeny by Duroc or Pietrain. Pietrain progeny in this study had a larger loin percentage (P < 0.05), differing from results of Garcia-Macias et al. (1996), in which both groups had similar loin percentages. Therefore, Pietrain progeny also had a greater ham-loin percentage (P < 0.001). Additionally, Pietrain progeny had the five primal cuts as a greater percentage of carcass weight (P < 0.01). Duroc sired progeny had larger bellies (P < 0.05), which was the same (18.6% vs. 17.5%) as was shown by Affentranger et al. (1996), but not in agreement with Garcia-Macias et al. (1996), who reported larger bellies for Pietrain sired animals (93.1 g/kg vs. 99.1 g/kg). No significant differences were seen in boston shoulder or picnic shoulder percentages, similar to results of Garcia-Macias et al. (1996), but Affentranger et al. (1996) found Pietrain progeny to have greater percentage shoulder (11.5% vs. 11.2%).

Table 12. Least squares means of primal cut measurements.

Trait [a]		Duroc	Pietrain	SEM	P-value
Carcass wt	kg ***	107.95	102.98	0.9738	<0.001
Ham wt	kg *	12.08	11.81	0.1135	0.038
	% **	22.44	23.02	0.1951	0.008
Loin wt	kg *	11.46	11.10	0.1466	0.027
	% *	21.21	21.59	0.1722	0.041
Boston wt	kg †	4.75	4.61	0.0719	0.078
	%	8.80	8.96	0.1000	0.500
Picnic wt	kg *	5.30	5.08	0.0781	0.021
	%	9.85	9.91	0.1494	0.380
Belly wt	kg ***	6.48	6.03	0.0857	<0.001
	% *	11.99	11.66	0.1210	0.021
Ham-loin wt	kg **	23.54	22.93	0.2330	0.005
	% ***	43.64	44.60	0.2806	<0.001
Five primal	% **	74.25	75.16	.3157	0.002

[a] Significance: †=P < 0.10, *=P < 0.05, **=P < 0.01, ***=P < 0.001

Meat Quality Traits

Least squares means of meat quality measures, standard errors of mean (SEM), and significance levels by sire breed are listed in Table 13. Subjective color scores were higher for Duroc progeny (P < 0.05), differing from no differences seen in earlier studies (Ellis et al. 1996; Garcia-Macias et al., 1996). Objective Minolta L^*, a^*, and b^* values were not different, similar to results of Garcia-Macias et al. (1996). Subjective scores indicated that chops from Duroc sired progeny had more marbling (P < 0.001), similar to Ellis et al. (1996), and were more firm (P < 0.001). Furthermore, chops from Duroc progeny had higher 24-h pH ($P < 0.001$), much like results from Affentranger et al. (1996) (5.98 vs. 5.70) and from Garcia-Macias et al. (1996) (5.69 vs. 5.60). Drip loss was lower for Duroc sired progeny ($P < 0.001$), as was reported by Affentranger et al (1996) (74.8 μl vs. 91.7 μl of water lost in 120 s). No significant differences were seen for cook loss or for W-B shear force, where Ellis et al. (1996) reported lower W-B shear force for Duroc progeny (5.35 kg) as compared to Pietrain progeny (5.67 kg).

Table 13. Least squares means of meat quality measures.

Trait [a]	Duroc	Pietrain	SEM	P-value
Color (1-5) *	2.540	2.354	0.1065	0.041
Marbling (1-5) ***	2.425	1.739	0.0968	<0.001
Firmness (1-5) ***	2.615	2.295	0.0700	<0.001
Minolta L	54.764	55.307	0.5355	0.157
Minolta a	17.348	17.272	0.2043	0.356
Minolta b	7.581	7.441	0.2066	0.248
24-h pH ***	5.526	5.468	0.0141	<0.001
Drip loss (%) ***	2.892	3.893	0.2404	<0.001
Cook loss (%)	28.629	29.187	0.7047	0.215
W-B shear force (kg)	6.942	7.095	0.2140	0.238

[a] Significance: † = $P < 0.10$, * = $P < 0.05$, ** = $P < 0.01$, *** = $P < 0.001$

Implications

Proper characterization of carcass and meat quality traits is essential to the choice of terminal sire within a pork production and marketing system. Differences seen between progeny sired by either Duroc or Pietrain boars were much as reported in previous studies (Affentranger et al. 1996; Ellis et al., 1996; Garcia-Macias et al., 1996) with some exceptions of primal cut weights, subjective color score, and shear force. Pietrain sired progeny had less backfat and more fat free lean. Duroc progeny had longer carcasses that were heavier, which led to larger primal cut weights. Ham-loin percent was greater for Pietrain sired animals.

Meat quality measures were either not different or favored Duroc sired progeny. Subjective scores for color, marbling, and firmness showed that loin chops from Duroc progeny were darker, more marbled, and firmer. In addition, Duroc sired progeny had higher 24-h pH and lower percent drip loss. No differences were seen in shear force.

Traits from both breeds demonstrate genetic differences that could be useful in pork production systems. While carcass traits and meat quality are important, other traits such as growth and feed efficiency must also be considered. Both Duroc and Pietrain populations merit further study into the genetic control of these carcass composition and meat quality traits.

SUMMARY AND CONCLUSIONS

Duroc sired progeny were similar in weight to Pietrain sired progeny at birth, three wk, six wk, and 10 wk of age, but grew at a faster rate from 10 to 26 wk of age (978.97 vs. 895.15 g/d). Models of body component growth curves were developed for BF10, LRF, and MTFAT that contained linear, quadratic, and cubic regression on age, while models for pig body weight, LMA, TOFAT, FFTOLN, and MTPRO additionally contained a quartic regression on age. Different intercepts and linear regression coefficients on age for each sire breed were obtained for the eight measures with the Pietrain by age factor set to zero to allow design matrices to be full-rank and all parameters to be identifiable. Higher polynomial orders on age were the same for both breeds. A random term for animal by linear regression on age was included in each model. Higher order terms of animal by age were non-significant.

Pietrain sired progeny were leaner at the tenth rib (6.877 for Duroc intercept, 6.534 for Pietrain intercept, and 0.1105 for Duroc by age linear regression coefficient) and last rib (5.525 for Duroc intercept, 5.314 for Pietrain intercept, and 0.06453 for Duroc by age linear regression coefficient) throughout the growth period. Loin muscle area at 26 wk of age ($P > 0.088$) and feed efficiency ($P > 0.096$ at all time periods) were similar for progeny of both breeds, which differed from earlier studies reporting Pietrain animals to have larger loin muscle area (Ellis et al., 1996; Garcia-Macias et al. 1996) and better feed efficiency (Kanis et al., 1990; Affrentranger et al., 1996). These studies all used Pietrain pigs with the mutant ryanodine receptor gene.

In the present study, Duroc progeny had a greater rate of backfat deposition which led to a higher rate of total fat tissue deposition (Duroc by age linear regression coefficient of 0.3221). An important measure of production efficiency, that was nearly identical for both sets of progeny, was rate of fat free total lean accretion (Duroc by age linear regression coefficient of only 0.09093). Growth rate of Duroc progeny and leanness of Pietrain progeny counterbalanced each other to create similar lean accretion curves.

Differences in carcass and meat quality traits seen between progeny sired by either Duroc or Pietrain boars were much as reported in previous studies (Affentranger et al. 1996; Ellis et al., 1996; Garcia-Macias et al., 1996) with some exceptions of primal cut weights, subjective color score, and shear force. Pietrain sired progeny had less backfat at the first rib (44.55 vs. 47.55 mm), tenth rib (23.04 vs. 25.48 mm), and last lumbar (20.85 vs. 22.96 mm) and more fat free lean (52.60% vs. 50.74%), similar to results of Ellis et al. (1996) and Garcia-Macias et al. (1996). Duroc progeny had longer carcasses (86.41 vs. 84.78 cm), while Garcia-Macias et al. (1996) reported no difference in carcass length. Carcasses of Duroc progeny were heavier (107.95 vs. 102.98 kg), which led to larger primal cut weights. Ham-loin percent was greater for Pietrain sired animals (44.60 % vs. 43.64%), similar to results of Affentranger et al. (1996), but Garcia-Macias et al. (1996) reported no difference in ham or loin percentage. Belly percentage was higher for Duroc progeny (11.99% vs. 11.66%), similar to findings of Affentranger et al. (1996).

Meat quality measures were not different or favored Duroc sired progeny. Subjective scores on a five-point scale for color, marbling, and firmness showed that loin chops from Duroc progeny were darker (2.540 vs. 2.354), more marbled (2.425 vs. 1.739), and firmer (2.615 vs. 2.295). Both Ellis et al. (1996) and Garcia-Macias et al. (1996) reported no difference in subjective color scores. Ellis et al. (1996) did report higher marbling scores for Durocs. In the current study, Duroc sired progeny had higher 24-h pH (5.526 vs. 5.468), agreeing with Affrentranger et al. (1996) and Garcia-Macias et al. (1996), and lower percent drip loss (2.892% vs. 3.893%), again agreeing with Affrentranger et al. (1996). No differences were seen in W-B shear force ($P > 0.237$). Ellis et al. (1996) had reported higher W-B shear force for Pietrains.

Duroc and Pietrain progeny did differ for many economically important traits. Traits from both breeds demonstrate genetic differences that could be useful in pork production systems. Through the use of serial measurement and random polynomial modeling, subtle differences that occurred during the growth phase were distinguished between these breeds. Much data can be summarized quickly through the use of a few parameters in a growth function. As market weights increase, progeny from both breeds will have similar amounts of fat free total lean; Duroc progeny have faster weight gain, while Pietrain progeny will be leaner. Duroc pigs have an advantage in meat quality measures over Pietrain pigs. Both Duroc and Pietrain breeds merit further study into the genetic control of these economically important traits.

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LITERATURE CITED

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