Comparison of production efficiency, product quality, nutrient excretion, and livability of 1979 versus 2005 pigs when fed “typical” 1979 and 2005 diets

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EXECUTIVE SUMMARY

Many changes occurred in the U.S. swine industry from 1980 to 2005. Integral parts of these industry wide changes were brought about by improvements in genetics and feeding programs. This study was an attempt to quantify both the industry changes and of those, which were attributable to genetics and/or feeding program improvements.

To accomplish this two groups of pigs, genetic samples representative of the 1980 and 2005 commercial industry, were fed feeding programs representative of the same time periods. Pigs representative of the 2005 commercial industry were obtained from a North Carolina commercial producer. Pigs representative of the 1980 swine industry were farrowed from females selected for minimum genetic gain since 1979 bred with semen commercially available around 1980. The 2005 feeding program was based on current industry practices while the 1980 feeding program was based on recommendations from the 1978 Pork Industry Handbook. Pigs from each genetic sample were assigned were randomly assigned to one of the feeding programs.

Pigs were on test from weaning (BW = 7 kg) to slaughter (BW = 116 kg). Feet and leg structure/mobility was scored on pigs. Body weights were collected every two weeks and feed

disappearance was also collected at this time. Daily gain, feed intake and feed efficiency were calculated. Beginning in week 8 or 10 backfat depth and longissimus dorsi muscle area at the 10th rib were measured with real-time ultrasound every four weeks and were measure on the carcass 24 hours post mortem. From these data, lean gain and lean efficiency were calculated. Other carcass measures included carcass weight, dressing percent, carcass length, backfat depth (first rib, last rib, last lumbar), and fatty acid composition of subcutaneous adipose tissue. Pork quality measures collected on the longissimus dorsi and ham included; pH (45 minute and 24 hour), L*, a*, b*, National Pork Board marbling score (1-10), firmness score (1-3), wetness score (1-3) and color score (1-6). National Pork Board marbling score, chemical analysis of percent intramuscular fat, 48 hour percent drip loss and Warner-Bratzler shear force test were also measured on the longissimus dorsi. A consumer sensory panel and trained flavor and texture descriptive panel were conducted on longissimus dorsi samples. Total feces and urine were collected for 3 days on 27 pigs to mesure apparent fecal CP and GE digestibility and to measure ammonia emissions from aged manure samples.

Differences in Economically Important Traits due to changes over 25 years in:

- Genetics
  - Feet and leg structure
    - Improved mobility 6.5%
  - Increased lean efficiency 16.7% due to:
    - Increased feed efficiency 10.8%
      - Increased daily gain 8%
        - Reduced days to slaughter 6.4%
      - No change to daily feed intake
    - Increased 10th rib longissimus dorsi muscle area 20%
    - Reduced 10th rib backfat depth 24%
  - Carcass composition
    - No change in dressing percent
    - No change in carcass length
    - Belly fat quality
      - Reduce belly firmness 13.6%
      - Increased calculated iodine value 3.5%

  - Pork Quality
    - Intramuscular fat
      - Increased chemical analysis 34.2%
      - Increased subjective marbling score 45.0%
    - No change in pH
      - Reduced drip loss from the longissimus dorsi 21.6%
    - Color
      - No change in Minolta (L*)
      - No change in subjective color score
    - Consumer taste panel
      - No Changes in:
        - Overall acceptance
        - Flavor
        - texture
        - Tenderness
        - Juiciness
- Feeding Program
  - Feet and leg structure
    - Reduced mobility 2.3%
  - Increased lean efficiency 16.7% due to:
    - Increased feed efficiency 20.8%
      - Increased daily gain 9.4%
        - Reduced days to slaughter 6.4%
      - Reduced daily feed intake 9.6%
    - Increased 10th rib longissimus dorsi muscle area 12.1%
    - Reduced 10th rib backfat depth
  - Carcass composition
    - Increased dressing percent 1.5%
    - Reduced carcass length 2.2%
    - Belly fat quality
      - Reduced belly firmness 35.0%
      - Increased calculated iodine value 12.9%
  - Pork Quality
    - Intramuscular fat
      - Reduced chemical analysis 38.5%
      - Reduced subjective marbling score 30.0%
    - Color
      - No change in Minolta (L*)
      - No change in subjective color score
    - Reduce ultimate ham pH 2.7%

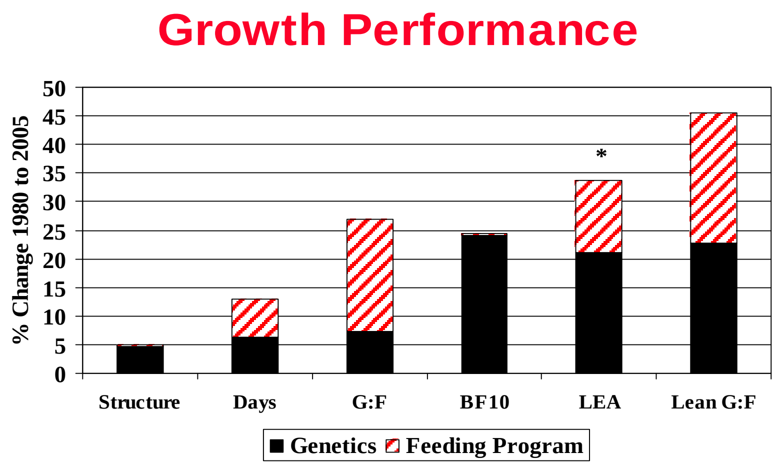
      Increased drip loss 26.6%
    - Consumer Taste Panel
      - Reduced
        - Overall acceptance 7.2%
        - Tenderness 5.9%

- No Change in:
    - Flavor
    - Texture
    - Juiciness

Overall Changes from 1980 to 2005 in Key Economically Important Traits

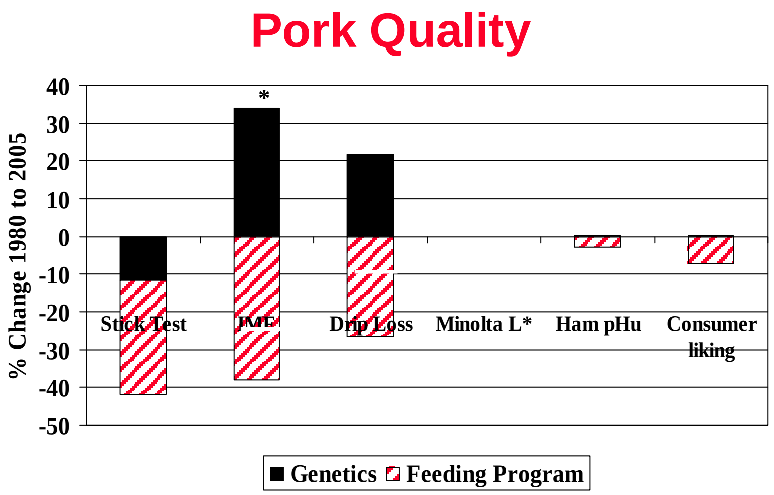
The following graphs represent change due to genetics, feeding program and overall change from 1980 to 2005 in specific growth traits and carcass traits.

Figure 1. Total change in growth performance over 25 yr



* Genetic Sample x Feeding Program Interaction (P < 0.05)

Figure 2. Total change in pork quality traits over 25 yr



* Genetic Sample x Feeding Program Interaction (P < 0.05)

The black portion is change due to genetics and the red portion is change due to feeding programs. If both are in the same direction the total bar is the cumulative change; however if not, then the white bar is where the cumulative change is. The * represents trait where a genetic sample by feeding program interaction was observed. This simply means the changes were not additive.

Implications

These findings show both genetics and feeding program changes from 1980 to 2005 increased lean efficiency, an important trait in regards to overall efficiency in the grow-finish phase of swine production. In regards to genetic effects, improvements in pork quality can coincide with the improvements in lean efficiency. Unfortunately the same cannot be said for changes in feeding program. The improvements due to feeding program resulted in unfavorable effects on important pork quality traits, which then translated into poorer consumer acceptance of the final product.

These findings could provide the swine industry with documentation showing how much the industry has improved in the past 25 years and quantify the contributions from improvements in genetics and feeding programs over this time period. They also bring to light areas where future research is needed to optimize improvements in all aspects of a commercial market hog.

DIFFERENCES IN GROWTH PERFORMANCE, LEAN GROWTH PERFORMANCE AND LEG STRUCTURE/MOBILITY OF COMMERCIAL PIGS REPRESENTATIVE OF 1980 AND 2005 GENETIC TYPES WHEN REARED ON 1980 AND 2005 REPRESENTATIVE FEEDING PROGRAMS

Introduction

Over the past 25 yr many changes have occurred in the US swine industry. Phenotypic improvements have been shown in USDA data (National Pork Board, 2005) from 1980 to 2005 in live weight at slaughter (109.8 to 122 kg), dressing percent (71 to 74.7%), and percent retail meat yield (55 to 58%).

Genetic trends from 1990 to 2000 in Swine Testing and Genetic Evaluation System (STAGES) records for the US swine breeds of Yorkshire, Duroc, Hampshire and Landrace show across breed improvements of -0.40 d/yr for days to 113.5 kg, 2.35g/d/yr for lean gain, -0.40 mm/yr for backfat, and 0.37 cm^2/yr longissimus dorsi muscle area (Chen et al., 2002). Comparable improvements in growth, muscling and leanness were reported for the Canadian Swine industry during parts of the same time period (Hudson and Kennedy, 1985; Sullivan and Dean, 1994; Kennedy et al., 1996).

Major changes in feeding programs over the past 25 yr have greatly affected growth performance and lean growth performance. Pelleting diets increases ADG, reduces ADFI, and improves feed efficiency (Baird, 1973; Skoch et al., 1983; Wondra et al., 1995). Inclusion of antibiotics in swine diets improves growth and efficiency in pigs (Cromwell and Dawson, 1992; Cromwell et al., 1996; Kendall et al., 2000). Adding dietary fat improves feed efficiency (Cline, 1990; Williams et al., 1994; De la Llata et al., 2001). Increasing percent protein in pig diets increases feed efficiency, loin muscle area, and reduces backfat (Hale and Southwell, 1967; Davey and Morgan, 1969; McConnell et al., 1971; Goerl et al.; 1995). Perhaps a more important measure of protein is the level of lysine, the first limiting amino acid in cereal grains. Increasing lysine in pig diets has been reported to improve pig growth performance while increasing muscling (Vipperman et al., 1963; Stahly et al., 1988; Friesen et al., 1994; Robison et al., 2000). Witte et al. (2000) noted reduced amounts of lysine in the diet decreased G:F. All of these changes in feeding programs have been shown to impact growth performance, leanness or muscling to some extent.

Studies conducted in the poultry industry evaluated contributions of genetic and nutritional changes to improvements observed in growth performance and carcass composition (Havenstein et al., 1994ab and 2003ab). They concluded that genetic, nutritional, and other management changes over the last 44 yr have reduced the time by two-thirds and feed intake by threefold required to produce a 1,815-g broiler. These authors concluded that 85 to 90% of the improvement in broiler growth rate and carcass composition over the past 45 yr was attributable to genetic improvements while 10 to 15% was due to changes in feeding programs. The authors also reported differences in leg problems observed in the 1991 study. A genetic strain x diet interaction was observed, where birds from the 1991 strain fed the 1991 diet had the greatest incidence of leg problems; these birds were also the fastest growing (Havenstein et al., 1994a).

The U.S. swine industry's shift to confinement style slatted and hard-surfaced flooring has led to an increased need to emphasize feet and leg structure (Bereskin, 1979a). Selection for structural correctness is typically done in two ways, direct selection where animals that are deemed unsound are not selected and indirect selection where animals whose soundness reduces longevity will have less influence in the herd. Heritabilities and genetic correlations) indicate selection for ADG is favorable (Bereskin,1979b; NPPC, 1995) or does not affect structural correctness (Webb et al., 1983; Rothschild et al., 1988). Selection for BF, LMA or Days to 113 kg has no affect or reduces structural correctness.

No studies were found involving the previously discussed differences in feeding program and their effect on leg structure.

This study was designed to estimate the effects of changes in genetics and feeding programs over the past 25 yr on growth performance, lean growth performance and leg structure/mobility in the US swine industry.

Material and Methods

Genetic Samples

A control population for a genetic selection study of commercially available white line animals was formed in 1979 at the University of Nebraska, Lincoln (Neal et al., 1989) and has been maintained at North Carolina State University since 1989 (Holl and Robison, 2003). Fifteen first parity females from this unselected population were mated using frozen semen from Hampshire and Duroc boars commercially available in 1979 and 1980, producing twelve litters (7 Duroc sired and 5 Hampshire sired). Semen from International Boar Semen (Eldora, IA) and Swine Genetics International, LTD (Cambridge, IA) representing three Duroc and three Hampshire sires was used. The 2005 genetic sample (GS) was comprised of commercial pigs sired by Duroc boars mated to F1 Large white x Landrace females, obtained from a North Carolina swine production company. Three farrowing groups contained pigs of similar age from both the 1980 and 2005 GS. Pigs (n = 162) from farrowing groups one and two were used in the evaluations of growth performance and lean growth performance. Pigs (n = 185) from farrowing groups one, two, and three were used for the evaluation of leg structure.

Feeding Programs

Assessment of the nutritional contribution to changes in pig growth performance, lean growth performance, and leg structure, was accomplished by placing one-half of the pigs from each genetic sample on one of two feeding programs (FP) representative of those used in 1980 vs. industry feeding practices common in 2005. All diets within FP were corn-soybean meal based. Table 1 and 2 describe the major differences in FP. Differences between the 1980 vs. 2005 feeding programs, included nutrient content, meal diets vs. pelleted diets, simple vs. phased feeding program, no-antibiotics vs. antibiotics, no added dietary fat vs. added dietary fat, and no synthetic amino acids vs. synthetic amino acids. The 1980 FP (Table 1) consisted of four meal diets based on formulations from the 1978 Pork Industry Handbook as reported in Krider et al. (1982). The 2005 FP included seven phases and was based on current diet formulation used by North Carolina producers (Table 2) (Hansen and Kendall, personal communication).

Management and Experimental Procedures

A 2 x 2 x 2 factorial design was used to compare genetic samples of barrows (n = 86) and gilts (n = 99) representative of 1980 and 2005 commercial industries when fed feeding programs representative of 1980 and 2005. Pigs from 1980 GS were farrowed at the North Carolina Swine Evaluation Station (Clayton, NC) and weaned at approximately 21 d of age. Pigs from the 2005 GS were delivered to North Carolina Swine Evaluation Station (Clayton, NC) at weaning, approximately 21 d of age. Pigs within GS, sex and farrowing group were randomly assigned to pens (3 pigs per pen) at 21 d of age. Pigs were given a one wk acclimation period before being randomly assigned to a feeding program at 7 ± 0.4 kg BW. Pigs with the three farrowing groups were comprised of pigs born within approximately one wk and were placed on test approximately two wk apart. Pen distribution for pigs used to measure growth performance and lean growth performance (farrowing groups 1, 2) is described in Table 3. Due to problems with limited number of sows, conception rate, and mortality, pens within 1980 GS were not evenly distributed among sex. Two gilts and one barrow from group 2 were removed before the trial along with one gilt from group 1 and one barrow from group 3 that were removed with two wk after the trial began due to illnesses. No illness or mortality was observed after wk two. Pigs were housed on solid concrete floors with 1.86 m^2 per pig and provided ad libitum access to feed and water. All animal procedures were approved by the Institutional Animal Care and Use Committee of North Carolina State University.

Pigs were weighed when placed on test, every two weeks throughout the study, and when taken off test. Feeding programs were provided according to a budget (Tables 1 and 2) and feed allotments were weighed daily to determine ADG, ADFI, and G:F. Average daily gain, ADFI, and G:F were calculated for on-test (7 ± 0.4 kg) to nursery (OTN) (26.9 ± 0.7 kg), nursery to slaughter (NS), and on-test to slaughter (OTS). Fat depth (BF) and longissimus dorsi muscle area (LMA) were measured using real-time ultrasound (Aloka 500; Corometrics Medical Systems, Wallingford, CT) beginning at week eight (Group 1) or ten (Group 2) and measured every four weeks thereafter resulting in three measurements. Ultrasound longissimus dorsi muscle area and BF were adjusted to 45 kg, 70 kg, and 95 kg. Lean gain was calculated using pounds of percent fat-free lean (NPPC, 2000) gain over the testing periods which was then converted to grams. Test periods for lean ADG (LADG), ADFI, and lean G:F (LG:F) were on-test to slaughter (OTS) and first real-time ultrasound to slaughter (FSS).

Pigs were slaughtered by pen on a weekly basis when average BW of pigs in a pen exceeded 116 kg. Carcass data was collected at a commercial abattoir (Bailey Foods, Bailey, NC).

Leg structure/mobility was scored by three experienced swine structure evaluators utilizing a scoring system based on the Pocket Guide for the Evaluation of Structural, Feet, Leg and Reproductive Soundness in Replacement Gilts (Stalder et al., 2005). Pen distribution for pigs used in leg structure/mobility evaluation (farrowing groups 1, 2, 3) is described in Table 4. Front and rear leg side views were scored on a 1 to 5 scale; 1 = excessive set to the joints, 3 = ideal and 5 = extreme straightness in the joints. Front and rear views of structure were scored from 1 to 3; 1= toes out, 2 = ideal, and 3 = toes in. Mobility scores were from 1 to 5; 1 = severely impaired due to injury, 3 = ideal, and 5 = severely impaired due to structure (Appendix Figures 1 – 3).

Statistical Analysis. Statistical analysis of growth performance, lean growth performance, BF, and LMA data was performed using the GLM procedure of SAS (SAS Inst., Inc, Cary, NC). Genetic sample (GS), feeding program (FP), sex, farrowing group, and interactions among GS, FP, and sex were used in the model to examine their effect on growth performance, real-time ultrasound (RTU) BF, and LMA and lean growth performance. Genetic sample x sex, FP x sex, and GS x FP x sex interactions were removed at ($P > 0.05$). Least square mean differences for RTU BF and LMA were analyzed using BW as a covariate to adjust RTU BF and LMA to the mean BW of all pigs. Pen was used as the experimental unit. Significance was declared at $P < 0.05$.

Statistical analysis of the leg structure and mobility data was performed using the GLM procedure of SAS (SAS Inst., Inc, Cary, NC). Genetic sample, FP, sex, farrowing group, evaluator, and interactions among GS, FP, and sex were used in the model to examine their effect on the five traits evaluating pig leg structure/mobility. Genetic sample x sex, FP x sex and GS x FP x sex interactions were removed at $P > 0.05$. Pig was used as the experimental unit for leg structure/mobility traits as evaluators scored individual pigs.

Results and Discussion

Growth Performance

Least squares means for growth performance and P-values for GS and FP are shown in Table 5. Genetic sample x FP interactions ($P < 0.05$) were observed for ADG NS and OTS where 1980 vs. 2005 GS pigs gained 7.0 vs. 12.6% more during NS and 6.3 vs. 12.3% more during OTS when fed 1980 vs. 2005 FP. These interactions of magnitude suggest the 1980 FP does not meet either 1980 or 2005 GS pigs nutrient requirements; however, it more closely meets the requirements of 1980 GS pigs. This led to a greater increased in 2005 GS pigs fed 1980 vs. 2005 FP.

Genetic Sample Differences. No difference in GS for ADG (OTN) was observed; however, 2005 GS pigs gained more ($P < 0.01$) per day NS and OTS than 1980 GS pigs. Consequently, the faster growing 2005 GS pigs reached the 116 kg slaughter weight sooner ($P < 0.01$) than 1980 GS pigs. During OTN 2005 GS pigs consumed less ($P < 0.01$) feed per day but did not differ from 1980 GS pigs in ADFI for OTN or OTS. These differences in ADG and ADFI led to higher ($P < 0.01$) G:F for 2005 GS sample pigs during OTN, NS, and OTS. The observed increase in ADG due to genetics is in agreement with genetic trends for growth in the U.S. (Chen et al., 2002) and Canadian (Hudson and Kennedy, 1985; Sullivan and Dean, 1994; Kennedy et al., 1996) swine industries. No genetic trends were reported for ADIF or feed efficiency; however, genetic correlations between feed efficiency and ADG reported in Stewart and Schinckel (1989) and Mrode and Kennedy (1993) when considered with reported genetic trends, agree with our findings of increased ADG and feed efficiency. Our results for ADFI were not in agreement with expected changes due to the genetic correlation reported between ADFI and ADG indicating increased genetic trends for ADG should result in increased ADFI.

Feeding Program Differences. Pigs fed 2005 FP gained more (P< 0.01) per day during OTN, NS, and OTS than pigs feed 1980 FP. Pigs fed 2005 feeding program took fewer (P < 0.01) days to reach slaughter wt. Increase in ADG coupled with no change in ADFI during OTN or reduced ADFI NS and OTS resulted in improved G:F during OTN, NS, and OTS for pig fed 2005 vs. 1980 FP. These findings are consistent with many of the effects of changes in FP on growth performance. In the literature, pelleting diets (Baird , 1973; Wondra et al., 1995) and five percent added dietary fat (Cline, 1990) appear to have the greatest impact on reduced ADFI. Reduction in ADFI with no change or greater ADG improves feed efficiency. Baird (1973) reported increased ADG due to pelleting. A study comparable to ours added five percent choice white grease during finishing and reported similar improvements in F:G (Williams et al., 1994). Pelleting of diets is believed to reduce ADFI due to reduced feed wastage (Wondra et al., 1995), while adding fat to pig diets allows pigs to eat less and still increase or maintain the metabolizable energy consumed (Pettigrew and Moser, 1991; Hazzledine and Whittemore, 2006). The improvement in ADG and G:F could also be attributable to dietary antibiotics, increased protein, or increased lysine content of the feed. Cromwell and Dawson (1992) reported ADG (4%) and F:G (2%) improved from nursery through slaughter with dietary antibiotics. Cromwell et al. (1996) reported similar findings during the grow-finish phase for 576 crossbred market pigs. Hale and Southwell (1967) increased protein four percent in a two diet feeding program for 60 Duroc and Hampshire pigs and found no change in ADG but improved feed efficiency. Robison et al. (2000) increased lysine in all four phases of a feeding program fed to 6 different genetic lines increased ADG. Feeding reduced levels of lysine, 6.4 g/kg vs. 4.8 g/kg, to hybrid gilts from 90 to 126 kg BW did not affect ADG or ADFI but reduced G:F (Witte et al., 2000).

Sex Differences. Sex differences are presented in Appendix Table 1. No GS x sex, FP x sex or GS x FP x sex interactions were significant. Barrows gained more per day than gilts for OTN (514 vs. 482 g/d; $P < 0.05$), NS (974 vs. 892 g/d; $P < 0.01$), and OTS (837 vs. 775 g/d; $P < 0.01$). Gilts ate less per day than barrows for NS (2383 vs. 2677 g/d; $P < 0.01$) and OTS (1946 vs. 2146 g/d; $P < 0.01$) but did not differ for ADFI during OTN. Increased ADG and ADFI in barrows is in agreement with Bereskin et al. (1975, 1976) and Quijandria et al. (1970). There was no difference between barrows and gilts for G:F during OTN. However, the difference in ADFI was greater than the difference in ADG during NS and OTS; subsequently, gilts had greater G:F for NS (0.377 vs. 0.365; $P < 0.01$) and OTS (0.401 vs. 0.392; $P = 0.05$). Our result that gilts were more efficient over the entire test period is in agreement with Bruner and Swiger (1968) and Bereskin et al. (1976) but not with Quijandria et al. (1970), Bereskin et al. (1975), and Siers (1975) where no differences in G:F were found. Barrows reached the 116 kg slaughter weight sooner (163.4 vs. 172.4 d; $P < 0.01$) and weighed more (119.7 vs. 118.2 kg; $P < 0.05$) than gilts at slaughter. Barrows reaching slaughter at a younger age is expected due to their advantage in ADG. This advantage is also the reason barrows were heavier at slaughter. Pens were removed from test on a weekly basis which in turn allowed pens of barrows to surpass the slaughter threshold of 116 kg BW by more than gilts.

Real-time Ultrasound Backfat and Longissimus dorsi Muscle Area

Least squares means for real-time ultrasound (RTU) BF and LMA and P-values for GS and FP are shown in Table 6. There was no GS x FP interaction for any of the RTU BF or LMA measurements.

Genetic Sample Differences. Pigs from 2005 GS had larger ($P < 0.01$) LMA RTU at 70 and 95 kg BW and less BF RTU at all weights than 1980 GS pigs. This is consistent with genetic trends in the U.S. and Canadian swine industries for LMA and BF (Hudson and Kennedy, 1985; Sullivan and Dean, 1994; Kennedy et al., 1996; Chen et al., 2002).

Pigs fed 2005 FP had larger ($P < 0.01$) LMA RTU but did not differ in BF RTU for any weights. In the literature, the FP differences which predominantly affect BF and LMA are increased protein level and more specifically increases in lysine level. Increased LMA is in agreement with McConnell et al. (1971), Robison et al. (2000), and Witte et al. (2000). A lack of reduction in BF due to increased protein/lysine is consistent with Vipperman et al. (1963) and Bereskin and Davey (1978) but does not agree with Hale and Southwell, (1967), Goerl et al. (1995), and Robison et al. (2000), who reported that lower percent protein or lysine resulted in increased BF.

Sex Differences. There were no significant GS x sex, FP x sex or GS x FP x sex interactions (Appendix Table 2). Gilts had less (2.07 vs. 2.33 cm; $P < 0.01$) BF RTU at 95 kg BW and tended to have less (1.09 vs. 1.16 cm; $P = 0.08$) BF RTU at 45 kg and (1.59 vs. 1.70 cm; $P = 0.06$) 70 kg BW than barrows. No difference was observed in LMA RTU at 45 kg BW; however, gilts had larger LMA for RTU at 70 kg and 95 kg BW (28.94 vs. 27.33 cm^2; $P < 0.01$ and 38.11 vs. 35.71 cm^2; $P < 0.01$). The difference in RTU BF and LMA between gilts and barrows became greater as pigs approached slaughter wt. This is in agreement with carcass measures for BF and LMA as reported by Bruner and Swiger (1968), Quijandria et al. (1970), Siers (1975) and Bereskin and Davey (1978). They indicated gilts have less BF and larger LMA than barrows at slaughter.

Lean Growth Performance

Least squares means for lean gain OTS and FSS and P-values for GS and FP are presented in Table 7. A GS x FP interaction ($P < 0.01$) for LADG during OTS was observed where 1980 GS pigs showed a 7.0% and 2005 GS pigs showed a 17.0% increase in LADG when fed 1980 vs. 2005 FP. The cause of this interaction is believed to be the same as that described for the ADG interactions. The 2005 GS pigs have greater potential for growth and muscle than the 1980 GS. The 2005 FP more closely meets the nutrient requirements of pigs, particularly the 2005 GS pigs. This is in agreement with a review by Baker and Speer (1983) of 25 yr of studies involving amount of protein in swine diets where pigs with a greater genetic potential for lean growth had greater response in lean gain when fed higher amounts of protein.

Genetic Sample Differences. Pigs from 2005 GS had higher ($P < 0.01$) LADG, did not differ in ADFI, and as a result had higher ($P < 0.01$) LG:F during OTS and FSS than 1980 GS pigs. The improvement in lean growth and efficiency agrees with our findings for ADG, G:F, LMA, and BF. These results also are consistent with the genetic trends in the U.S and Canadian swine industries for growth, muscling and leanness and genetic correlations among traits previously discussed. Chen et al. (2002) reported yearly genetic improvement in the Yorkshire, Duroc, Landrace and Hampshire breeds for lean gain during part of the 1980 to 2005 time period that is consistent with our findings.

Feeding Program Differences. Pigs fed 2005 FP had higher ($P < 0.01$) LADG OTS but did not differ from pigs fed 1980 FP in lean gain per day (FSS). Feeding the 2005 FP caused pigs to consume less ($P < 0.01$) feed per day (OTS and FSS) and consequently increased ($P < 0.01$)

LG:F (OTS and FSS). The increased lean efficiency was the result of pigs gaining more per day, consuming less feed per day, and being heavier muscled; even without a reduction in BF. Again these improvements are in agreement with the literature previously discussed for increased growth, reduced feed intake, increased muscling and varying effects on fatness.

Sex Differences. No GS x sex, FP x sex or GS x FP x sex interactions were significant (Appendix Table 3). Barrows and gilts did not differ in LADG OTS or FSS. The larger LMA and lower BF in gilts were off-set by the higher ADG in barrows and as result there was no difference in LADG. Similar to results and other studies previously discussed, gilts consumed less feed on a daily basis for OTS (1946 vs. 2146 g/d; $P < 0.01$) and FSS (2554 vs. 2921 g/d; $P < 0.01$) than barrows. No difference in LADG combined with gilts lower ADFI led to higher LG:F for gilts during OTS (137 vs. 124; $P < 0.01$) and FSS (113 vs. 98; $P < 0.01$). Cromwell et al. (1993) reported comparable differences in barrows vs. gilts. They found barrows gained faster but also consumed more feed per day, had smaller LMA and more BF than gilts. These factors contributed to gilts that were more efficient but no gender differences for LADG.

Leg Structure/Mobility

Least squares means for leg structure/mobility and P-values for GS and FP are shown in Table 8. Pigs from the 1980 GS were straighter ($P < 0.01$) in their front leg and rear leg joints than pigs from the 2005 GS. Genetic samples did not differ in front leg front view or rear leg rear view. Pigs fed different FP did not differ for front leg views or rear leg views. Based on a GS x FP interaction ($P < 0.01$) pigs from the 2005 GS fed the 1980 FP were the most mobile. Pigs from the 2005 GS were more ($P < 0.01$) mobile than 1980 GS pigs and pigs fed the 1980 FP were more ($P < 0.05$) mobile than pigs fed the 2005 FP.

No genetic trends for leg structure or mobility were reported for this time period; however, genetic improvement in leg structure/mobility and ADG found in this study is consistent with the favorable genetic correlations reported in Bereskin (1979b) and NPPC (1995) between ADG and structural correctness. However, Woltmann et al. (1995) found no effect for selection for ADG on front leg soundness. Bereskin (1979b) and NPPC (1995) also reported unfavorable genetic correlations between structural correctness and LMA and BF. Webb et al. (1983) and Rothschild et al. (1988) also reported unfavorable correlations between BF and front leg soundness. These are not in agreement with our findings of increased LMA and reduced BF with improved structural correctness for the 2005 GS compared to the 1980 GS. Conversely, Webb et al. (1983) did report favorable genetic correlations between front leg soundness and LMA.

No other studies were found which compared differences in the two FP in this study and their effect on structural correctness. However, the reduction in mobility due to the 2005 FP could be a result of those pigs being heavier muscled and consequently somewhat impeded in their movement.

Sex Differences. A GS x sex interaction ($P < 0.01$) was observed where gilts from the 1980 GS were the straightest in their front leg joints (Appendix Table 4). Gilts tended to be straighter (3.32 vs. 3.18; $P = 0.07$) in their front leg joints than barrows. Woltmann et al. (1995) and Rothschild et al. (1988) indicated gilts are more correct than boars in their front leg structure. Realizing our study involved barrow vs. gilts rather than boars vs. gilts, our findings are not in agreement with theirs. A FP x sex interaction ($P < 0.01$) indicated barrows fed the 1980 FP were more in at their hocks than pigs fed the 2005 FP. Gender did not affect front leg front view, rear leg side view, rear leg rear view or overall mobility.

Changes in genetics and nutrition from 1980 to 2005 have been both positive and negative for the U.S. swine industry. However, these changes have been mostly favorable for growth performance, lean growth performance and structure. The observed 15% reduction in days to slaughter and 45% increase in lean efficiency are almost equally attributable to both genetics and nutrition. A 30% increase in G:F is approximately two-thirds the result of feeding program changes. Reduction in real-time ultrasound BF is near fully attributable to genetic improvement, while increased LMA appears to have equal response from genetic and feeding program improvements. Overall improvement in leg structure was due to genetic changes despite minor negative effects from feeding program.

The information from this study could provide the pork industry with a greater understanding of industry changes from 1980 to 2005. Specifically, which phenotypic changes are attributable to genetics, nutrition or both. It provides documentation that can be used with general public and regulatory groups on positive developments that have occurred. In addition, the results of this study may provide the industry with knowledge of how far it has come and areas for potential future studies.

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Table 1. Ingredients and nutrient composition of the 1980 feeding program

	Prestarter	Starter	Grower	Finisher
Corn	52.70	71.55	79.25	83.90
Soybean meal (48)	24.30	52.20	17.90	13.25
Whey	20.00	0	0	0
Dicalcium phosphate	1.50	1.75	1.35	1.25
Limestone	0.75	0.75	0.75	0.85
Salt	0.50	0.50	0.50	0.50
Vitamin-minerals premix[1]	0.25	0.25	0.25	0.25
Total	100.00	100.00	100.00	100.00
Calculated analysis				
Crude Protein, %	18.3	17.9	15.0	13.3
Metabolizable Energy, kcal/kg	3262	3299	3315	3317
Calcium, %	0.87	0.78	0.67	0.67
Phosphorus, %	0.74	0.70	0.60	0.56
Lysine, %	1.05	0.95	0.75	0.62
Amount budgeted per pig, kg	11.3	15.9	90.7	to market

[1] Vitamin and mineral premix supplied the following per kg of complete diet - 5,540 IU of vitamin A as retinyl acetate, 1,108 IU of vitamin D3, 22 IU of vitamin E as dl-x-tocopherol acetate, 1.98 mg of vitamin K as menadione dimethylpyrimidinol bisulfite, 165 mg of choline as choline chloride, 22 mg of niacin as niacinamide, 17.6 mg of d-pantothenic acid as dl-calcium pantothenate, 4.4 mg of riboflavin, 1.1 mg of pyridoxine as pyridoxine·HCl, 0.55 mg thiamine as thiamine mononitrate, 0.022 mg of vitamin B12 , 0.33 mg of folic acid, 0.04 mg of d-biotin, 110 mg Zn as ZnSO4 , 110 mg Fe as FeSO4 , 22 mg Cu as CuSO4 , 55 mg Mn as MnO, 0.28 mg I as ethylenediamine dihydriodide, and 0.30 mg Se as NaSeO3

Table 2. Ingredients and nutrient composition of the 2005 feeding program ingredient

	Prestarter	Starter 1	Starter 2	Grower 1	Grower 2	Finisher 1	Finisher 2
Corn	42.07	48.80	47.79	64.24	66.86	72.25	79.30
Soybean meal (48% CP)	22.12	26.46	34.36	26.15	23.85	18.75	12.20
Dried whey	7.50	4.20	0	0	0	0	0
Prestarter vitamin-mineral premix[1]	6.50	0	0	0	0	0	0
Lactose	5.07	1.20	0	0	0	0	0
Ground wheat	5.00	0	0	0	0	0	0
Menhaden fishmeal	4.20	3.00	0	0	0	0	0
Lard	2.84	3.73	4.67	6.95	6.97	6.97	6.67
Oat groats	2.50	0	0	0	0	0	0
Monocalcium phosphate	1.00	0.92	0.94	1.00	0.67	0.49	0.42
Limestone	0.58	0.89	1.05	0.62	0.69	0.70	0.66
Salt	0.30	0.24	0.38	0.27	0.31	0.34	0.34
Zinc oxide	0.32	0	0	0	0	0	0
Wheat midds	0	7.50	10	0	0	0	0
Nursery vitamin-mineral premix[2]	0	3.00	0	0	0	0	0
Selenium premix (0.06% Se)	0	0.05	0.05	0.05	0.05	0.05	0.05
Pregrower vitamin-mineral premix[3]	0	0	0.50	0	0	0	0
Lysine HCL (78.8% Lysine)	0	0	0.17	0.34	0.30	0.24	0.19
Copper sulfate	0	0	0.09	0	0	0	0
DL. Methionine	0	0	0.01	0.13	0.10	0.03	0
Vitamin-mineral premix[4]	0	0	0	0.12	0.10	0.10	0.10
L-threonine (98.5)	0	0	0	0.09	0.07	0.06	0.03
Ronozyme[5]	0	0	0	0.02	0.02	0.02	0.02
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Calculated analysis							
Crude Protein, %	22.6	22.3	22.1	17.9	16.9	14.7	12.0
Metabolizable Energy, kcal/kg	3428	3405	3438	3630	3643	3655	3651
Calcium, %	0.84	0.79	0.72	0.52	0.48	0.43	0.39
Phosphorus, %	0.72	0.68	0.64	0.55	0.47	0.41	0.37
Lysine, %	1.51	1.43	1.36	1.22	1.13	0.94	0.73
Antibiotics							
Chlortetracyline, g/t	440.92	440.92	440.92	440.92	-	-	-
Tiamulin, g/t	38.58	38.58	38.58	-	-	-	-
Tylosin, g/t	-	-	-	-	22.05	-	-
Virginiamycin , g/t	-	-	-	-	-	11.03	5.51
Amount budgeted per pig, kg	4.54	9.07	13.61	18.1	45.4	56.7	to market

[1]

[2]

[3]

[4]

[5]

Table 3. Pen distribution and number of pigs per treatment for growth performance and lean growth performance

	1980 Genetic sample		2005 Genetic sample	
Feeding program	Barrows	Gilts	Barrows	Gilts
1980	6 (18)	7 (21)	7 (21)	7 (21)
2005	5 (15)	8 (24)	7 (21)	7 (21)

Table 4. Pen distribution and number of pigs per treatment for leg structure/mobility evaluation

	1980 Genetic sample		2005 Genetic sample	
Feeding program	Barrows	Gilts	Barrows	Gilts
1980	7 (21)	8 (24)	8 (24)	8 (24)
2005	6 (18)	9 (27)	8 (24)	9 (27)

Table 5. Effect of genetic sample and feeding program on growth performance

	Genetic Sample				P-value[1]		
	1980		2005				
	Feeding program						
Trait	1980	2005	1980	2005	GS*FP	Genetic sample	Feeding program
On-test to nursery							
ADG, g	480	534	435	544	0.10	0.29	<0.01
ADFI, g	936	888	811	830	0.29	<0.01	0.65
G:F	0.52	0.60	0.54	0.66	0.15	<0.01	<0.01
Nursery to slaughter							
ADG, g	853^{a}	912^{b}	926^{b}	1042^{c}	0.05	<0.01	<0.01
ADFI, g	2682	2388	2590	2461	0.09	0.85	<0.01
G:F	0.32	0.38	0.36	0.42	0.98	<0.01	<0.01
On-test to slaughter							
ADG, g	751^{a}	799^{b}	788^{b}	885^{c}	0.05	<0.01	<0.01
ADFI, g	2208	1936	2091	1947	0.08	0.13	<0.01
G:F	0.34	0.41	0.38	0.46	0.60	<0.01	<0.01
Slaughter							
Slaughter age, d	177.6	169.2	170.1	154.6	0.08	<0.01	<0.01
Slaughter wt, g	118.4	118.9	119.2	119.3	0.75	0.39	0.63

[a-c] Least squares means with no common superscript differ ($P < 0.05$)

[1] P-values from final model; GS + FP + sex + farrowing group + GS*FP

Table 6. Effect of genetic sample and feeding program on real-time ultrasound backfat and longissimus dorsi muscle area taken at the 10th rib

	Genetic sample						
	1980		2005		P-value[1]		
	Feeding program					Genetic	Feeding
Trait[2]	1980	2005	1980	2005	GS*FP	sample	program
BF at 45 kg BW, cm	1.18	1.28	1.00	1.03	0.39	<0.01	0.10
LMA at 45 kg BW, cm^2	17.99	19.45	18.20	20.38	0.42	0.20	<0.01
BF at 70 kg BW, cm	1.79	1.81	1.45	1.51	0.78	<0.01	0.43
LMA at 70 kg BW, cm^2	26.20	28.28	27.29	30.76	0.13	<0.01	<0.01
BF at 95 kg BW, cm	2.34	2.50	1.93	2.03	0.70	<0.01	0.10
LMA at 95 kg BW, cm^2	34.29	36.39	36.69	40.27	0.21	<0.01	<0.01

[1] P-values from final model; GS + FP + sex + farrowing group + GS*FP

[2] BF = backfat depth; LMA = longissimus dorsi area

Table 7. Effect of genetic sample and feeding program on lean growth performance

	Genetic sample						
	1980		2005		P-value[1]		
	Feeding program					Genetic	Feeding
Trait	1980	2005	1980	2005	GS*FP	sample	program
Lean gain, on-test to slaughter							
Lean ADG, g	233^a	250^b	266^c	311^d	<0.01	<0.01	<0.01
ADFI, g	2208	1939	2091	1947	0.08	0.13	<0.01
Lean G:F	0.11	0.13	0.13	0.16	0.07	<0.01	<0.01
Lean gain, first scan to slaughter							
Lean ADG, g	248	250	313	334	0.21	<0.01	0.14
ADFI, g	2883	2546	2833	2689	0.09	0.40	<0.01
Lean G:F	0.09	0.10	0.11	0.13	0.84	<0.01	<0.01

[a-d] Least squares means with no common superscript differ ($P < 0.05$)

[1] P-values from final model; GS + FP + sex + farrowing group + GS*FP

Table 8. Effect of genetic sample and feeding program on structural correctness

	Genetic sample						
	1980		2005		P-value[1]		
	Feeding program					Genetic	Feeding
Trait	1980	2005	1980	2005	GS*FP	sample	program
Front front[2][4]	1.85	1.86	1.90	1.82	0.24	0.88	0.34
Front side[3][4][5]	3.27	3.45	3.13	3.16	0.33	<0.01	0.19
Rear side[3][4]	1.36	1.44	1.42	1.42	0.26	0.64	0.31
Rear rear[3][4][6]	3.53	3.40	3.27	3.35	0.11	<0.01	0.80
Mobility[3][4]	3.73[a]	3.68[ab]	3.35[c]	3.56[b]	<0.01	<0.01	0.05

[a-c] Least squares means with no common superscript differ ($P < 0.05$)

[1] P-values from final model

[2] 1 to 5 scale; 1 = excessive set to the joints, 3 = ideal and 5 = extreme straightness in the joints

[3] 1 to 3 scale; 1= toes out, 2 = ideal, and 3 = toes in

[4] Final model: GS + FP + sex + farrowing group+ evaluator + GS*FP

[5] Final model: GS + FP + sex + farrowing group+ evaluator + GS*FP + GS*sex

[6] Final model: GS + FP + sex + farrowing group+ evaluator + GS*FP + FP*sex

DIFFERENCES IN CARCASS COMPOSITION AND FATTY ACID PROFILES OF COMMERCIAL PIGS REPRESENTATIVE OF 1980 AND 2005 GENETIC TYPES WHEN REARED ON 1980 AND 2005 REPRESENTATIVE FEEDING PROGRAMS

Introduction

Changes in USDA data over the past 25 yr show phenotypic improvements have been made. From 1980 to 2005 changes in live weight at slaughter (109.8 to 122 kg), dressing percent (71 to 74.7%), and percent retail meat yield (55 to 58%) have been reported in USDA data (National Pork Board, 2005). During this time it has been shown changes in both genetics and nutrition have contributed to these improvements. Fix (2007) reported a 45% increase in lean efficiency and nearly 15% reduction in days to slaughter which are equally attributable to genetics and nutrition.

Genetic trends during this time period in the U.S. and Canadian swine industries show improvements have been made in muscling and leanness (Hudson and Kennedy, 1985; Sullivan and Dean, 1994; Kennedy et al., 1996; Chen et al., 2002). Because genetic trends for carcass traits other than leanness and muscling are not typically analyzed, it is important to look at genetic correlations between carcass traits and traits for which genetic trends have been reported. Genetic correlations between carcass length and traits commonly selected for are both favorable and unfavorable (Stewart et al., 1989; NPPC, 1995). Stewart et al. (1989) also reported selection for reduced backfat results in lower dressing percent.

Changes in feeding programs over the past 25 yr, summarized in Fix (2007), have varying effects on carcass composition. Both increases in percent protein and lysine improve carcass percent lean (Hale and Southwell, 1967; Bereskin and Davey, 1978; Witte et al. 2000). Carcass length, belly thickness and dressing percent were not affected by changes in protein or lysine (Hale and Southwell, 1967; Friesen et al., 1995; Witte et al., 2000). There was not a consensus in the literature for changes in protein and lysine and their effect on backfat or muscling. Engel et al. (2001) and Baird (1973) reported neither adding dietary fat nor pelleting diets affected dressing percent, backfat, carcass length, longissimus dorsi muscle area, nor percent lean.

Similar studies in poultry indicated no change in carcass fatness of birds at their respective market ages, from 1957 to 1991 (Havenstein et al., 1994). In a related study evaluating similar traits from 1957 to 2001 the 2001 feeding regimen increased carcass fat, but once again the two genetic strains did not differ in carcass fat at their respective slaughter weights (Havenstein et al., 2003).

When evaluating carcass composition it is important to evaluate fat quality and more specifically fatty acid composition of pork fat. Soft fat causes inefficiency in pork processing facilities due to increases in cutting error and products of lower quality (Morgan et al., 1994). Both genetics and dietary factors influence the fatty acid composition; however, dietary factors impact composition to a greater extent (De Smet et al., 2004). Selection based on fatty acid composition is uncommon; however, individual fatty acid concentrations have been shown to be heritable and genetically correlated with performance traits (Piedrafita et al., 2001; Suzuki et al., 2006). More specifically, pigs selected for leanness have lower concentrations of saturated fatty acids in adipose tissue (Scott et al., 1981).

It is well established dietary factors influence the firmness of pork fat (Ellis and Isbell, 1926). The dietary factors previously discussed that have the greatest impact on fatty acid composition are added dietary fat, both level and type of fat, and increased crude protein. Adding choice white grease at a 5% level or greater decreased saturated fatty acid concentration in pork fat (Engel et al., 2001; Rentfrow et al. 2003; Weber et al., 2006). Increasing the protein content of swine diets has been shown to decrease the saturated fatty acid concentration of pork fat (Teye et al., 2006).

This study was designed to estimate the effects of changes in genetics and feeding programs over 25 yr on carcass composition and fatty acid composition of pork fat in the US swine industry.

Materials and Methods

Genetic Samples, Feeding Programs and Management

Pigs representative of 1980 GS were farrowed from females from a control population, formed in 1979 at the University of Nebraska, Lincoln (Neal et al., 1989) and has been maintained at North Carolina State University since 1989 (Holl and Robison, 2003). Semen was made available from International Boar Semen (Eldora, IA) and Swine Genetics International, LTD. (Cambridge, IA). The 2005 GS pigs were obtained from a North Carolina commercial producer. Feeding programs representing 1980 and 2005 (Fix, 2007) were used to assess effects of changes in feeding practices on carcass composition and fatty acid composition of subcutaneous adipose tissue. The 1980 FP was based on suggested formulations from the 1978 Pork Industry Handbook as reported in Krider et al. (1982). The 2005 FP was based on current industry practices. Both diets were corn and soybean meal based and complete details are outlined in (Fix, 2007). Major differences between 1980 vs. 2005 FP included diet ingredients and nutrient composition, increased number of phases, meal diets vs. pelleted diets, no-antibiotics vs. antibiotics, added dietary fat vs. no added dietary fat, and no synthetic amino acids vs. synthetic amino acids. Important dietary aspects specific to this portion of the study are summarized in Tables 1 and 2 for 1980 and 2005 FP, respectively.

Fix (2007) provides complete details of the experimental design and management of pigs during the growth portion of the study. However, a brief description follows. A 2 x 2 x 2 factorial design was used (2 GS, 2 FP, 2 sexes) with 3 pigs per pen (pen = 54) in two farrowing groups. Pigs were housed on solid concrete floors with 1.86 m^2 per pig and provided ad libitum access to feed and water. All animal procedures were approved by the Institutional Animal Care and Use Committee of North Carolina State University.

Slaughter Procedures

Pigs were slaughtered by pen on a weekly basis when average BW of pigs in a pen exceeded 116 kg. Slaughter data were collected at a commercial abattoir (Bailey Foods, Bailey, NC).

Carcass collection procedures followed NPPC (2000). At slaughter, initial carcass weight, carcass length, and backfat (BF) depth at the 1st rib, last rib, and last lumbar were collected. Initial slaughter weight included only removal of hair, blood, viscera, and anus. Hot carcass weight (HCW) was calculated based on initial carcass weight minus leaf fat and head weight. Dressing percent was calculated by dividing HCW by BW. Carcasses were chilled for 24 h. Twenty-four h post-mortem, BF depth and longississmus muscle area (LMA) at the 10th rib were measured. Trimmed belly length and thickness (shoulder end, belly edge, ham end, and loin edge) were measured. A test for belly firmness (stick test) was conducted by laying a belly across a 1.27 cm diameter pipe and measuring the distance between the outside edges of the belly. The greater the distance of the stick test, firmer the belly. Backfat measures, LMA, carcass length, and belly stick test were adjusted to a carcass weight of 85 kg. Belly length was adjusted to a mean adjusted carcass length of 86 cm.

Subcutaneous adipose tissue samples were collected from loin, belly, and ham primal cuts. Loin adipose tissue was collected from the rib end of the boneless loin. Belly adipose tissue was collected from the anterior end of the belly primal. Ham adipose tissue was collected from the collar fat of the four cushion region. Samples were immediately placed in air-tight bags and put on ice. Within 5 hours samples were vacuum packaged and stored at -20°C.

Fatty Acid Analysis.

Skin and muscle tissue were removed from adipose samples. Duplicate adipose samples (0.35 to 0.50 grams) were placed in 13 x 100 cm test tubes and heated in a heating block at 80°C for one hour. An aliquot of lipid weighing 0.03 ± 0.01 g was used for fatty acid compositional analysis. One ml of 0.5 N sodium hydroxide in methanol was added and test tubes were heated for 12 min followed by the addition of 1 ml of boron-trifluoride and an additional 12 min, of heating. Fatty acid methyl esters (FAME) were partitioned by the addition of two ml of saturated sodium chloride followed by two extractions with 2 ml each of hexane with the combined extracts dried over anhydrous sodium sulfate prior to drying under a nitrogen flush at 40°C. The FAME were re-dissolved in hexane and transferred to GC vials for analysis. A Perkin Elmer Model XL Autosystem Gas Chromatograph (PerkinElmer Inc., Waltham, MA) equipped with a flame ionized detector (FID) and BPX-70 capillary column (SGE, Inc., Austin TX) 30 cm in length with 0.25 mm i.d. and 0.25 µm film thickness was used to analyze the FAME. Helium was used as the gas carrier at 20 psi. Injection volume was 1 µL. The injection was split with a split flow rate of 1 mL/min. Initial oven temp was 60°C and increased 10°C per minute to 180°C and then 4°C per minute to 235°C. Total run time was 27.7 minutes. Compounds were identified using fatty acid methyl ether standards from Matreya, LLC (Pleasant Gap, PA). Response factors were calculated based upon the standard with peak areas of sample FAME expressed as a percentage of the total peak area of the standard.

Calculated Iodine Values. Calculated iodine values (CIV) were estimated for FAME obtained from loin, belly and ham primal cuts based upon the AOCS Standard Method Cc-1c-85 (AOCS Methods, 1993) Iodine value = (% hexadecenoic acid x 0.950) + (% octadecenoic acid x 0.860) + (% octadecadienoic acid x 1.732) + (% octadecatienoic acid x 2.616) + (% eicosenoic acid x 0.785) + (% docosenoic acid x 0.723).

Statistical Analysis

Statistical analysis of the carcass and fatty acid composition data was performed using the GLM procedure of SAS (SAS Inst., Inc, Cary, NC). Genetic sample (GS), feeding program (FP), sex, farrowing group, slaughter week and interactions among GS, FP, and sex were used in the model to examine their effect on carcass composition and fatty acid profiles. Individual fatty acids with greater than 2% concentrations (C16:0, C16:1, 18:0, C18:1, C18:2) were analyzed. Total saturated fatty acids (SFA) and total polyunsaturated fatty acids (PUFA) concentrations along with SFA:PUFA ratio and CIV were also analyzed. Genetic sample x sex, FP x sex, and GS x FP x sex interactions were removed at ($P > 0.05$). Hot carcass weight was used a covariate for LMA, BF (1st rib,10th rib, last rib, and last lumbar), belly stick test, and carcass length. Adjusted carcass length was used as a covariate for belly length. Pen was used as the experimental unit. Least squares means differences were evaluated using PDIFF and STDERR options of GLM.

Results

Carcass Composition

Least squares means and P-values for GS and FP are presented in Tables 3 and 4. A GS x FP interaction was observed where pigs from 2005 GS fed 1980 vs. 2005 FP showed a 15.4% increase in LMA while 1980 GS pigs fed 1980 vs. 2005 FP had an 8.2% increase.

Genetic Sample Differences. There was no difference between GS for carcass length, hot carcass weight, or dressing percent (Table 3). Longissimus dorsi muscle area was larger ($P < 0.01$) for pigs from 2005 vs. 1980 GS. Pigs from 2005 GS had less BF depth at first rib ($P < 0.05$), 10th rib ($P < 0.01$), last lumbar ($P < 0.01$), and tended ($P = 0.08$) to have less BF depth at the last rib than 1980 GS pigs. Bellies from 2005 GS pigs were firmer ($P < 0.05$) than 1980 GS pigs as measured by the stick test (Table 4). However, no other measurements taken from the belly differed between GS.

Feeding Program Differences. Pigs fed 1980 FP had longer carcasses ($P < 0.01$) than pigs fed 2005 FP (Table 3). Pigs fed 2005 FP had heavier carcasses ($P < 0.01$) but did not differ in slaughter weight from pigs fed 1980 FP (Fix, 2007) and thus had a higher ($P < 0.05$) dressing percent. Pigs fed 2005 FP had larger ($P < 0.01$) LMA than pigs fed 1980 FP. Pigs fed 2005 FP had more BF depth for first rib ($P<0.01$), last rib ($P<0.05$), and a tendency at last lumbar ($P < 0.10$) measurements than pigs fed 1980 FP; however, there was no difference in BF depth at the 10th rib measurement. Bellies from pigs fed 2005 FP were thicker ($P < 0.01$) on the loin edge but did not differ in belly thickness on the shoulder end, belly edge, or ham end from pigs fed 1980 FP (Table 4). Pigs fed 1980 FP had firmer bellies ($P < 0.01$) as measured by the stick test but did not differ in belly length from pigs fed 2005 FP.

Sex Differences. Gilts had longer ($P < 0.01$) carcasses than barrows (Appendix Table 5). Because gilts had lower live weight at slaughter (Fix, 2007) but did not differ in HCW, gilts had higher ($P < 0.01$) dressing percent than barrows. Gilts had larger ($P = 0.01$) LMA and less BF depth 1st rib ($P < 0.01$), 10th rib ($P < 0.01$), last rib ($P < 0.01$), and tended to have less BF depth at last lumbar ($P < 0.10$) than barrows. Bellies from barrows were thicker ($P < 0.01$) on the loin edge but did not differ in other belly thickness measures or belly length from gilts. Barrows had firmer ($P < 0.01$) bellies as measured by the stick test than gilts (Appendix Table 6.

Fatty Acid Composition

Subcutaneous Adipose Tissue from Pork Loins

Least squares means for fatty acid composition of subcutaneous adipose tissue taken from the loin primal are summarized in Table 5.

Genetic Sample Differences. Concentrations of C18:1 ($P < 0.05$) were lower in 2005 GS pigs while C16:1 did not differ between GS (Table 5). Pigs from 2005 GS had lower concentrations of C16:0 ($P = 0.05$) but did not differ for C18:0 between GS. However, total SFA concentration tended ($P = 0.07$) to be lower in 2005 GS pigs. Individual PUFA concentrations of C18:2 were higher ($P < 0.01$) in 2005 GS pigs. Subsequently, total PUFA concentrations in 2005 GS pigs were higher ($P < 0.01$). Due to differences in individual fatty acids the SFA:PUFA ratio was lower ($P < 0.01$) and CIV higher ($P < 0.01$) in 2005 GS pigs.

Feeding Program Differences. Pigs fed 2005 FP had lower concentrations of C18:1 ($P < 0.05$) and tended to have lower concentrations of C16:1 ($P = 0.10$) than pigs fed 1980 FP (Table 5). Concentrations of C16:0 and C18:0 were lower ($P < 0.01$) in pigs fed 2005 FP. Total SFA were lower ($P < 0.01$) in pigs fed 2005 FP vs. 1980 FP. Individual PUFA concentrations of C18:2 and total PUFA were considerably higher ($P < 0.01$) in pigs fed 2005 FP. Pigs fed 2005 FP had a lower ($P < 0.01$) SFA:PUFA ratio and higher ($P < 0.01$) CIV than pigs fed 1980 FP.

Sex Differences. Sex differences are presented in Appendix Table 7. There were no significant differences between sexes.

Subcutaneous Adipose Tissue from Pork Bellies

Least squares means for fatty acid composition of subcutaneous adipose tissue taken from the belly primal are summarized in Tables 6 and 7. A GS x FP x sex interaction ($P < 0.05$) for C18:0 concentration where 1980 GS barrows and 2005 GS gilts did not differ between FP while 2005 GS barrows and 1980 GS gilts fed 1980 vs. 2005 FP had higher concentrations. A similar three-way interaction ($P < 0.01$) where 1980 GS barrow and 2005 GS gilts fed 1980 vs. 2005 FP had higher concentration of C18:1 but 2005 GS barrows and 1980 GS gilts did not differ between FP. Genetic sample x FP x sex interactions for total SFA ($P = 0.01$) and total SFA:PUFA ($P < 0.05$) were observed where 1980 GS gilts and 2005 GS barrows and gilts differed between FP for SFA and SFA:PUFA while 1980 GS barrows did not.

Genetic Sample Differences. Monounsaturated fatty acid C18:1 did not differ between GS. Pigs from 2005 GS had lower concentrations of SFA C16:0 ($P < 0.05$) but did not differ for C18:0 concentrations from 1980 GS pigs. Consequently, total SFA concentration was higher ($P < 0.05$) in 1980 GS pigs. Concentrations of PUFA C18:2 ($P < 0.01$) and total PUFA ($P < 0.01$) were higher in pigs from 2005 GS pigs. As a result total SFA:PUFA was lower ($P = 0.01$) and CIV higher ($P < 0.05$) in 2005 GS pigs compared to 1980 GS pigs.

Feeding Program Differences. Pigs fed 1980 FP had higher monounsaturated fatty acids C16:1 ($P < 0.01$) and C18:1 ($P < 0.01$) than pigs fed 2005 FP. Pigs fed 1980 FP vs. 2005 FP had higher SFA concentrations of C16:0 ($P < 0.01$), C18:0 ($P < 0.05$), and total SFA ($P < 0.01$). Pigs fed 2005 FP had higher concentrations of C18:2 ($P < 0.01$) and total PUFA ($P < 0.01$) than pigs fed 1980 FP. Differences led to higher ($P < 0.01$) total SFA:PUFA ratio and lower ($P < 0.01$) CIV in pigs fed 1980 vs. 2005 FP.

Sex Differences. A GS x sex interaction ($P < 0.05$) was observed where 1980 vs. 2005 GS barrows did not differ in C16:0 concentrations however 2005 GS gilts had lower concentrations of C16:0 than 1980 GS gilts. No other differences between sexes were found.

Subcutaneous Adipose Tissue from Ham Pork Hams

Least squares means and P-values for fatty acid profiles of subcutaneous adipose tissue taken from the ham primal are summarized in Tables 8 and 9. A GS x FP x sex interaction ($P < 0.05$) for C18:0 where 1980 GS barrows, 1980 GS gilts, and 2005 GS barrows did not differ between FP but 2005 GS gilts fed 1980 vs. 2005 FP had higher concentrations of C18:0. Since C18:0 was the most prevalent SFA a comparable three-way interaction was observed for total SFA. Neither 1980 GS barrows nor gilts differed between FP, while 2005 GS barrows and gilts fed 1980 FP had higher total SFA concentrations than 2005 GS barrows and gilts fed 2005 FP. A GS x FP x sex ($P < 0.05$) was observed for C18:2 where barrows and gilts from 2005 GS had higher concentrations of C18:2 when fed 2005 FP; however, barrows and gilts from 1980 GS did not differ between FP. As a result of the C18:2 and SFA GS x FP x sex interactions, three-way interactions for SFA:PUFA ($P < 0.05$) and CIV ($P = 0.01$) were also significant. Gilts from 1980 GS did not differ between FP while 1980 GS barrows, 2005 GS barrows, and 2005 GS gilts fed 1980 vs. 2005 FP had higher SFA:PUFA and lower CIV.

Genetic sample x FP interactions were also significant. A GS x FP interaction ($P < 0.05$) for concentrations of C18:1 for 1980 GS pigs did not differ between FP; however, 2005 GS pigs fed 1980 FP had higher concentrations. Individual (C18:0 and C18:2) and total SFA and PUFA GS x FP interactions ($P < 0.01$) were observed where 1980 GS pigs did not differ between FP while 2005 GS pigs fed 1980 FP had lower PUFA and higher SFA concentrations. These interaction led to similar GS x FP interactions for total SFA:PUFA ($P< 0.01$) and CIV ($P < 0.01$).

Once again 1980 GS pigs did not differ between FP while 2005 GS pigs fed 1980 FP had higher SFA:PUFA ratio and lower CIV than 2005 GS pigs fed 2005 FP.

Genetic Sample Differences. Pigs from 2005 GS had lower ($P < 0.01$) C18:1 concentrations than pigs from 1980 GS. No other differences were observed between GS.

Feeding Program Differences. Concentrations of C18:1 ($P < 0.01$) monounsaturated fatty acids were higher in pigs fed 1980 FP while C16:1 did not differ between FP. Saturated fatty acids C16:0 ($P < 0.01$) and C18:0 ($P < 0.01$) concentrations were lower in pigs fed 2005 vs. 1980 FP. This led to higher ($P < 0.01$) concentrations of total SFA in pigs fed 1980 FP. Polyunsaturated fatty acid concentrations of C18:2 ($P < 0.01$) were higher in pigs fed 2005 FP which resulted in higher ($P < 0.01$) concentrations of total PUFA in those same pigs. Differences in SFA and PUFA between FP led to higher ($P < 0.01$) total SFA:PUFA and lower ($P < 0.01$) CIV for pigs fed 1980 FP.

Sex Differences. A GS x sex interaction ($P < 0.05$) was observed where 1980 GS barrows vs. gilts did not differ but 2005 GS barrows had lower concentrations of C18:1 than 2005 GS gilts. Barrows tended to have higher C18:0 ($P = 0.06$) which led to higher ($P < 0.05$) total SFA concentrations and subsequently lower ($P = 0.05$) CIV than gilts.

Discussion

Carcass Composition

The interaction of magnitude for LMA would suggest pigs under selection pressure for muscling and leanness over the past 25 yr had a greater response to changes in feeding programs. This is in agreement with McConnell et al. (1971), where lean type pigs fed high vs. low protein levels had larger LMA while fatter type pigs did not differ between high and low protein for

LMA. The response appears to be similar to growth differences reported in Fix (2007). Likely due to the 1980 FP inability to match nutrient requirements of either GS; however, it more closely meets the 1980 GS than 2005 GS. This results in a greater difference between FP for 2005 GS than 1980 GS.

It would be expected that no differences were observed between GS for carcass length, hot carcass weight and dressing percent. No selection pressure is generally placed on theses traits and there is little to no genetic correlation between these measures and commonly selected traits (Stewart et al., 1989; NPPC, 1995). The increase in LMA and reduction in BF over 25 yr agrees with genetic trends for the U.S. and Canadian swine industries (Hudson and Kennedy, 1985; Chen et al., 2002; Sullivan and Dean, 1994; Kennedy et al., 1996). Genetic selection for BF typically takes place at the 10th rib which would explain why 10th rib BF depth had the greatest difference between GS.

Belly firmness differences between GS may be due in part to pigs from 1980 GS being fatter. Increased fatness tends to result in greater amounts of SFA in the subcutaneous adipose tissue (Scott et al., 1981). Increased SFA results in firmer bellies (Rentfrow et al., 2003). This is also supported by our findings of fatty acid concentrations in the belly adipose tissue.

Differences between FP in carcass length, hot carcass weight and dressing percent are not in agreement with studies that evaluated pelleted diets (Baird, 1973; Wondra et al., 1995), added dietary fat (Engel et al., 2001) or increased protein and lysine (Hale and Southwell, 1967; Bereskin and Davey, 1978), all of which reported no changes due to those specific dietary changes. However, it is difficult to determine what interactions may have occurred amongst the feeding program changes. Increased carcass length in pigs fed 1980 FP could be a result of slower growing pigs that were older at slaughter and thus, more physiologically developed.

Increased carcass weight with no change in slaughter weight of pigs fed 2005 FP is likely due to the increased fat deposition and LMA of those pigs, both of which have been reported to have positive phenotypic correlations with dressing percent (Stewart and Schinckel, 1989). Increased LMA is in agreement with studies involving increased protein and/or lysine in diets (Hale and Southwell, 1967; Bereskin and Davey, 1978; Friesen et al., 1995; Robison et al., 2000). However, these papers also noted reduced BF or no difference in BF due to increased protein or lysine. Findings in our study were in contradiction as we found no difference between FP or increased BF in pigs fed 2005 FP. It is commonly accepted that pigs eat to meet their energy needs. Formulation for energy in the 1980 FP may have been low enough that pigs ate to their fill before consuming their energy requirement leading to slower growth (Fix, 2007), less muscle and less BF. A potential reason for no difference at the 10th rib BF depth but difference for the other three measures could be due to selection pressure for reduced BF at the 10th rib. Pigs fed similar feeding programs are selected for reduced BF depth; therefore, pigs selected are those with a genetic tendency to have less 10th rib BF on a similar feeding program.

Few papers involving changes in feeding regime such as ours evaluated belly thickness; however, Bereskin and Davey (1978) increased protein 4% and found no difference in belly thickness. Varying degrees of difference in belly thickness measures could be attributed to variation in fabrication.

Differences between sexes for BF, LMA, and carcass length are in agreement with the literature (Hale and South well, 1967; Bereskin and Davey, 1976, 1978). Hale and Southwell (1967) found similar differences in dressing percent between sexes. No difference observed in our study for belly thickness is likely due to variation in fabrication. The belly thickness difference which was observed is not in agreement with Bereskin and Davey (1978) which reported gilts had thicker bellies. Our difference in belly firmness is likely due to the increased fatness of barrows vs. gilts. A sex difference in belly firmness agrees with Gatlin et al. (2003) and is possibly due to increased fat in barrows which leads to more SFA and thus a firmer fat (Scott et al., 1981; De Smet et al., 2004).

Fatty Acid Composition

Several GS x FP x sex interactions for fatty acid concentrations were significant for adipose tissue collected from the belly and ham. Due to the many changes in feeding program and potential variation in genetic selection which has occurred it is difficult to determine what interactions may be occurring. Reasons for no GS x FP x sex interactions at loin location are unknown. However, it has been shown that adipose tissue taken from different sites on the pork carcass vary in fatty acid composition (Suzuki et al., 2006).

The GS x sex interaction for C16:0 in belly adipose tissue may be explained by similar differences in fat measure at the first rib. Barrows were similar in fat depth between GS while 2005 vs.1980 GS gilts had less fat depth which would agree with the higher SFA (C16:0) in the 1980 GS gilts. We realize these are different anatomical places; however, they are within close proximity to one another. However, the FP x sex interaction for C18:1 in adipose tissue taken from the ham does not appear to be explained by differences in fat depth measures within close proximity to the ham.

The GS x FP interactions for adipose tissue taken from the ham are all related. Concentrations of the various fatty acids from the 1980 GS pigs did not differ between FP while the 2005 GS pigs did. This is not explained by differences in fat depth. The 2005 GS pigs fed 1980 vs. 2005 FP are leaner which does not agree with our fatty acid concentrations. However, in agreement with the literature is that 2005 GS pigs fed 2005 FP had the highest PUFA concentrations and CIV. The 2005 GS is leaner and the 2005 FP has added lard. Both have been shown to increase PUFA and reduce SFA which leads to increased CIV (Scott et al., 1981; Rentfrow et al., 2003; Engel et al., 2003; Weber et al., 2006).

As previously discussed, fatty acid concentrations of adipose tissue vary at different locations of the pig carcass. However, genetic correlations between sites of adipose tissue for fatty acid concentrations have been shown to be both high and positive (Suzuki et al., 2006) indicating the concentrations should be similar between sites. Differences between GS for fatty acid composition of adipose tissue taken from the loin and belly are in agreement with the genetic correlations. Pigs are not generally selected based on fatty acid composition in their adipose tissue. Therefore, it is important to evaluate genetic correlations between fatty acids and the commonly selected traits of growth, muscling, and leanness. Genetic correlations between fatty acid concentrations and performance traits may explain our differences between GS. The 2005 GS were leaner and heavier muscled with higher PUFA and lower SFA concentrations which coincide with the genetic correlations reported in Suzuki et al., (2006). Scott et al. (1981) also found greater concentrations of SFA in pigs selected for increased BF depth and higher PUFA concentrations in pigs selected for reduced BF depth. Cameron et al. (2000) reported similar results for fatty acid concentrations in intramuscular adipose tissue. In this study pigs, selected for lean feed efficiency and lean growth rate had lower SFA concentrations in neutral lipid. Our findings of increased SFA concentrations and CIV in subcutaneous adipose tissue taken from the loin and belly agree with the literature. However, the lack of difference found between GS for fatty acid concentrations taken from ham adipose tissue is perplexing. Variation in magnitude of fatty acid concentration is expected between sites. However, this does not fully explain why no difference was found between GS. Fat is typically deposited from the anterior to the posterior end of the skeleton. A possibility is there was a greater fat difference in the anterior of the skeleton, where the loin and belly adipose tissue were collected than the posterior where the ham adipose tissue was collected.

Differences between FP for fatty acid concentrations were found at all sites. However, the magnitude of difference was not consistent across sites, which is in agreement with Weber et al. (2006). Decreased individual and total SFA and increased individual and total PUFA in adipose tissue taken from pigs fed 2005 FP is consistent with the literature for added choice white grease at the 5% level or higher (Engel et al., 2003; Rentfrow et al., 2003; Weber et al., 2006). Teye et al. (2006) fed high vs. low protein diets and noted similar increased total SFA, decreased total PUFA, and higher PUFA:SFA ratio as our high protein (2005 FP) vs. low protein diets (1980 FP). Differences found between FP in CIV were similar to those reported in Weber et al., (2006). This was expected due to CIV being calculated based on PUFA and SFA concentrations. Added dietary fat and increased protein are changes in FP which the literature has shown to most affect fatty acid profiles in pork adipose tissue. Adding dietary fat in the form of lard increases the amount of PUFA in the diet and it is well known that fatty acid profiles of animals reflects what they have been fed. Our findings appear to be in line with the literature (De Smet et al., 2004).

Only small differences were found between barrows and gilts for fatty acid concentrations. Studies which reported sex differences found higher SFA in barrows and less PUFA. Tendencies for higher C18:0 ($P = 0.06$) concentrations with higher ($P < 0.05$) total SFA concentration and lower ($P = 0.05$) CIV is in agreement (Suzuki et al., 2006). This is believed to be the result of both a sex effect and increased fat in barrows.

Muscling and leanness have shown vast improvements over 25 yr. The improvement in muscling is virtually equally attributable to both genetics and nutrition while nearly all the BF reduction is the result of genetic improvement. However, it appears these improvements have come at a cost. Both genetic and feeding program changes have resulted in increased PUFA concentrations in subcutaneous adipose tissue which resulted in increased CIV. While this may be beneficial for human health it is costly for the pork processing industry. The increase in CIV could lead to inefficiencies in slaughter which could reduce profitability for the swine industry. These results show that with improvements come unfavorably correlated responses.

This study provides the pork industry with a greater understanding of industry changes in pork carcass composition and fatty acid composition of adipose tissue from 1980 to 2005. Specifically, which phenotypic changes are attributable to genetics, nutrition or both. This combined with the results of other portions of this study, specifically, the growth and performance portion, could provide documentation to show what improvements have been made and areas for potential future studies to improve pork carcass composition. These results could also provide information which indicates not focusing on or at least being conscious of all economically important traits could result in inefficiencies within the swine industry.

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Table1. 1980 Feeding program

	Prestarter	Starter	Grower	Finisher
Calculated analysis				
Crude Protein,%	18.3	17.9	15.0	13.3
Metabolizable Energy, kcal/kg	3262	3299	3315	3317
Calcium,%	0.87	0.78	0.67	0.67
Phosphorus,%	0.74	0.70	0.60	0.56
Lysine,%	1.05	0.95	0.75	0.62

Table 2. 2005 Feeding program

	Prestarter	Starter 1	Starter 2	Grower 1	Grower 2	Finisher 1	Finisher 2
Calculated analysis							
Crude protein,%	22.6	22.3	22.1	17.9	16.9	14.7	12.0
Metabolizable energy, kcal/kg	3428	3405	3438	3630	3643	3655	3651
Calcium,%	0.84	0.79	0.72	0.52	0.48	0.43	0.39
Phosphorus,%	0.72	0.68	0.64	0.55	0.47	0.41	0.37
Lysine,%	1.51	1.43	1.36	1.22	1.13	0.94	0.73
Added antibiotics							
Chlortetracycline, g/t	440.92	440.92	440.92	440.92	-	-	-
Tiamulin, g/t	38.58	38.58	38.58	-	-	-	-
Tylosin, g/t	-	-	-	-	22.05	-	-
Virginiamycin, g/t	-	-	-	-	-	11.03	5.51
Added dietary fat							
Lard,%	2.84	3.73	4.67	6.95	6.97	6.97	6.67

Table 3. Effect of genetic sample and feeding program on carcass measurements

	Genetic sample						
	1980		2005		P-value[1]		
	Feeding program					Genetic sample	Feeding program
Trait	1980	2005	1980	2005	GS*FP		
Carcass length, cm	86.98	85.16	87.04	84.88	0.68	0.81	<0.01
Dressing percent, %	73.03	73.64	72.40	73.81	0.27	0.58	0.02
HCW, kg	84.88	87.31	85.42	88.05	0.90	0.44	<0.01
LMA[3], cm^2	36.84^{a}	39.87^{b}	42.73^{c}	49.31^{d}	0.04	<0.01	<0.01
Backfat (BF) depth							
BF 10th rib, cm	3.19a	3.30	2.51	2.41	0.25	<0.01	0.94
BF 1st rib, cm	3.99	4.34	3.73	4.09	0.96	0.04	<0.01
BF last rib, cm	2.89	3.05	2.72	2.92	0.75	0.08	0.05
BF last lumbar[2], cm	2.56	2.62	2.27	2.45	0.30	<0.01	0.09

$^{a-c}$ Least squares means with no common superscript differ ($P < 0.05$)

[1] P-values from final model; GS + FP + Sex + farrowing group + slaughter week + GS*FP

[2] Final model: GS + FP + sex + farrowing group + slaughter week + GS*FP + GS*sex

[3] LMA: loin muscle area

Table 4. Effect of genetic sample and feeding program on trimmed belly measurements

	Genetic sample						
	1980		2005		P-value[1]		
	Feeding program					Genetic sample	Feeding program
Trait	1980	2005	1980	2005	GS*FP		
Belly thickness							
Loin edge, cm	4.01	4.43	4.14	4.35	0.40	0.87	0.04
Teat edge, cm	3.25	3.53	3.41	3.63	0.84	0.41	0.14
Ham end, cm	3.63	3.75	3.66	3.88	0.82	0.71	0.46
Shoulder end, cm	4.90	4.78	5.24	4.75	0.34	0.45	0.17
Stick test[2], cm	33.54	20.62	27.70	19.12	0.13	0.02	<0.01
Belly length, cm	53.29	52.79	53.92	52.43	0.99	0.55	0.45

[1] P-values from final model; GS + FP + sex + farrowing group + slaughter week + GS*FP

[2] Belly stick test is a measure of belly firmness; higher value = more firm belly

Table 5. Effect of genetic sample and feeding program on fatty acid composition of subcutaneous adipose tissue taken from pork loins

	Genetic sample						
	1980		2005		P-value[1]		
	Feeding program					Genetic sample	Feeding program
Trait	1980	2005	1980	2005	GS*FP		
Palmitic acid; C16:0	24.40	21.70	23.60	21.18	0.64	0.05	<0.01
Palmitoleic acid; C16:1	2.15	1.93	2.03	1.94	0.36	0.54	0.10
Stearic acid; C18:0	14.88	13.05	14.63	12.80	0.99	0.42	<0.01
Oleic acid; C18:1	44.70	43.41	43.56	42.22	0.96	0.02	0.02
Linoleic acid; C18:2	9.91	15.44	11.87	17.72	0.80	<0.01	<0.01
Total SFA[2]	41.25	36.39	40.22	35.47	0.91	0.07	<0.01
Total PUFA[3]	10.55	16.71	12.74	19.23	0.81	<0.01	<0.01
SFA:PUFA[2][3]	4.03	2.31	3.34	1.97	0.27	<0.01	<0.01
CIV[4]	59.07	68.09	61.66	71.39	0.69	<0.01	<0.01

[1] P-values from final model; final model: GS + FP + sex + farrowing group + slaughter week + GS*FP

[2] SFA: saturated fatty acids

[3] PUFA: polyunsaturated fatty acids

[4] CIV: calculated iodine value

Table 6. Effect of genetic sample, feeding program and sex on fatty acid composition of subcutaneous adipose tissue taken from pork bellies

	Genetic sample									
	1980				2005					
	Feeding program									
	1980		2005		1980		2005		P-value[1]	
	Sex									Pooled SEM
Trait	B	G	B	G	B	G	B	G	GS*FP*S	
Palmitic acid; C16:0	24.47	26.07	22.82	22.92	24.67	24.20	22.11	21.95	0.10	0.423
Palmitoleic acid; C16:1	2.53	2.67	2.14	2.30	2.50	2.33	2.09	2.16	0.46	0.114
Stearic acid; C18:0	13.08	14.32	13.50	12.50	13.55	13.69	12.09	12.66	0.03	0.451
Oleic acid; C18: 1	47.10	44.76	42.85	43.94	44.85	45.44	44.04	43.28	0.01	0.680
Linoleic acid; C18:2	9.47	8.58	14.20	14.44	10.22	10.17	15.59	15.96	0.66	0.633
Total SFA[2]	39.91	42.30	37.94	36.96	40.13	39.80	35.83	36.09	0.01	0.670
Total PUFA[3]	9.82	8.95	15.40	15.65	10.98	10.89	16.96	17.29	0.71	0.708
SFA:PUFA[2][3]	4.27	5.15	3.74	2.93	4.23	4.22	1.73	2.51	0.03	0.426
CIV[4]	60.42	56.93	65.59	67.12	60.20	60.46	69.17	69.17	0.06	1.066

[1] P-values from complete model: GS + FP + sex + farrowing group + slaughter week + GS*FP + GS*sex + FP*sex + GS*FP*sex

[2] SFA: saturated fatty acids

[3] PUFA: polyunsaturated fatty acids

[4] CIV: calculated iodine value

Table 7. P-values of main effects and two-way interactions for fatty acid composition of subcutaneous adipose tissue taken from pork bellies

	P-value[1]					
Trait	GS	FP	Sex	GS*FP	GS*Sex	FP*Sex
Palmitic acid; C16:0[3]	0.02	<0.01	0.45	0.92	0.05	0.28
Palmitoleic acid; C16:1[2]	0.12	<0.01	0.72	0.61	0.19	0.36
Stearic acid; C18:0[2]	0.32	<0.01	0.47	0.03	0.68	0.12
Oleic acid; C18: 1[4]	0.63	<0.01	0.48	<0.01	0.53	0.24
Linoleic acid; C18:2[2]	<0.01	<0.01	0.94	0.70	0.55	0.35
Total SFA[4,5]	0.03	<0.01	0.34	0.49	0.23	0.06
Total PUFA[2,6]	<0.01	<0.01	0.91	0.93	0.63	0.41
SFA:PUFA[4,5,6]	0.01	<0.01	0.51	0.23	0.51	0.42
CIV[2,7]	0.02	<0.01	0.73	0.49	0.41	0.09

[1] P-values from complete model unless included in final model; complete model: GS + FP + sex + farrowing group + slaughter week + GS*FP + GS*sex + FP*sex + GS*FP*sex

[2] Final model: GS + FP + sex + farrowing group + slaughter week + GS*FP

[3] Final model: GS + FP + sex + farrowing group + slaughter week + GS*FP + GS*sex

[4] Final model: GS + FP + sex + farrowing group + slaughter week + GS*FP + GS*sex + FP*sex + GS*FP*sex

[5] SFA: saturated fatty acids

[6] PUFA: polyunsaturated fatty acids

[7] CIV: calculated iodine value

Table 8. Effect of genetic sample, feeding program and sex on fatty acid composition of subcutaneous adipose tissue taken from pork hams

	Genetic sample									
	1980				2005					
	Feeding program									
	1980		2005		1980		2005		P-value[1]	
	Sex									
Trait	B	G	B	G	B	G	B	G	GS*FP*S	Pooled SEM
Palmitic acid; C16:0	23.06	22.25	22.02	22.47	23.54	23.15	21.89	20.59	0.05	0.417
Palmitoleic acid; C16:1	1.86	1.86	1.77	1.81	1.88	1.89	1.73	1.75	0.90	0.079
Stearic acid; C18:0	14.82	14.00	14.01	14.28	15.29	14.99	14.45	13.17	0.04	0.371
Oleic acid; C18: 1	44.48	43.82	44.54	44.28	44.01	44.84	41.44	42.10	0.60	0.416
Linoleic acid; C18:2	11.09	13.68	13.19	12.66	10.39	10.39	15.62	17.47	0.02	0.781
Total SFA[2]	39.77	37.89	37.73	38.50	40.86	40.11	38.06	35.35	0.02	0.736
Total PUFA[3]	12.06	14.89	14.34	13.77	11.28	11.25	17.04	19.02	0.02	0.847
SFA:PUFA[2,3]	3.29	2.62	2.64	2.93	3.75	3.56	2.25	1.85	0.05	0.232
CIV[4]	61.03	65.18	64.81	63.68	59.35	60.00	66.61	70.54	0.01	1.041

[1] P-value from complete model: GS + FP + Sex + Farrowing group + slaughter week + GS*FP + GS*sex + FP*sex + GS*FP*sex

[2] SFA: saturated fatty acids

[3] PUFA: polyunsaturated fatty acids

[4] CIV: calculated iodine value

Table 9. P-values of main effects and two-way interactions for fatty acid composition of subcutaneous adipose tissue taken from pork hams

	P-value[1]					
Trait	GS	FP	Sex	GS*FP	GS*Sex	FP*Sex
Palmitic acid; C16:0[4]	0.63	<0.01	0.11	<0.01	0.21	0.75
Palmitoleic acid; C16:1[3]	0.81	0.09	0.72	0.52	0.99	0.81
Stearic acid; C18:0[4]	0.50	0.01	0.06	0.05	0.28	0.91
Oleic acid; C18:1[2]	<0.01	<0.01	0.62	<0.01	0.03	0.84
Linoleic acid; C18:2[4]	0.18	<0.01	0.10	<0.01	0.91	0.54
Total SFA[4,5]	0.83	<0.01	0.04	<0.01	0.22	0.72
Total PUFA[4,6]	0.18	<0.01	0.10	<0.01	0.89	0.53
SFA:PUFA[4,5,6]	0.93	<0.01	0.17	<0.01	0.73	0.22
CIV[4,7]	0.65	<0.01	0.05	<0.01	0.63	0.55

[1] P-values from complete model unless included in final model; complete model: GS + FP + sex + farrowing group + slaughter week + GS*FP + GS*sex + FP*sex + GS*FP*sex

[2] Final model: GS + FP + sex + farrowing group + slaughter week + GS*FP

[3] Final model: GS + FP + sex + farrowing group + slaughter week + GS*FP + GS*sex

[4] Final model: GS + FP + sex + farrowing group + slaughter week + GS*FP + GS*sex + FP*sex + GS*FP*sex

[5] SFA: saturated fatty acids

[6] PUFA: polyunsaturated fatty acids

[7] CIV: calculated iodine value

DIFFERENCES IN PORK QUALITY TRAITS AND SENSORY CHARACTERISTICS OF COMMERCIAL PIGS REPRESENTATIVE OF 1980 AND 2005 GENETIC TYPES WHEN REARED ON 1980 AND 2005 REPRESENTATIVE FEEDING PROGRAMS

Introduction

Pork quality is becoming more important to the swine industry due to emphasis being placed on consumer acceptance of the product (Brisbane and Chesnais, 1998; Emmet et al., 2000; Newcom et al., 2003). Genetic selection and changes in nutrition can affect intramuscular fat, color, water holding capacity, pH, and tenderness, which are the most common measures for pork quality (Barton-Gade, 1990; Schwab et al., 2006). Not until recently have these traits been emphasized in selection programs (J. Holl, personal communication, August, 2006; D. Casey, personal communication, March, 2007) and still, seldom receive the emphasis growth performance, muscling, and carcass leanness do. Therefore, it is important to evaluate genetic trends over the past 25 yr for the traits selected for and genetic correlation between those and pork quality traits.

Genetic trends throughout parts of 1980 to 2005 in the U.S. and Canadian swine industries show improvements have been made in growth performance, muscling, and leanness (Hudson and Kennedy, 1985; Sullivan and Dean, 1994; Kennedy et al., 1996; Chen et al., 2002). Genetic correlations vary between populations. However, genetic correlations for backfat, longissimus dorsi muscle area, and lean gain with pork quality traits indicate selection with emphasis on those three traits will lead to poorer pork quality traits (Lo et al., 1992; Hovenier et al., 1992; NPPC, 1995). Similar genetic correlations with eating quality indicate increased muscling and leanness leads to lower consumer acceptance as measured by taste panels (Lo et al., 1992; NPPC, 1995). Schwab et al. (2006) reported on the effect of long term selection for increased leanness on pork quality and found pigs sired by boars in the 1980’s had higher marbling, intramuscular fat, and more desirable tenderness than pigs sired by boars from the early 2000’s.

The level of protein and lysine in the diet affect intramuscular fat. Goerl et al. (1995) reported pigs fed the lowest percentage protein had the most intramuscular fat. Comparable results were reported in both Cisneros et al. (1996) and Witte et al. (2000) for lower levels of lysine in the diet prior to slaughter. Reducing lysine from in diets fed to hybrid gilts increased the intramuscular fat (Witte et al., 2000). Cisneros et al. (1996) fed 5.6 vs. 4.0 g/kg lysine for 21 or 35 d prior to slaughter and found less intramuscular fat in the gilts fed higher amounts of lysine. The literature for other feeding program differences in this study has shown no effects on pork quality or sensory characteristics.

This study was designed to evaluate the effects of genetic improvement and changes in nutrition over the past 25 yr on pork quality traits and sensory characteristics of pork LD muscle.

Materials and Methods

Genetic Samples, Feeding Programs and Management

This study was designed to compare pigs representative 1980 and 2005 genetic samples (GS) fed feeding programs (FP) representative of those time periods. This was accomplished using pigs farrowed from females from a control population, formed in 1979 at the University of Nebraska, Lincoln (Neal et al., 1989) and has been maintained at North Carolina State University since 1989 (Holl and Robison, 2003) bred to frozen semen from boars commercially available around 1980. Semen was made available from International Boar Semen (Eldora, IA) and Swine Genetics International, LTD. (Cambridge, IA). Feeding programs representing 1980 and 2005 (Fix, 2007a) feeding practices were used to assess effects of changes in feeding practices on pork quality and sensory characteristics. The 1980 FP was based on suggested formulations from the 1978 Pork Industry Handbook as reported in Krider et al. (1982). The 2005 FP was based on current industry practices. Both diets were corn and soybean meal based and complete details are outlined in Fix (2007a). Major differences between 1980 vs. 2005 FP included ingredient and nutrient composition, increased number of phases, meal diets vs. pelleted diets, no-antibiotics vs. antibiotics, added dietary fat vs. no added dietary fat, and no synthetic amino acids vs. synthetic amino acids. Important dietary aspects specific to this portion of the study are summarized in Tables 1 and 2 for 1980 and 2005 FP, respectively.

Fix, (2007a) provides complete details of the design and management of pigs during the growth portion of the study. However, a brief description follows. A 2 x 2 x 2 factorial design was used (2 GS, 2 FP, 2 sexes) with 3 pigs per pen (pen = 54) in two farrowing groups. Pigs were housed on solid concrete floors with 1.86 m2 per pig and provided ad libitum access to feed and water. All animal procedures were approved by the Institutional Animal Care and Use Committee of North Carolina State University.

Carcass Measures

Pigs were slaughtered by pen on a weekly basis when average BW of pigs in a pen exceeded 116 kg. Slaughter data was collected at a commercial abattoir (Bailey Foods, Bailey, NC).

Procedures for collection of carcass quality data followed NPPC (2000) recommendations. All carcass measures were taken from the right side of the carcass. Longissimus dorsi (LD) (10th rib face) and ham pH (semimembranosus) were measured at slaughter (45 min pH) and 24 h post mortem (ultimate pH) with an IQ240 (IQ Scientific Instruments Inc., Carlsbad, CA). Twenty-four h post mortem, after allowing a minimum of 30 min to bloom, subjective measures for color (1 = pale pinkish gray to white; 6 = darkish purple red), firmness (1 = soft; 3 = very firm) and wetness (1 = exudative; 3 = dry) were evaluated on the 10th rib face and ham face (all ham face measures on the gluteus medius muscle) according to NPPC (2000). Marbling (1 = 1% intramuscular fat; 10 = 10% intramuscular fat) was evaluated on the 10th rib face. Objective color was also measured in triplicate on the LD 10th rib face and ham face using a Minolta Chroma Meter CR-200 (Minolta, Ramsey, NJ) with D65 illuminant and calibrated with a standard white plate. Means for lightness (L*), redness (a*) and yellowness (b*) were calculated and used for analysis. Boneless LD were placed in ice and returned to the North Carolina State University Processed Meat Laboratory (Raleigh, NC). Samples (40-55 g) from LD were used to determine 48 h drip loss (Honikel, 1987). Fresh LD were vacuum packaged and stored at 0ºC for 7 days and then stored at -20ºC.

Within 7 months, LD were cut into 2.54 cm thick chops. Due to the small size of some LD there were slight variations in the chop number used for various tests. Chops were cut from beginning from the anterior portion of the boneless LD. The first chop was used for percent lipid analysis (IMF) in the muscle (Appendix Figure 4). The second or third chop was used for Warner-Bratzler shear force test. The third or fourth and fourth or fifth chops were used for consumer sensory analysis and trained flavor and descriptive panels, respectively.

Chops were sent to the University of Illinois (Urbana-Champaign, IL) for chemical analysis of percent lipid in the LD muscle. Proximate analysis for moisture and fat were conducted on duplicate samples similar to that of Novakofski et al. (1989). Samples were oven dried at 110°C for at least 24 h, before extraction in an azeotropic mixture of chloroform and methanol.

Warner-Bratzler shear force test was conducted based on recommendations from AMSA (1995). Chops were cooked on a Farberware model 150A electric grill (Farberware Inc., Bronx, NY) to an internal temperature of 70°C, a HH21 microprocessor thermometer (Omega Engineering Inc., Stamford, CT) equipped with a Type T thermocouple (Cu-CuNi) was used to monitor the internal temperature. Chop weights were collected immediately before and after cooking. Samples were wrapped in cellophane wrap and chilled (2-5°C) overnight. A minimum of four and maximum of six 1.27 cm cores were removed parallel to the muscle fibers from chops representing each pig. Cores were sheared using an Instron Universal Testing Machine (model 5565, Instron Corp., Norwood, MA) with Bluehill Software and a v-notch blade (G-R Electric, Manhattan, KS). Mean shear force values for all cores from a chop were used for analysis.

Thirty-six LD chops were randomly selected from each treatment for use in a consumer sensory panel. Samples were thawed for 24 h in a 5°C cooler. Chops were cooked to an internal temperature of 70°C as described in the Warner-Bratzler shear force test preparation. Following removal from the grill, chops were cut into 1.27 x 2.54 x 2.54 cm cubes and served to consumers. Ninety-three panelists were served chops identified with three digit treatment numbers in a random order. Samples were scored on a hedonic scale of 1-9 (1 = extreme disliking and 9 = extreme liking) for overall liking, texture liking and flavor liking and an intensity scale of 1-8 for juiciness intensity (1 = extremely dry and 8 = very juicy) and tenderness intensity (1 = extremely tough and 8 = extremely tender) (Appendix Table 5 and 6).

Chops from six LD from each treatment were randomly selected for trained flavor and texture descriptive panels. Chops were thawed, cooked, and served to panelists as described in consumer sensory analysis. Seven panelists, trained in the Sensory Spectrum™ (Meilgaard et al,

2007) method of descriptive analysis and each having over 1000 hours experience, developed a lexicon using product specific and non-product specific references. Fresh, non-enhanced pork LD from a local grocer were used as reference samples. A universal intensity scale was used to quantify aroma, flavor, and aftertaste attributes and ranged from 0 (minimum intensity) to 15 (maximum intensity). A product specific intensity scale (also 0 to 15) was used to quantify the texture attributes. Descriptors for flavor, aroma, and texture of the longissimus dorsi chop samples are described in Table 3.

Statistical Analysis

Statistical analysis of pork quality and sensory panels data was performed using the GLM procedure of SAS (SAS Inst., Inc, Cary, NC). Genetic sample (GS), feeding program (FP), sex, farrowing group, slaughter week, and interactions among GS, FP, and sex were used in the model to examine their effect on pork quality traits. Genetic sample, FP, and the interaction GS x FP were used in the model to examine consumer sensory panel traits. That model along with session, replicate, and panelist were used to evaluate their effect on the flavor and texture descriptive traits. Samples given to panelists for the consumer analysis had only known GS and FP. Therefore other effects were not included in the model. The sampling of chops for the trained panel was not a complete representation of all other independent variables (sex, farrowing group, and slaughter week). Consequently, those were not included in the model. Least squares means differences were evaluated using PDIFF and STDERR options of GLM.

Results and Discussion

Pork Quality of the Longissimus dorsi Muscle

Least square means and P-values for pork quality measures of the LD muscle are presented in Table 4. No GS x FP x sex interactions were significant. Genetic Sample x FP interactions for marbling ($P = 0.01$) and IMF ($P < 0.05$) were observed where LD from 2005 GS pigs fed 1980 FP had the greatest amount of marbling and IMF. Witte et al. (2000) and Cisneros et al. (1996) both reported increased intramuscular fat with lower levels of lysine which agrees with our study. It is also known that different genetics require different levels of lysine, particularly lean vs. non-lean (NRC, 1998). The interactions appear to result from the 1980 FP not meeting either GS lysine requirement to maximize lean growth. However, the 2005 GS showed the greatest reduction in lean gain when fed 1980 vs. 2005 FP (Fix, 2007a). This result would support the 2005 GS fed the 1980 FP having the highest percentage IMF. There tended to be a GS x FP interaction ($P < 0.10$) for Warner-Bratzler shear force test where 2005 GS pigs fed 1980 FP and 1980 GS pigs fed 2005 FP had lower shear force values.

Genetic Sample Differences. Both subjective marbling score and IMF in the LD were higher ($P < 0.01$) for LD from 2005 vs. 1980 GS pigs. Percentage drip loss measured on LD samples was less ($P < 0.05$) for LD from 2005 vs. 1980 GS pigs. The increase in IMF in LD from 1980 to 2005 is not in agreement with Lonergan et al. (2001) or Schwab et al. (2006). Both reported reduced intramuscular fat with selection for lean gain. However, the company which provided our 2005 GS incorporated intramuscular fat into their genetic selection criteria (J. Holl, personal communication, August, 2007). This could explain the observed increase in IMF. No other pork quality traits measured on the LD differed between GS. Genetic correlations reported by Lo et al. (1992), Hovenier et al. (1992), and NPPC (1995) indicate there is considerable variation in the genetic correlations between performance and pork quality traits. Subsequently, the lack of other differences between GS for pork quality traits of the LD is not unexpected.

Feeding Program Differences. Longissimus dorsi from pigs fed 1980 FP had higher ($P < 0.01$) subjective marbling score and IMF in the LD than LD from pigs fed 2005 FP. This agrees with Witte et al. (2000) and Cisneros et al. (1996) reports of lower levels of lysine increased intramuscular fat in the LD. Percentage drip loss measured on LD samples was lower ($P < 0.05$) in LD from pigs fed the 1980 vs. 2005 FP. Longissimus dorsi from pigs fed 1980 FP had higher ($P = 0.01$) 45 min pH and a tendency for higher ($P = 0.09$) ultimate pH than LD from pigs fed 2005 FP. Differences in drip loss and pH due to FP are not in agreement with Engel et al. (2001) who added 6% choice white grease, Goerl et al. (1995) who increased protein, or Witte et al. (2000) who increased lysine. All of which found no differences in pH or drip loss of the LD. Changes in FP may not have directly caused the differences in pH and drip loss. However, reductions in pH can cause increased drip loss (NPPC, 2000). Increased stress has been shown to increase pH measure 30 min post-slaughter and increase percentage drip loss of the LD muscle (Hambrecht et al., 2004). In our study pigs fed 2005 FP were more impaired in their mobility (Fix, 2007a) and therefore could have had greater stress during loading and unloading for slaughter. This increased stress may have led to higher 45 min pH and increased drip loss of the LD.

No differences in color and tenderness of the LD were in agreement with Engel et al. (2001) and Witte et al. (2000), reduced lysine, along with Baird (1973), pelleted vs. meal diets.

Sex Differences. Sex differences are presented in Appendix Table 8. A FP x sex interaction ($P < 0.01$) was observed for L* value of the LD where LD from gilts fed 2005 FP had the lowest L* (darkest) value. An explanation may be that gilts fed 2005 FP also tended to have the lowest IMF in the loin. Since L* value is a measure of lightness, less IMF which is white might result in a darker LD surface. A FP x sex interaction ($P < 0.05$) for subjective wetness score of the LD surface was significant. Barrows did not differ between FP while gilts fed 1980 vs. 2005 FP tended to have higher (less moisture) subjective wetness score. A FP x sex interaction ($P < 0.5$) for 48 h drip loss of the LD was observed where gilts did not differ between FP while barrows fed 1980 vs. 2005 FP had less drip loss. These interactions would seem to contradict one another but are difficult to interpret based on the combination of differences among FP and selection pressure which has occurred over 25 yr.

Pork Quality of the Ham

Least square means and P-values for pork quality measures of the ham are presented in Table 5. No GS x FP x sex or GS x FP interactions were significant.

Genetic Sample Differences. Hams from 1980 GS pigs were more ($P < 0.05$) red (a*) and more ($P < 0.01$) yellow (b*) than hams from 2005 GS pigs. Reasons for these differences are unknown. No genetic correlations between performance traits and the ham were found; however, those reported for the LD are small and inconsequential. Therefore, the differences in a* and b* were unexpected while the lack of other differences was expected.

Feeding Program Differences. Ham pH measured 24 h postmortem was higher ($P < 0.05$) and ham subjective wetness score was more desirable ($P < 0.05$) for hams from pigs fed 1980 vs. 2005 FP. Pigs fed 2005 FP were more restricted in their movement (Fix, 2007a) and thus could have been more stressed during loading and unloading which could result in higher pH and more purge (surface wetness). No studies were found involving pre-slaughter stress and its affect pH of the ham; however similar effects of stress on the LD and ham could be expected. No difference in the color of the ham face agrees with Goerl et al. (1995), where similar increases in protein did not affect the color.

Sex Differences. Sex differences are presented in Appendix Table 9. A GS x sex interaction ($P < 0.05$) was observed for 45 min pH of the ham where 1980 GS barrows vs. gilts and 2005 GS gilts vs. barrows tended to have lower pH values. A FP x sex interaction for L* value ($P < 0.01$) of the ham was observed. Barrows and gilts fed 1980 FP did not differ however barrows fed 2005 FP had higher L* (lighter color) value than gilts fed 2005 FP. Barrows and gilts differing on the 2005 FP is in agreement with Uttaro et al. (1993) which reported higher L* value in barrows. We do not have an explanation for the lack of difference between sexes fed 1980 FP.

Ultimate pH was higher ($P < 0.05$) in hams from gilts than barrows which does not agree with Barton-Gade (1987) where gilts had lower pH in the ham than barrows. Hams from barrows were more ($P < 0.01$) red (a*) and more ($P < 0.01$) yellow (b*) than hams from gilts. Uttaro et al. (1993) reported hams from barrows had a higher b*. This study also found higher L* for hams from barrows and no difference in a*, both of which contradict our findings. No other pork quality traits measured in the ham differed between sexes.

Consumer Sensory Analysis

Least square means and P-values for consumer sensory analysis traits are shown in Table 6. No GS x FP interactions were significant.

Genetic Sample Differences. No differences were observed between GS for consumer sensory panel traits. The only pork quality trait known to affect eating quality which differed between GS, was IMF. Lonergan et al. (2007) reported only a small amount of the variation in sensory quality is attributable to variation in IMF when pH is between 5.50 and 5.80. Indicating increased IMF with our levels of pH would minimally increase sensory traits. These data would appear to support Lonergan et al. (2007).

Feeding Program Differences. Longissimus dorsi samples from pigs fed 1980 FP had higher overall liking ($P < 0.01$), and texture liking ($P = 0.05$) with tendencies for higher flavor liking ($P = 0.08$) and juiciness intensity ($P = 0.07$) than LD samples from pigs fed 2005 FP. Huff-Lonergan et al. (2002) reported correlations between pH and sensory analysis which appear to agree with our findings of increased pH and lower consumer sensory traits for LD from pigs fed 2005 FP. Longissimus dorsi from pigs fed 2005 FP had lower 45 min pH and tended to have lower ultimate pH than LD from pigs fed 1980 FP. Also, increased IMF in loins from pigs fed 1980 FP in the 5.50 to 5.80 pH range could result in more desirable eating quality (Lonergan et al., 2007).

Trained Panel Analysis

Least square means and P-values for trained panel aroma, flavor and texture descriptors are presented in Table 7.

Flavor and Aroma Descriptors

A GS x FP interaction ($P < 0.01$) for cooked pork flavor of LD samples was observed. Chops from 1980 GS pigs did not differ between FP while chops from 2005 GS pigs fed 1980 vs. 2005 FP had more cooked pork flavor.

Genetic Sample Differences. Chops from 2005 GS pigs tended to have more ($P = 0.06$) metallic flavor than chops from 1980 GS pigs. No other flavor or aroma descriptors differed between GS.

Feeding Program Differences. Samples of LD muscle from pigs fed 1980 FP had more cooked pork aroma than samples from pigs fed 2005 FP. No other flavor or aroma descriptors different between FP.

No other studies were found involving differences in GS or FP similar to those in this study. Therefore, it is difficult to interpret these results. Of note, however, are differences found between FP in the consumer panel were not observed in the trained panel.

Texture Descriptors

Similar GS x FP interactions for hardness ($P < 0.01$) and fibrousness ($P < 0.01$) were observed where LD samples from 2005 GS pigs fed 2005 FP and 1980 GS pigs fed 1980 FP were the hardest and most fibrous. Similar GS x FP interactions for moisture release ($P < 0.01$) and juiciness ($P < 0.01$) was observed. Chops from 2005 GS pigs did not differ between FP while LD samples from 1980 GS pigs fed 1980 vs. 2005 FP had less moisture release and were less juicy. The GS x FP interactions appear to agree with one another. The tenderness measures are in agreement for a trend observed in Warner-Bratzler shear force where samples from 2005 GS pigs fed 2005 FP and 1980 GS pigs fed 1980 FP had a slight tendency to have higher shear force measures. A GS x FP interaction ($P < 0.01$) for number of chews resulted in chops from 1980 GS pigs not differing between FP while chops from 2005 GS pigs fed 2005 vs. 1980 FP required more chews. This result is also in agreement with other tenderness findings.

Genetic Sample Differences. Loin samples from 1980 GS pigs were juicier ($P < 0.01$) than samples from 2005 GS pigs. This does not agree with our findings for consumer sensory panel, pH, or IMF content of the LD. All of which suggest no difference in juiciness or LD from 2005 GS pigs should be juicier. No other texture descriptors differed between FP.

Feeding Program Differences. Samples of loin from pigs fed 1980 FP had more ($P < 0.05$) cohesiveness of mass. No other texture descriptors differed between FP.

Many of the differences in the trained panel analysis are difficult to explain, particularly the interactions. Differences were found in pH, IMF, and fatty acid concentrations (Fix, 2007b) all of which have been shown to affect trained panel descriptors. Therefore it is hard to speculate the exact causes of differences observed in trained panel descriptors.

Based on findings from this study, it appears changes in pork quality, consumer acceptance, and trained panel descriptors have been minimal over 25 yr. Genetic improvements have increased IMF content and reduced drip loss of the LD muscle. Unfortunately, changes in feeding programs have virtually nullified these advancements by reducing IMF, reducing pH, and increasing drip loss of the LD muscle. Feeding program changes have also resulted in increased pH in the ham. The unfavorable effects of changes in feeding practices on pork quality traits resulted in reduced consumer acceptance. Results from the trained panel are inconsistent and show interactions occurring between GS and FP.

These results, along with other portions of this study suggest improvements in pork quality measures and growth performance can coincide. While changes in FP did result in improved performance traits, unfortunately these changes came at a cost to pork quality traits. Not all changes in pork quality measures resulted in changes in consumer acceptance. Improvements in pork quality traits due to genetic changes did not translate into greater consumer acceptance; however reductions in the same traits due to changes in FP did result in lower consumer acceptance.

These results could allow the industry to evaluate what improvements have been made in the U.S. swine industry over the past 25 yr in pork quality and consumer acceptance. They also could provide the industry with documentation that can be used to determine what areas within pork quality can be improved to increase overall consumer acceptance of pork products.

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Table1. 1980 Feeding program

	Prestarter	Starter	Grower	Finisher
Calculated analysis				
Crude Protein,%	18.3	17.9	15.0	13.3
Metabolizable Energy, kcal/kg	3262	3299	3315	3317
Calcium,%	0.87	0.78	0.67	0.67
Phosphorus,%	0.74	0.70	0.60	0.56
Lysine,%	1.05	0.95	0.75	0.62

Table 2. 2005 Feeding program

	Prestarter	Starter 1	Starter 2	Grower 1	Grower 2	Finisher 1	Finisher 2
Calculated analysis							
Crude protein,%	22.6	22.3	22.1	17.9	16.9	14.7	12.0
Metabolizable energy, kcal/kg	3428	3405	3438	3630	3643	3655	3651
Calcium,%	0.84	0.79	0.72	0.52	0.48	0.43	0.39
Phosphorus,%	0.72	0.68	0.64	0.55	0.47	0.41	0.37
Lysine,%	1.51	1.43	1.36	1.22	1.13	0.94	0.73
Added antibiotics							
Chlortetracycline, g/t	440.92	440.92	440.92	440.92	-	-	-
Tiamulin, g/t	38.58	38.58	38.58	-	-	-	-
Tylosin, g/t	-	-	-	-	22.05	-	-
Virginiamycin, g/t	-	-	-	-	-	11.03	5.51
Added dietary fat							
Lard,%	2.84	3.73	4.67	6.95	6.97	6.97	6.67

Table 3. Definitions used by trained sensory panelists to describe the aroma, flavor, and texture of loin samples

Descriptor	Definition
Flavor and aroma	
Cooked uncured pork; aroma	Meaty aromatic associated with uncured lean pork muscle
Cooked uncured pork; flavor	Meaty aromatic associated with uncured lean pork muscle
Piggy/ Boar taint	Wet pig; the musk-like aroma associated with boar meat
Metallic	Flavor resembling tin or copper penny held in mouth; also blood or serum
Oxidized	General term for the oxidized characteristic(s) of foods such as cardboard, painty, and stale
Astringent	Mouth feel sensation of shrinking, drawing, or puckering of skin surfaces of the oral cavity, or tooth coating
Sweet	Basic taste stimulated on the tongue by sugars and high potency sweeteners
Salt	Salt water; also basic taste on the tongue stimulated by sodium salt
Sour	Pungent, sharp aromatic; also the basic taste on the tongue associated with acids
Bitter	Taste stimulated by substances such as caffeine or quinine when solubilized
Texture	
Hardness	Force required to bring incisors together on first bite
Moisture release	Degree to which juices (moisture and/or fat) exude from product
Cohesiveness of mass	Degree to which sample product holds together in mass
Juiciness	Degree to which juices (moisture and/or fat) are perceived in the product during mastication
Fibrous/geometrical	Degree to which sample is fibrous or stringy
Number of chews	Number of chews required to prepare sample for swallowing (masticating at one chew/s)
Oily mouth coating	Degree to which oil is coating mouth surfaces

Table 4. Effect of genetic sample and feeding program on pork quality of the loin muscle

	Genetic sample						
	1980		2005		P-value[1]		
	Feeding program						
Trait	1980	2005	1980	2005	GS*FP	GS	FP
pH at 45 min[1]	6.28	6.13	6.28	6.10	0.77	0.78	0.01
pH at 24 h[2]	5.69	5.66	5.74	5.60	0.21	0.99	0.09
L*[3]	53.22	52.14	53.20	52.42	0.77	0.82	0.13
a*[2]	9.39^{ab}	9.38^{ab}	10.06^{a}	8.93^{b}	0.09	0.75	0.14
b*[2]	6.45	6.26	6.76	6.24	0.47	0.57	0.20
Color score[2,4]	2.30	2.20	2.56	2.38	0.75	0.15	0.38
Firmness score[2,4]	2.49	2.31	2.65	2.41	0.80	0.26	0.09
Wetness score[3,4]	2.55	2.43	2.57	2.58	0.51	0.45	0.69
Marbling score[2,4]	1.71^{a}	1.44^{a}	2.85^{b}	1.74^{a}	0.01	<0.01	<0.01
Lipid Content, %[2]	4.20^{a}	3.00^{b}	6.25^{c}	3.42^{ab}	0.02	<0.01	<0.01
Drip loss, %[3]	2.88	3.52	2.17	2.85	0.95	0.02	0.03
WBS[5], kg[2]	2.98	2.78	2.87	3.06	0.10	0.50	0.97

[a-c] Least squares means with no common superscript differ ($P < 0.05$)

[1] P-values from final model unless not included in final model then P-values are from complete model; complete model: GS + FP + sex + farrowing group + slaughter week + GS*FP + GS*sex + FP*sex + GS*FP*sex

[2] Final model: GS + FP + sex + farrowing group + slaughter week + GS*FP

[3] Final model: GS + FP + sex + farrowing group + slaughter week + GS*FP + FP*sex

[4] Scored on the following scales (NPPC, 2000): color score (1 to 6) 1 = pale pinkish gray to white and 6 = darkish purple red; firmness score (1 to 3) 1 = soft and 3 = very firm; wetness score (1 to 3) 1 = exudative and 3 = dry; marbling score (1 to 10) 1 = 1% intramuscular fat and 10 = 10% intramuscular fat

[5] WBS: Warner-Bratzler shear force test; measured in kg of force; lower value = more tenderness

Table 5. Effect of genetic sample and feeding program on pork quality of the ham

	Genetic sample						
	1980		2005		P-value[1]		
	Feeding program						
Trait	1980	2005	1980	2005	GS*FP	GS	FP
pH at 45 min[4]	5.96	5.89	5.88	5.97	0.17	0.98	0.86
pH at 24 h[2]	5.83	5.72	5.89	5.69	0.37	0.74	0.01
L*[3]	50.52	50.33	49.82	50.25	0.66	0.62	0.90
a*[2]	11.03	11.54	10.65	10.23	0.16	0.02	0.91
b*[2]	4.13	4.61	3.56	3.67	0.42	<0.01	0.29
Color score[25]	2.73	2.77	2.90	2.64	0.46	0.91	0.65
Firmness score[25]	2.18	2.05	2.41	2.23	0.90	0.31	0.48
Wetness score[25]	2.02	1.84	2.31	1.62	0.10	0.85	0.02

[1] P-values from final model unless not included in final model then P-values are from complete model; complete model: GS + FP + sex + farrowing group + slaughter week + GS*FP + GS*sex + FP*sex + GS*FP*sex

[2] Final model: GS + FP + sex + farrowing group + slaughter week + GS*FP

[3] Final model: GS + FP + sex + farrowing group + slaughter week + GS*FP + FP*sex

[4] Final model: GS + FP + sex + farrowing group + slaughter week + GS*FP + GS*sex

[5] Scored on the following scales (NPPC, 2000): color score (1 to 6) 1 = pale pinkish gray to white and 6 = darkish purple red; firmness score (1 to 3) 1 = soft and 3 = very firm; wetness score (1 to 3) 1 = exudative and 3 = dry

Table 6. Effect of genetic sample and feeding program on consumer sensory analysis of pork loin chops

	Genetic sample						
	1980		2005		P-value[1]		
	Feeding program						
Trait	1980	2005	1980	2005	GS*FP	GS	FP
Overall liking[2]	6.05	5.49	5.94	5.65	0.40	0.92	<0.01
Flavor liking[2]	5.89	5.46	5.79	5.63	0.42	0.84	0.08
Texture liking[2]	5.68	5.17	5.76	5.59	0.34	0.15	0.05
Juiciness intensity[3]	4.24	3.82	4.39	4.14	0.66	0.20	0.07
Tenderness intensity[3]	4.23	4.03	4.55	4.21	0.70	0.17	0.15

[1] P-values from full model; full model: GS + FP + GS*FP

[2] Ranked on a scale of (1 to 9) 1 = lowest liking and 9 = higher liking

[3] Ranked on a scale of (1 to 8) 1 = lowest intensity and 8 = highest intensity

Table 7. Effect of genetic sample and feeding program on trained flavor and texture descriptive panels

	Genetic sample				P-value[1]		
	1980		2005				
	Feeding program						
Trait	1980	2005	1980	2005	GS*FP	GS	FP
Flavor and aroma							
Cooked uncured pork; aroma	3.50^{a}	3.39^{a}	3.67^{b}	3.37^{a}	0.06	0.10	<0.01
Cooked uncured pork; flavor	4.77^{a}	4.87^{ab}	4.97^{b}	4.81^{a}	<0.01	0.11	0.48
Piggy/ boar taint	0.00	0.00	0.00	0.00	0.32	0.32	0.32
Metallic	1.54	1.57	1.62	1.61	0.63	0.06	0.76
Astringent	1.53	1.52	1.54	1.53	0.98	0.61	0.59
Oxidized	0.00	0.02	0.00	0.00	0.32	0.32	0.32
Sweet	1.57^{a}	1.59^{a}	1.61^{a}	1.56^{a}	0.07	0.95	0.48
Salt	0.48	0.50	0.54	0.48	0.42	0.59	0.60
Sour	1.78	1.77	1.78	1.84	0.27	0.23	0.46
Bitter	0.00	0.01	0.00	0.00	0.32	0.32	0.32
Texture							
Hardness	7.07^{a}	6.63^{b}	6.62^{b}	7.28^{a}	<0.01	0.27	0.25
Moisture release	3.65^{a}	4.02^{b}	3.76^{a}	3.67^{a}	<0.01	0.10	0.06
Cohesiveness of mass	6.51	6.28	6.47	6.33	0.54	0.95	0.02
Juiciness	4.10^{a}	4.36^{b}	4.14^{a}	3.99^{a}	<0.01	0.01	0.42
Fibrous/geometrical	5.38^{a}	5.21^{b}	5.21^{b}	5.47^{a}	<0.01	0.47	0.49
Oily mouth coating	0.56	0.57	0.59	0.58	0.36	0.20	0.88
Number of chews	35.94^{ab}	34.71^{a}	34.98^{a}	37.63^{b}	<0.01	0.15	0.29

$^{a-c}$ Least square means without common superscript differ ($P < 0.05$)

[1] P-values from full model; full model: GS + FP + session + replicate + panelist + GS*FP

DIFFERENCES IN NUTRIENT DIGESTIBILITY AND MANURE ODORANTS OF COMMERCIAL PIGS REPRESENTATIVE OF 1980 AND 2005 GENETIC TYPES WHEN REARED ON 1980 AND 2005 REPRESENTATIVE FEEDING PROGRAMS

INTRODUCTION

Both genetics and dietary improvements contributed significantly to increased growth performance of pigs over the last 25 years. Higher lean mass growth allows more nutrients to be deposited (Campbell and Taverner, 1988).Pigs with the genotypes of high lean tissue gain potential had been reported to have higher growth performance and higher protein deposition than the other pigs with the genotypes of medium lean gain potential (Friesen et al., 1994).

More balanced diets and a series of feed additives supplementation improved the feed digestibility. Growth performance was improved by enzyme supplementation even sometimes the effects on nutrients digestibility were not significant (Pettey et al., 2002). Harper et al. (1997) reported that phytase supplementation in low-phosphorus diets improved phytate P bioavailability and improved growth performance in growing-finishing pigs. The effect of phytase on reducing P excretion by improving P bioavailability was demonstrated already (Sands et al., 2001; Traylor et al., 2001; Nyachoti et al., 2006; Radcliffe et al., 2006). Smith et al. (2004) also reported that dietary phytase contributed to decrease the manure pH value and decreased ammonia emission. The contributions of genotype and diet to improvements in broilers' growth performance were evaluated by Havenstein et al. (1994; 2003). The results showed that both of modern genotypes and modern diets improved growth performance significantly (using 1991 diet increased BW of the 1957 genotype birds by 22% and increased BW of the 1957 genotype birds by 14%). However, the incidence of tibial dyschondroplasia

(TD) was much higher for the 1991 genotype birds which may caused by the extremely high growth speed.

The effects of low CP diet with crystalline amino acids supplementation on manure ammonia emissions were wildly accepted (Sutton et al., 1999; Panetta et al., 2006). Higher feed utilization ability also contributes to reduce odor-causing agents in manure because less substrate for bacterial activity, which produce odor compounds. Yokoyama et al. (1982) found weaning pigs on the chlortetracycline-sulfamethazine-penicillin diet tended to have a better growth performance and rate, attained a higher percentage weight gain, also tended to decrease fecal and urinary p-cresol. Addition of lincomycin sulfate in the diet had the similar tendency but with lower range. Pelleted pig diets also increased 3% of DM digestibility and 10% of N digestibility than meal diets (Wondra et al., 1995).

So far, no data was founded about the interactions between genotype and diet affect nutrients digestion and odorants emission in swine production. Therefore, the objective of our study was to compare the contribution of genotype or diet on the improved growth performance during the recent 25 years. This trial was designed to asses how these two factors affect nutrients digestion and retention in growing-finishing pigs, then probe how the genotype or diet affect on swine odor issue.

MATERIALS AND METHODS

Obtaining representative pigs of 1980 genotype: First parity white line females were obtained from an unselected commercial population formed in 1980 and has be maintained at NCSU since 1989. These sows were mated using frozen semen of Hampshire or Duroc boars of 1980.

Pigs representative of 2005 genotype of similar age were obtained from a NC swine production company.

All pigs were reared at the North Carolina Swine Evaluation Station in Clayton. After fallowing period, 28 piglets (14 pigs of 1980 genotype and 14 pigs of 2005 genotype) at approximately 7 kg BW were selected and allotted to a 2 x 2 factorial design (1980 genotype vs 2005 genotype, 1980 diet vs 2005 diet). Simple diet was fed to Group 1(1980 genotype, 1980 diet) and Group 2 (2005 genotype, 1980 diet) and modern diet was fed to Group 3 (1980 genotype, 2005 diet) and Group 4 (2005 genotype, 2005 diet). Total number of replicates were7 (6 for the modern genotype old diet group of the second batch) pigs within each group. The characteristics of diets were as table 1.

The pigs were allowed ad libitum access to feed and water. After the pigs' body weight reached to around 65 kg, 16 pigs with an initial average BW of 65.2 kg were transferred to Grinnells lab where the pigs were housed individually in metabolism cages (0.6 × 1.5 m) and given ad libitum access to feed and water. After 6 days of adaptation, each pig was fed by 6 g of Cr_2O_3 mixed with 300 diets on day seven and such a marked diet was fed again on day 10. The amounts of normal feed intake between the above two meals were recorded. Then total feces and urine was collected for around 3 days depending on the duration between the appearances of the two peaks of green feces.

Feces were collected quantitatively on wire screens and were frozen at -20°C until further chemical analysis was conducted. Urine also was collected quantitatively on slope-shaped stainless steel trays in plastic containers placed in ice to minimize gaseous losses of nitrogen. Quantity of feces and urine was recorded and frozen at -20°C as soon as it was collected twice daily.

Two weeks later, 11 pigs (only two pigs for the 1980 genotype and 1980 diet treatment) with an initial BW of 69.6 kg were used and all the procedures were same to the batch 1. All of the animal trial procedures were approved by the Institutional Animal Care and Use Committee of North Carolina State University.

After the animal trial, refrigerated feces and urine were mixed together and homogenized within respective animal (at the rates they were produced) and homogenized within respective animal. A portion of this manure was used to determine fresh manure ammonia emission and the remaining manure were stored in a 1-L plastic container and sit at room temperature for 21 days of anaerobic aging. Both fresh and aged manure were sampled for odor evaluation by a professional odor panel.

Ammonia emission of the manure samples was determined by placing 400 ml of the manure mixture in a rectangular (28 L × 9.5 W × 6 H cm) container (Super Oval 1, Tupperware Co., Orlando, Fl). Air was drawn through a flow meter (Cole Palmer, Vernon Hills, IL) at a rate of 1.4 L/min, the container with manure, and then through a gas dispersion tube (Fisher, Pittsburg, PA) placed in a 500 ml Erlenmeyer flask containing 400 ml dilute sulfuric acid (N/10) in order to trap the ammonia released from the manure. This sulfuric acid solution was sampled (6 ml) at 12, 24, 36, 48, 72, and 96 h and analyzed for ammonia using the procedure of Willis et al. (1996).

Feces samples were dried by a freeze dryer (Heto PowerDry LL3000, ATR, Laurel, MD) then all the samples as well as 2 feed samples were ground through a 1 mm screen for dry matter analysis and chemical analysis. Dry matter content of 2 feed samples, 27 fecal samples will be measure by dying to constant weight in an oven at 60 °C. GE will be determined by an adiabatic bomb calorimeter (model C5000, IKA, Wilmington, NC).

Feed samples (2), fecal samples (27) were sent to the Experimental Station Chemical

Laboratories (University of Missouri-Columbia, MO 65211) for chromium and P and N analyses (urine samples were measured for N only). N content was measured by the Kjedahl method (AOAC, 1990). Chromium was measured by an atomic absorption spectrometry after predigestion with periodic acid. Total P was measured by the AOAC method (AOAC, 1990).

Statistical analyses: To compare differences in measured variables among treatments, data were analyzed by two-way ANOVA using the GLM procedures of SAS (SAS Institute, Cary, NC) as a 2 × 2 factorial arrangement. The statistical model included main effects for genotype and diet and the genotype x diet interaction.

RESULTS AND DISCUSSION

The growth performance data were summarized in Table 4. In agreement to the previous studies (Havenstein et al., 2003; Friesen et al., 1994), our data indicated that both of modern genotype and modern diet improved the body weight of pigs and the contribution from diet was much higher than genotype. But the of feed intake of the 1980 genotype pigs fed by 2005 diet during the metabolism trial period, for some reason, was significantly lower than other groups. The low intake impaired other growth performance index such as ADG and feed/gain ratio. The possible reason maybe the nutrients density of the 2005 diet exceeded the lean tissue potential of the 1980 genotype pigs. More excess nutrients were transformed into fat which decreased pigs' ad libitum feed intake. Such a impact may be more significant during the metabolism trial period as the pigs were at finishing phase when the metabolism trial started.

Also in table 5, the feces mass excretion of 1980 genotype 2005 diet pigs were lower than other treatments. The interesting thing on table 5 is the lowest GE of non-urea stuff in dried urine sample also showed the 1980 genotype 2005 diet pigs. Which means more energy in the urine sample of this group of pigs was from urea. The possible reason for the high urea concentration is the amino acid levels in 2005 diet were higher than what the 1980 genotype pigs needed.

Similarly, in table 6, the N excretion from urine of the 1980 genotype 2005 diet pigs was higher than that of other groups, while the number of its N excretion from feces was lower than other groups. The lower fecal N excretion was consistent with its higher apparent CP and GE digestibility. Diet had extremely significant effect on apparent CP and GE digestibility improvement. While the highest number of 1980 genotype 2005 diet pigs may because of the lowest feed intake they had during the metabolism trial period. As for the N intake and N retention, the numbers of 1980 genotype 2005 diet pigs were significantly higher than those of other treatments and no any significant difference was noticed among the numbers of rest three treatments.

Table 7 listed the ammonia emissions from fresh or aged manure samples. There were no significant difference among all the treatment of fresh manure samples except for the data of 72 hours, which showed the manure of 2005 genotype pigs fed by 2005 diet emitted more higher on this point. The reason is hard to explain as no other specific related index was studied, also no fixed trend of ammonia emission profile with the time was found. And for the aged manure samples, the roughly trend was ammonia emissions from manure fed by 2005 diet were higher. The possible reason is 1980 diet relatively contained higher dietary fiber and the acidic fermentation products of fiber trapped more ammonium, so less ammonia was converted and emitted out.

Table 8 showed the result of odor scores evaluated by a professional panel. There was a slight trend that the aged manure of 2005 genotype pigs had higher odor intensity. The only significant difference was between the 1980 genotype 1980 diet treatment (lowest number) and the 2005 genotype 1980 diet treatment (highest number). The existence of such a difference also is hard to explain as data such as odorants concentration or odorants emissions were available.

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Table 1. Comparison of characteristics of 1980 vs 2005 feeding programs

1980 Feeding Program	**2005 Feeding Program**
Diet formulation common to 1980	Diet formulation common to 2005
No antibiotics	Antibiotics
No synthetic amino acids	Synthetic amino acids
Simple nursery diets	Complex nursery diets
Simple feeding program	Phased feeding program
No enzymes	Phytase
Meal feed	Pellet diet

Table 2. 1980 Feeding Program

	Prestarter	Starter	Grower	Finisher
Crude Protein, %	18.3	17.9	15.0	13.3
Metabolizable Energy, kcal/kg	3262	3299	3315	3317
Calcium, %	0.87	0.78	0.67	0.67
Phosphorus, %	0.74	0.70	0.60	0.56
Lysine, %	1.05	0.95	0.75	0.62
Amount budgeted per pig, kg	11.3	15.9	90.7	to market

Table 3. 2005 Feeding Program

	Prestarter	Starter 1	Starter 2	Grower 1	Grower 2	Finisher 1	Finisher 2
Crude Protein, %	22.6	22.3	22.1	17.9	16.9	14.7	12.0
Metabolizable Energy, kcal/kg	3428	3405	3438	3630	3643	3655	3651
Calcium, %	0.84	0.79	0.72	0.52	0.48	0.43	0.39
Phosphorus, %	0.72	0.68	0.64	0.55	0.47	0.41	0.37
Lysine, %	1.51	1.43	1.36	1.22	1.13	0.94	0.73
CTC, g/ton	400	400	400	400	-	-	-
Denaguard, g/ton	35	35	35	-	-	-	-
Tylan, g/ton	-	-	-	-	20	-	-
Stafac, g/ton	-	-	-	-	-	10	5
Amount budgeted per pig, kg	4.54	9.07	13.61	18.1	45.4	56.7	to market

Table 4. Effect of genotype and diet on growth performance[1].

Genotype	1980		2005		pooled	p value		
Diet	1980	2005	1980	2005	SEM	genotype	diet	genotype×diet
Start BW(kg)	58.89^{a}	68.04^{b}	61.75^{ab}	78.08^{c}	2.88	0.0352	0.0002	0.225
End BW (kg)	66.60^{a}	73.55^{a}	69.40^{a}	86.38^{b}	3.02	0.0168	0.0006	0.111
ADG (kg)	0.771^{a}	0.551^{b}	0.765^{a}	0.829^{a}	0.0741	0.0802	0.306	0.0677
ADFI (kg)	2.29^{a}	2.00^{b}	2.39^{a}	2.39^{a}	0.0890	0.0021	0.0524	0.0547
Feed: Gain	3.10	4.04	3.34	3.15	0.411	0.442	0.377	0.185

[1] Least squares means

^{ab} Means within a row with different superscripts differ ($P < 0.05$).

Table 5. Effect of genotype and diet program on waste excretion and feces sample dry matter[1].

Genotype	1980		2005		pooled	p value		
Diet	1980	2005	1980	2005	SEM	genotype	diet	genotype×diet
Feces weight per day (kg)	0.807^{a}	0.591^{b}	0.835^{a}	0.832^{a}	0.0655	0.055	0.112	0.122
Urine weight per day (kg)	1.978	1.848	1.930	1.684	0.191	0.588	0.340	0.766
Freeze dried urine GE (cal/g)	2387^{a}	2370^{a}	2396^{a}	2525^{b}	35.59	0.034	0.138	0.054
GE of non-urea stuff[2] in dried urine sample(cal/g)	1035^{a}	658^{b}	1053^{a}	1135^{a}	69.53	0.0022	0.049	0.0039
Feces dry matter ratio	0.324	0.341	0.323	0.320	0.0105	0.315	0.516	0.362
Feces dry matter per day (kg)	0.261^{a}	0.198^{b}	0.270^{a}	0.261^{a}	0.0183	0.069	0.067	0.160

[1] Least squares means

[2] Caculated as GE (per gram) of freeze dried urine minus GE (per gram) of urea

^{ab} Means within a row with different superscripts differ ($P < 0.05$).

Table 6. Effect of genotype and diet program on nutrients digestibility

Genotype	1980		2005		pooled	p value		
Diet	1980	2005	1980	2005	SEM	genotype	diet	genotype×diet
Apparent fecal CP digestibility	0.797^{a}	0.862^{b}	0.809^{a}	0.843^{b}	0.0101	0.742	<0.0001	0.113
Apparent fecal GE digestibility	0.848^{a}	0.894^{c}	0.859^{a}	0.884^{bc}	0.0067	0.957	<0.0001	0.124
Apparent fecal P digestibility	0.331	0.416	0.405	0.415	0.0364	0.332	0.202	0.308
N intake (g/ day)	39.2^{a}	48.9^{b}	44.2^{ab}	58.6^{c}	3.238	0.0367	0.0015	0.484
N excretion from feces (g/ day)	7.67^{ab}	6.71^{a}	8.26^{ab}	9.05^{b}	0.695	0.0474	0.905	0.222
N excretion from urine (g/ day)	6.23^{a}	16.01^{c}	10.44^{b}	12.68^{bc}	1.468	0.774	0.0018	0.0265
N retention (g/ day)	25.08^{a}	27.05^{a}	25.48^{a}	37.20^{b}	3.047	0.101	0.0377	0.128

[1] Least squares means

^{abc} Means within a row with different superscripts differ ($P < 0.05$).

Table 7. Effects of genotype and diet program on ammonia emissions of 400 mL fresh or aged manure samples[1].

Genotype	1980		2005		pooled	p value		
Diet	1980	2005	1980	2005	SEM	genotype	diet	genotype×diet
Fresh manure								
12 hour (mmol)	0.54	0.84	0.94	1.53	0.339	0.127	0.204	0.672
24 hour (mmol)	2.75	2.74	4.45	6.08	1.23	0.052	0.518	0.512
36 hour (mmol)	8.96	7.22	7.01	12.42	2.16	0.460	0.404	0.112
48 hour (mmol)	18.76	14.34	13.04	21.05	3.85	0.899	0.645	0.12
72 hour (mmol)	35.77^{ab}	26.81^{a}	28.05^{a}	41.34^{b}	4.89	0.494	0.663	0.033
96 hour (mmol)	40.14	36.42	39.05	44.03	3.37	0.345	0.855	0.211
Aged manure								
12 hour (mmol)	17.99^{a}	36.31^{b}	21.91^{a}	37.22^{b}	4.01	0.556	0.0005	0.713
24 hour (mmol)	30.24^{a}	46.88^{b}	36.64^{a}	55.90^{c}	4.76	0.124	0.0024	0.787
36 hour (mmol)	40.86^{a}	53.48^{ab}	46.28^{a}	59.89^{b}	4.52	0.209	0.010	0.915
48 hour (mmol)	44.46^{a}	50.04^{ab}	48.23^{a}	60.76^{b}	3.92	0.082	0.033	0.389
72 hour (mmol)	46.83^{ab}	48.01^{ab}	46.25^{a}	55.19^{b}	2.79	0.254	0.087	0.183
96 hour (mmol)	43.66^{a}	45.32^{a}	41.93^{a}	51.22^{b}	2.04	0.323	0.015	0.079

[1] Least squares means

^{abc} Means within a row with different superscripts differ ($P < 0.05$).

Table 8. Effects of genotype and diet program on manure odor intensity and hedonic score[1].

Genotype	1980		2005		pooled	p value		
Diet	1980	2005	1980	2005	SEM	genotype	diet	genotype×diet
Fresh manure odor intensity	2.35	2.35	2.44	2.34	0.183	0.815	0.781	0.798
Aged manure odor intensity	3.19^{a}	3.65^{ab}	3.83^{b}	3.75^{ab}	0.206	0.0866	0.367	0.214
Fresh manure hedonic score	-3.96	-2.88	-2.95	-3.08	0.261	0.713	0.944	0.690
Aged manure hedonic score	-4.63	-4.83	-4.73	-5.03	0.297	0.616	0.409	0.874

[1] Least squares means

^{ab} Means within a row with different superscripts differ ($P < 0.05$).