Effect of long-term selection for increased leanness on meat and eating quality traits in Duroc swine

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ABSTRACT: A study was conducted to evaluate differences in meat and eating quality traits between purebred Duroc pigs sired by boars currently available and pigs sired by boars from the mid 1980s. Two lines were developed by randomly allocating littermate and half-sib pairs of females to matings by current time period (CTP) or old time period (OTP) boars. Matings by CTP boars were made using fresh semen, and matings by OTP boars were via frozen semen. All available barrows and randomly selected gilts were sent to a commercial abattoir and used for meat and eating quality evaluation. A total of 178 pigs from 23 CTP sires and 99 pigs from 15 OTP sires, across 2 replications and at a mean live weight of 109 kg, were slaughtered and analyzed. Chemical intramuscular fat percentage was determined by lab analysis of a slice from the LM at the 10th rib. Additional meat and eating quality traits measured on the LM were Minolta reflectance and Hunter L color (24 h); pH (24 h and 7 d); water-holding capacity; subjective visual scores for color, marbling, and firmness (48 h); Instron tenderness; cooking loss; and trained sensory panel evaluations (7 d). Time period differences were assessed by use of a mixed model that included fixed effects of sire time period, replication, sex, contemporary group, and the interaction of sex × time period. The random effect of dam and the random effect of sire nested within time period were also included. Loins from pigs sired by OTP boars had greater intramuscular fat (3.48 vs. 3.09%) and visual marbling scores (3.54 vs. 3.07), required less Instron force (5.31 vs. 5.98 kg) to compress, and had darker visual color scores (4.09 vs. 3.87) compared with loins from pigs sired by CTP boars (P < 0.05). No differences were observed between time periods for Minolta reflectance, Hunter L (24 h), water-holding capacity, pH (24 h and 7 d), or subjective firmness scores. Trained sensory evaluations revealed more pork flavor and less off-flavor (P < 0.05) for OTP-sired pigs; however, no differences in tenderness score, juiciness score, chewiness score, or cooking loss were found between lines. Long-term selection response in carcass composition has been at the expense of meat and eating quality traits.

Key words: eating quality, leanness, meat quality, selection, swine

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INTRODUCTION

Initiation of grid-based marketing systems within the past 20 yr has allowed producers to receive increased value for hogs they market with increased lean percentage. Before 1985, 90% of hogs marketed were sold as traditional commodity pork, where price was determined on a live weight basis (Hayenga et al., 1985). Incentive-based marketing systems became increasingly important to add value to hogs marketed by producers, corresponding to increased selection for lean percentage. As a result, the percentage of hogs sold on a carcass merit basis rose to 28% in 1988, to 78% in 1997 (Brørsen et al., 1998), and to 83% in 2002 (Grimes and Plain, 2005).

In nearly 20 yr, pork producers have made tremendous strides toward providing a leaner product to the packer and ultimately to the consumer. However, through intense selection for increased carcass leanness, consumer acceptance issues have arisen as a result of decreased meat quality. Quality characteristics that play an integral role in consumer acceptance, such as tenderness, color, pH, and intramuscular fat, have decreased as breeders have intensely selected for increased leanness (Barton-Gade, 1990; Cameron, 1990).

Today, the Duroc breed is used extensively as a terminal sire in production of crossbred market hogs because of its growth rate and meat quality advantages over other breeds (NPPC, 1995). The primary objective of this study was to quantify the effect that selection for
decreased backfat and increased loin muscle area (LMA; i.e., increased percent lean) has had on meat and eating quality traits since the initiation of incentive-based hog pricing in the mid to late 1980s. The second objective was to investigate differences in phenotypic relationships among carcass composition, meat quality, and sensory traits that may have arisen due to marketing scheme changes since the mid 1980s.

**MATERIALS AND METHODS**

**Animals**

Experimental protocols for this study were approved by the Iowa State University Institutional Animal Care and Use Committee. Two lines were formed by randomly allocating littermate and half-sib pairs of females to matings by current time period (CTP) or old time period (OTP) boars. Boars from each time period were randomly selected from available resources from 2 commercially oriented regional boar studs (Swine Genetics International, Cambridge, IA; International Boar Siremen, Eldora, IA). All boars and females utilized in the study were DNA tested to ensure absence of the recessive mutant HAL1843 allele (Fujii et al., 1991).

Matings by CTP boars were made using fresh semen whereas matings by OTP boars were made using frozen semen. Six females per boar from the OTP and 5 females per boar from the CTP were mated to obtain a minimum of 3 litters per sire and to account for potential conception rate differences among fresh and frozen semen. Matings were performed across 2 subsequent breeding seasons. To reduce the effect of dam on pig performance across both lines, females were mated to CTP boars in the first parity, then subsequently mated to OTP boars in the second parity, and vice versa. Pigs were housed in a mechanically ventilated, curtain-sided finishing building with fully slotted floors and were allowed 0.77 m² of floor space each in pens of 20 to 25 pigs from 34 kg until they were marketed at an average BW of 109 kg. A 17.5% CP, 1.15% lysine corn-soy diet was provided ad libitum from 34 to 68 kg, followed by a 16.0% CP, 0.85% lysine corn-soy diet from 68 to 91 kg and a 15.0% CP, 0.70% lysine corn-soy diet from 91 kg to market weight.

**Carcass Evaluation**

Barrow and gilt progeny from 2 replications were weighed off test at a mean live weight of 109 kg. All available barrows and randomly selected gilts were slaughtered at a commercial abattoir (Hormel Foods, Austin, MN). Records on pigs sired by CTP boars (n = 178) represented 23 sires, whereas pigs sired by OTP boars (n = 99) were from 15 sires. Carcass measurements were obtained by Iowa State University personnel 24 h postmortem.

Standard carcass collection procedures, as outlined in Pork Composition and Quality Assessment Procedures (NPPC, 2000), were followed to obtain measurements of 10th-rib backfat (BF10) and LMA. Ultimate pH was measured on the 10th-rib face of the LM using a pH star probe (SFK Ltd, Hvidovre, Denmark). Hunter L (24 h) score and Minolta Reflectance (a measure of light reflectance, where lower values indicate darker and more desirable color) were measured on the 10th-rib face of the loin using a Minolta CR-310 (Minolta Camera Co., Ltd., Osaka, Japan) with a 50-mm-diameter aperture, D65 illuminant, and calibrated to the white calibration plate. A section of bone-in loin containing the 10th to 12th ribs was excised from the carcass and transported to the Iowa State University Meat Laboratory. A 3.2 mm slice from the 10th-rib face was then removed and utilized for intramuscular fat (IMF) determination (Bligh and Dyer, 1959).

The 11th and 12th rib sections were cut into 2.54-cm chops and set with the freshly cut side up for 10 min to allow the sample to bloom. Subjective measures of color (1 = pale pinkish gray to white; 6 = dark purplish red), marbling (1 = 1.0% IMF; 10 = 10.0% IMF), and firmness (1 = soft; 3 = very firm) were evaluated on the 11th rib face according to NPPC (2000) by a person trained in meat quality evaluation. Water-holding capacity was measured on the 11th-rib face by the filter paper method of Kauffman et al. (1986) and is reported in milligrams of water absorbed by the filter paper (lower values are more desirable).

**Sensory Evaluation**

The 11th and 12th rib chops were vacuum-packaged and taken to the Iowa State University Food Science Laboratory, where they were refrigerated at 0°C for 7 d. A trained sensory panel with 3 members evaluated cooked loin quality attributes (Huff-Lonergan et al., 2002). Chops were cooked to 71°C in an electric broiler (model ARE 640; Amana, Amana, IA), with the sample temperature monitored with Chromega/Alomega thermocouples attached to an Omega digital thermometer (DSS-650; Omega Engineering Inc., Stamford, CT). Weights before and immediately after cooking were used to calculate the percentage of cooking loss.

Three 1.3-cm³ cubes were removed from the center of the 11th-rib sample and evaluated by the trained sensory panel for juiciness (1 = dry; 10 = juicy), tenderness (1 = tough; 10 = tender), chewiness (1 = not chewy; 10 = very chewy), flavor (1 = little pork flavor, bland; 10 = extremely flavorful, abundant pork flavor), and off-flavor (1 = no off-flavor; 10 = abundant nonpork flavor) using an end-anchored, 10-point scoring system (AMSA, 1995). Individual booths with red overhead lighting were provided for each panelist. Room temperature, deionized distilled water, and unsalted crackers were served between samples to cleanse the palette. Sample evaluations were averaged across panelists for analysis. The 12th-rib section was evaluated for tenderness using an Instron Universal Testing Machine (model 1122, Instron Corp., Canton, MA) fitted with a
circular, 5-pointed star probe (9-mm diameter with 6 mm between points; Oltrogge-Hammernick and Prusa, 1987).

Statistical Analysis

Time period differences for meat and eating quality traits were assessed with the use of the Proc Mixed procedure of SAS (SAS Inst. Inc., Cary, NC). Least squares means and corresponding SE were computed with the use of the following mixed model:

\[
y_{ijklmnp} = TP_i + S_j + CG_k + b_1OD_l + b_2CWT_m + SR(TP)_{ni} + DM_p + \varepsilon_{ijklmnp},
\]

where

\[
y_{ijklmnp} = \text{the trait measured on pig m of sex j in time period i and in contemporary group k;}

TP_i = \text{fixed effect of time period i;}

S_j = \text{fixed effect of sex j;}

CG_k = \text{fixed effect of contemporary group k (based on on-test date);}

OD_l = \text{fixed effect of off-test date l;}

CWT_m = \text{linear effect of the carcass weight of pig m;}

SR(TP)_{ni} = \text{effect of sire n nested within time period i, assumed random with SR(TP)_{ni} \sim N(0, \sigma_{SR}^2);}

DM_p = \text{effect of dam p, assumed random with DM_p \sim N(0, \sigma_{DM}^2); and}

\varepsilon_{ijklmnp} = \text{residual with } \varepsilon_{ijklmnp} \sim N(0, \sigma^2).
\]

This model is the result of a stepwise process of fitting all 2-way interactions between fixed effects, along with second and third order polynomial effects of the covariate CWT, and subsequently removing nonsignificant \(P > 0.05\) individual effects sequentially. Associations between traits were determined by calculating phenotypic correlations with the use of the Proc Corr procedure of SAS.

RESULTS AND DISCUSSION

Carcass and Meat Quality Characteristics

Least squares means and corresponding SE for carcass and meat quality traits are presented by time period in Table 1.

Carcass Traits. The effect of sire time period was significant for measures of BF10 and LMA. Carcass evaluation revealed less BF10 and more LMA \(P < 0.05\) in pigs sired by CTP boars compared with OTP-sired pigs. Findings of this study confirm the success of industry-wide selection for carcass leanness and coincide with genetic and phenotypic trends reported by Kaplon et al. (1991) and Chen et al. (2002).

Table 1. Least squares means (±SE) for carcass and meat quality traits in purebred Duroc pigs sired by boars from 2 time periods

<table>
<thead>
<tr>
<th>Item</th>
<th>Time period1</th>
<th>Current</th>
<th>Old</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tenth-rib backfat, mm</td>
<td>20.32 ± 0.62a</td>
<td>28.19 ± 0.70b</td>
<td></td>
</tr>
<tr>
<td>Loin muscle area, cm²</td>
<td>41.73 ± 0.58b</td>
<td>34.83 ± 0.71b</td>
<td></td>
</tr>
<tr>
<td>Intramuscular fat percentage, %</td>
<td>3.09 ± 0.13a</td>
<td>3.48 ± 0.15b</td>
<td></td>
</tr>
<tr>
<td>Longissimus tenderness, kg</td>
<td>5.98 ± 0.12a</td>
<td>5.51 ± 0.13b</td>
<td></td>
</tr>
<tr>
<td>Subjective color score²</td>
<td>3.87 ± 0.08b</td>
<td>4.09 ± 0.08b</td>
<td></td>
</tr>
<tr>
<td>Subjective firmness score³</td>
<td>2.08 ± 0.04</td>
<td>2.14 ± 0.04</td>
<td></td>
</tr>
<tr>
<td>Subjective marbling score⁴</td>
<td>3.07 ± 0.13a</td>
<td>3.54 ± 0.15b</td>
<td></td>
</tr>
<tr>
<td>24 h Minolta reflectance, ⁵ %</td>
<td>22.70 ± 0.31</td>
<td>23.25 ± 0.34</td>
<td></td>
</tr>
<tr>
<td>24 h Hunter L value⁶</td>
<td>47.67 ± 0.32</td>
<td>48.10 ± 0.35</td>
<td></td>
</tr>
<tr>
<td>24 h pH</td>
<td>5.77 ± 0.02</td>
<td>5.80 ± 0.02</td>
<td></td>
</tr>
<tr>
<td>7 d pH</td>
<td>5.65 ± 0.01</td>
<td>5.65 ± 0.01</td>
<td></td>
</tr>
<tr>
<td>Water-holding capacity, mg</td>
<td>47.33 ± 2.31</td>
<td>47.75 ± 2.46</td>
<td></td>
</tr>
<tr>
<td>Percent cooking loss, %</td>
<td>19.09 ± 0.38</td>
<td>18.96 ± 0.42</td>
<td></td>
</tr>
</tbody>
</table>

¹Means with different superscripts within each row differ \(P < 0.05\).

<table>
<thead>
<tr>
<th>Item</th>
<th>Time period1</th>
<th>Current</th>
<th>Old</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hunter L values are objective measures of exposed lean color (0 = black; 100 = white).</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Intramuscular Fat. Loins from pigs sired by OTP boars had greater amounts of intramuscular fat compared with pigs sired by CTP boars \(P < 0.05\). Likewise, the OTP line had greater \(P < 0.05\) subjective marbling scores than the CTP line. Line differences for the 2 aforementioned traits are consistent in amplitude and illustrate that differences in IMF have arisen through long-term selection for carcass leanness as a result of their antagonistic genetic relationships documented by Berger et al. (1994) and Knapp et al. (1997). Though pigs from both lines are above acceptable levels of IMF (>3.0%), the advantage in IMF found in the OTP line would be beneficial in improving IMF in progeny if boars from this line were mated to females from genetic lines that are low in IMF.

Pork Color. Loins from pigs sired by OTP boars received greater \(P < 0.05\) subjective color scores than loins from pigs sired by CTP boars, indicating that the darker lean color observed in the OTP line may be detectable by consumers. No differences were observed \(P > 0.05\) between lines for Minolta reflectance and Hunter L values measured at 24 h postmortem. It is important to note that the inconsistency between these results may be influenced by the greater amounts of IMF \(P < 0.05\) in pigs sired by OTP boars. Objective measures of lean color were evaluated on a section of the exposed lean tissue, a portion of which is IMF. Thus, samples from the OTP line may have greater and less desirable reflectance values on consistent samples of lean color due to elevated levels of IMF.
Table 2. Least squares means (±SE) for sensory panel evaluation of eating quality traits in purebred Duroc pigs sired by boars from 2 time periods

<table>
<thead>
<tr>
<th>Item</th>
<th>Time period¹</th>
<th>Current</th>
<th>Old</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tenderness score</td>
<td></td>
<td>6.67 ± 0.19</td>
<td>7.19 ± 0.22</td>
<td>&gt;0.05</td>
</tr>
<tr>
<td>Flavor score</td>
<td></td>
<td>1.98 ± 0.10</td>
<td>2.35 ± 0.11</td>
<td>&gt;0.05</td>
</tr>
<tr>
<td>Off-flavor score</td>
<td></td>
<td>3.08 ± 0.14</td>
<td>2.63 ± 0.14</td>
<td>&gt;0.05</td>
</tr>
<tr>
<td>Juiciness score</td>
<td></td>
<td>6.12 ± 0.15</td>
<td>6.18 ± 0.16</td>
<td>&gt;0.05</td>
</tr>
<tr>
<td>Chewiness score</td>
<td></td>
<td>2.52 ± 0.13</td>
<td>2.23 ± 0.15</td>
<td>&gt;0.05</td>
</tr>
</tbody>
</table>

¹²Means with different superscripts within a row differ (P < 0.05).
²Current = pigs sired by boars commercially available in 2000; old = pigs sired by boars from the mid 1980s.

No difference was detected (P > 0.05) for slightly greater pH measurements at 24 h postmortem for pigs sired by OTP boars compared with pigs sired by CTP boars. No difference was detected (P > 0.05) for pH measured at 7 d postmortem. Evaluation of water-holding capacity, percent cooking loss, and subjective firmness scores revealed no difference (P > 0.05) between time periods in this study. Huffman et al. (2002) reported significant correlations between marbling and meat quality measures of firmness (r = 0.37), percent drip loss (r = –0.12), and 24 h pH (r = 0.15) to suggest that an increase in IMF should result in slightly firmer, less exudative product with greater pH at 24 h postmortem. The genetic correlations between IMF percentage and quality measures such as pH and various water retention properties reported by Sellier (1998) are small and similar to the phenotypic correlations found in this study.

Tenderness. Sire time period affected (P < 0.05) loin Instron tenderness in the current study as loins from pigs sired by OTP boars required less force (5.31 vs. 5.98 kg) to compress compared with loins from CTP-sired pigs. As intense selection pressure is applied to enhance carcass leanness, as was done by producers over the last 2 decades, an antagonistic genetic relationship between BF10 and tenderness (r = 0.12; Berger et al., 1994), may yield tenderness differences similar to those detected in the current study.

Sensory Panel Characteristics

Least squares means and corresponding SE for eating quality traits are presented by time period in Table 2. Palatability of pork is generally described and measured using a combination of sensory and objective measurements. Previous studies in beef cattle have evaluated in-plant measures of meat quality and their relationship with sensory evaluations of palatability. As illustrated by Thompson (2004), consumer panels are effective when used to estimate sensory attributes but have the disadvantage that the correlations between the different attributes are generally high within a given panelist. This complicates interpretation of relationships among sensory evaluations and carcass traits. Elevated levels of IMF percentage in pork have been reported to be associated with greater juiciness, more desirable flavor, greater tenderness, and greater overall palatability (Murray et al., 2004). However, as illustrated by Van Oeckel et al. (1999), IMF has a greater association with flavor (r = 0.31) and tenderness (r = 0.31) than with juiciness (r = 0.15).

Sensory panel evaluation revealed no differences in tenderness scores between pigs sired by boars from the 2 different time periods. As described by Thompson (2004), sensory evaluations of tenderness in beef tend to have a strong relationship with objective tenderness measures such as peak force. However, they are inherently more variable in nature and do not take into account the complex interactions that occur with flavor and juiciness during the eating process. Shakelford et al. (1995) examined the relationship between shear force and trained sensory panel tenderness ratings in beef cattle and reported that shear force did not accurately reflect differences in overall tenderness (a combined measurement of initial and sustained tenderness) and that overall tenderness varies much more than juiciness or flavor. Though differences in objective (Instron) tenderness values were detected between time periods in this study, such differences between lines may not be detectable by consumers.

Juiciness and Chewiness. Sensory panel scores for juiciness and chewiness of loins from OTP-sired pigs were not different from loins of CTP-sired pigs. Indirectly, these results are inconsistent with differences detected in IMF percentage between lines in this study. Greater levels of IMF in beef are associated with elevated juiciness as detected by taste panelists (Thompson, 2004). The lubrication effect of marbling, as stated by Thompson (2004), stimulates salivation and leads to the perception of increased juiciness.

Flavor and Off-Flavor. Significant differences were detected between time periods by sensory taste panelists for the evaluation of flavor and off-flavor. Pigs sired by OTP boars had greater (P < 0.05) pork flavor scores and lower off-flavor scores, producing loins with more pork flavor and less incidence of off-flavor than pigs sired by CTP boars. These results are consistent with documented relationships among various meat and eating quality traits. Flavor has a relatively strong relationship with IMF content (Van Oeckel et al., 1999); species-specific flavors are contained in fat and can affect taste panel evaluations of flavor.

Carcass lean percentage is a complicated trait influenced by many factors, many of which may be genetic. Unfavorable correlated responses, typically in the form of decreased meat quality, have resulted when strong selection emphasis is placed on this trait. This study illustrated that long-term selection response for increased carcass leanness has been at the expense of...
meat quality traits, namely IMF percentage, objective measures of tenderness, and visual color, as well as eating quality traits such as flavor and off-flavor scores.

**Phenotypic Correlations**

The unique population under study provides an opportunity to evaluate any changes in correlations that may have resulted from drastic changes in lean percentage over time. Relationships among measures of carcass composition, meat quality traits, and eating quality traits are presented by time period in Tables 3 and 4. In most cases, correlation coefficients among meat quality traits and sensory evaluation traits were in the same direction and similar in magnitude compared across both time periods. However, relationships between measures of carcass composition and meat quality yielded contrasting results between lines.

**Correlations Among Carcass Composition and Measures of Meat Quality.** Correlation coefficients among carcass composition and meat quality characteristics are presented in Table 3. Within both time periods, BF10 was negatively correlated ($P < 0.05$) with LMA and had a positive association with subjective marbling and IMF. These data are consistent with previous research (Huff-Lonergan et al., 2002) and indicate that fatter carcasses have less LMA and greater percentages of IMF. Within the CTP line, BF10 was associated with Minolta reflectance and Hunter L values. However, no significant correlation was detected between BF10 and either objective measure of loin color in the OTP line. Huff-Lonergan et al. (2002) reported a correlation of 0.19 between BF10 and Hunter L color, which is comparable to the findings for the CTP line in the current study.

Loin muscle area was more highly correlated with 24 h pH and subjective measures of color and firmness within the OTP line than in the CTP line. In all 3 cases, this correlation coefficient was not different from zero for pigs sired by CTP boars. Within the OTP line, the correlation between 24 h pH and measures of carcass composition (LMA and BF10) is significant and low to moderate in magnitude. However, these 2 correlation coefficients are not significantly different from zero within the CTP line, illustrating that the correlation between pH and measures of carcass composition has eroded as a result of long-term selection for carcass leanness. Relationships among these traits within the CTP line correspond favorably to previous reports (Huff-Lonergan et al., 2002; Hamilton et al., 2003).

**Correlations Among Carcass Composition, Meat Quality, and Sensory Attributes.** Correlation coefficients among carcass composition, meat quality, and sensory attributes are presented in Table 4. Relationships among measures of carcass composition and sensory attributes were comparable between time periods in this study. Within the CTP line, BF10 was correlated with juiciness score ($r = 0.25; P = 0.001$) and tenderness score ($r = 0.20; P = 0.006$), indicating that loins from pigs with more subcutaneous fat were perceived to be juicier and more tender by panelists. Loin muscle area was negatively correlated with flavor score ($r = -0.22; P = 0.004$) and positively correlated with off-flavor score ($r = 0.16; P = 0.031$) in pigs sired by CTP boars. These data indicate that loins from CTP-sired pigs with larger LMA measurements had less pork flavor and more off-flavor. Correlation coefficients between BF10 and sensory evaluations of juiciness score ($r = 0.22; P = 0.023$) and flavor score ($r = 0.25; P = 0.011$) were significant within the OTP line. This is as expected, because subcutaneous fat is typically associated with a greater amount of IMF, a contributor to product juiciness. No significant correlations were detected between LMA and sensory attributes within the OTP line.

### Table 3: Phenotypic correlations by time period among carcass composition and measures of meat quality in purebred Duroc pigs sired by boars from 2 time periods

<table>
<thead>
<tr>
<th>Item $^2$</th>
<th>BF10</th>
<th>LMA</th>
<th>pH</th>
<th>MIN</th>
<th>HUNT</th>
<th>C</th>
<th>M</th>
<th>F</th>
<th>WHC</th>
<th>IMF</th>
<th>CL</th>
<th>INST</th>
</tr>
</thead>
<tbody>
<tr>
<td>BF10</td>
<td>-0.23</td>
<td>0.01</td>
<td>0.16</td>
<td>0.16</td>
<td>0.10</td>
<td>0.45</td>
<td>-0.02</td>
<td>0.02</td>
<td>0.39</td>
<td>-0.14</td>
<td>-0.28</td>
<td></td>
</tr>
<tr>
<td>LMA</td>
<td>0.39</td>
<td>0.09</td>
<td>-0.07</td>
<td>-0.07</td>
<td>0.07</td>
<td>-0.19</td>
<td>0.05</td>
<td>-0.15</td>
<td>-0.23</td>
<td>-0.04</td>
<td>0.00</td>
<td></td>
</tr>
<tr>
<td>pH</td>
<td>0.25</td>
<td>-0.30</td>
<td>-0.34</td>
<td>-0.34</td>
<td>0.39</td>
<td>0.15</td>
<td>0.36</td>
<td>-0.41</td>
<td>0.09</td>
<td>-0.08</td>
<td>-0.26</td>
<td></td>
</tr>
<tr>
<td>MIN</td>
<td>0.01</td>
<td>-0.01</td>
<td>-0.15</td>
<td>0.99</td>
<td>-0.61</td>
<td>0.03</td>
<td>-0.37</td>
<td>0.55</td>
<td>0.21</td>
<td>0.14</td>
<td>0.13</td>
<td></td>
</tr>
<tr>
<td>HUNT</td>
<td>-0.03</td>
<td>0.00</td>
<td>-0.15</td>
<td>0.99</td>
<td>-0.61</td>
<td>0.03</td>
<td>-0.38</td>
<td>0.55</td>
<td>0.21</td>
<td>0.14</td>
<td>0.14</td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>0.16</td>
<td>0.22</td>
<td>-0.21</td>
<td>-0.66</td>
<td>-0.67</td>
<td>0.24</td>
<td>0.41</td>
<td>-0.49</td>
<td>0.00</td>
<td>-0.11</td>
<td>-0.24</td>
<td></td>
</tr>
<tr>
<td>M</td>
<td>0.50</td>
<td>-0.46</td>
<td>0.23</td>
<td>-0.05</td>
<td>-0.06</td>
<td>0.29</td>
<td>0.12</td>
<td>-0.07</td>
<td>0.68</td>
<td>-0.01</td>
<td>-0.28</td>
<td></td>
</tr>
<tr>
<td>F</td>
<td>0.18</td>
<td>0.28</td>
<td>0.18</td>
<td>-0.42</td>
<td>-0.42</td>
<td>0.54</td>
<td>0.33</td>
<td>-0.21</td>
<td>0.06</td>
<td>-0.16</td>
<td>-0.19</td>
<td></td>
</tr>
<tr>
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<td>0.03</td>
<td>0.65</td>
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<tr>
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</table>

1Correlations for current time period (pigs sired by boars commercially available in 2000) are above the diagonal; correlations for old time period (pigs sired by boars from mid 1980s) are below the diagonal; bold values indicate correlations that are different from zero ($P < 0.05$).

2BF10 = 10th-rib backfat, mm; LMA = loin muscle area, cm$^2$; pH = 24 h pH; MIN = 24 h Minolta reflectance, %; HUNT = 24 h Hunter L value (0 to 100); C = subjective color (1 to 6); M = subjective marbling (1 to 10); F = subjective firmness (1 to 6); WHC = water-holding capacity, mg; IMF = intramuscular fat percentage, %; CL = percent cooking loss, %; INST = Instron tenderness, kg.
gan et al. (2002) reported comparable significant correlations between BF10 and tenderness score (0.19), flavor score (0.24), and off-flavor score (0.21). Similarly, correlations were also reported between LMA and tenderness score (−0.18), flavor score (−0.16), and off-flavor (0.10). In general, these same relationships were found in the CTP-sired population used in this study. However, genetic relationships noted by NPPC (1995) show little or no consistent association among measures of carcass composition and sensory attributes, similar to phenotypic relationships within the OTP line in the current study. Although the relationships between carcass composition and measures of palatability found in the CTP line are significant and supported by previous research, the magnitude of the correlations are small enough to indicate that other factors outside of carcass composition may also contribute to such associations with sensory evaluations of pork.

**Correlations Among Meat and Eating Quality Traits.** Typically, pH measurements are used to predict several meat quality characteristics. Correlations of pH measured at 24 h postmortem with other quality traits were consistent across time periods. Because of the greater number of observations and smaller SE for correlations within the CTP line (data not shown), more correlations among meat and eating quality characteristics were significantly different from zero in this line. However, minimal differences in the magnitude of correlation coefficients among time periods were detected between pH and other measures of pork quality. Within the CTP line, water-holding capacity and all measures of color were highly associated with 24 h pH (Table 3), in a manner that indicated that greater loin pH values correspond to darker color and greater water retention. These correlations, though similar in direction, were not significantly different from zero within the OTP line, and this result is likely due to the lower number of observations in this line. The moderate associations between pH and measures of color found within the CTP line of this population are in agreement with several studies showing that greater pH values are related to darker loin color (De Vol et al., 1988; Hovenier et al., 1992; NPPC, 1995). A significant relationship, supported by reports of Huff-Lonergan et al. (2002), was found between subjective measures of marbling and firmness within the OTP line. The same relationship, however, was not significantly different from zero within the CTP line. A greater degree of IMF saturation found in OTP-sired pigs may aid in the firmness of loins within this line.

Numerous important relationships between various meat quality traits were detected across both time periods. Highly significant phenotypic associations between water-holding capacity and all measures of color were found for both lines, similar to genetic correlations reported by NPPC (1995). The significant association between percent IMF and Instron tenderness detected in both lines in this population is also supported by several studies involving percent lipid and shear force evaluations of tenderness, illustrating that greater percentages of IMF are correlated to enhanced tenderness of pork (De Vol et al., 1988; Huff-Lonergan et al., 2002). Additionally, a moderate correlation was detected between subjective firmness and all measures of color,
indicating that firmer loins are also darker in color. Percent cooking loss had a relationship significantly different from zero and moderate in magnitude with sensory attributes of juiciness score, tenderness score, and chewiness score (Table 4). Huff-Lonergan et al. (2002) also reported similar values for subjective firmness and Hunter L values, as well as the association between percent cooking loss and sensory evaluations of juiciness score and tenderness score.

**IMPLICATIONS**

Because of economic incentives initiated by packers during the mid 1980s, breeding programs have focused on selection for rapid production of lean pork during the last 2 decades. As markets are ultimately dictated by consumer preference, selection practices should include emphasis on pork quality (in addition to lean percentage) in commercial breeding programs. The fact that meat quality characteristics are influenced by many factors makes the prediction and genetic improvement of these traits difficult. Understanding the relationships among measures of pork quality is important if phenotypic variation is to be controlled and genetic progress is to be made. By quantifying the effect that long-term intensive selection for increased carcass leanness has had on meat quality characteristics and indicators of consumer acceptance, we may begin to identify opportunities for producers to add value to the pork products they produce.

**LITERATURE CITED**


