Introduction

A number of factors affect pork quality, with swine genetics, preslaughter handling, harvest, and pork carcass chilling having the greatest impacts. However, there is considerable evidence indicating that manipulating the nutrient composition of swine diets may offset the negative effects of genetic predisposition and/or pig handling on pork quality, and may actually enhance pork quality traits of well-handled pigs of good quality genotypes.

Pork quality traditionally refers to the measurement of muscle pH, color, firmness, marbling or intramuscular fat (IMF) content, shelf-life, and cooked pork palatability. Yet, domestic and international consumers may define pork quality in terms associated with environmental, ethical, and animal welfare aspects of pork production, whereas pork processors typically include fat color, firmness, and composition, as well as nutrient composition and microbiological safety in their definition of pork quality. The purpose of this review is to provide an overview of the effects of dietary modifications on: 1) postmortem muscle metabolism and technological quality attributes (i.e., pH, color, and water-holding capacity); 2) pork IMF content; 3) pork fat quality; 4) color and lipid stability during refrigerated storage/display; and 5) cooked pork palatability.

Dietary Effects on Postmortem Metabolism and Pork Quality

When blood is lost during exsanguinations, oxygen availability to muscles is eliminated, thereby shifting muscle metabolism from aerobic metabolism of lipids to anaerobic metabolism of muscle glycogen reserves. The end-product of anaerobic postmortem muscle metabolism is the accumulation of lactic acid, which, in turn, causes postmortem muscle pH to decline from approximately 7.1 to 7.3 to an ultimate pH value of 5.4 to 5.7. There are three basic pork quality defects associated with abnormal postmortem pH decline (Figure 1): pale, soft, and exudative (PSE) pork; dark, firm, and dry (DFD) pork; and red, soft, and exudative pork (RSE).

When muscle pH declines rapidly (falls below 5.8 to 6.0 within the first hour postmortem) due to excessive lactic acid accumulation, the high intramuscular acidity coupled with high muscle temperature results in muscle protein denaturation and the development of PSE pork. The rapid decrease in muscle pH can be attributed to the genetic predisposition (halothane or ryanodine receptor genotype in particular), preslaughter stress, or both acting in concert. Conversely, when muscle glycogen reserves are low, the accumulation of lactic acid is greatly curtailed; leading to ultimate pH values in excess of 6.0 being established early in the postmortem period and development of DFD pork. The low preslaughter muscle glycogen reserves are typically the synergistic effect of a combination of stressors increasing energy demands prior to slaughter. Lastly, there is a swine genotype, generally referred to as the Rendement Napole (RN-) gene that has abnormally high concentrations of muscle glycogen; therefore, excessive intramuscular lactic acid accumulation can cause ultimate muscle pH to decline to values less than 5.5. Even though the
The color of RSE pork is virtually normal, the extremely low pH causes muscle proteins to lose their affinity for water, which leads to excessive moisture losses (i.e., decreased water-holding capacity).

**Preslaughter Feed Withdrawal.** Obviously, manipulating preslaughter muscle glycogen reserves could lead to improvements in fresh pork color and water-holding capacity (WHC). In fact, there is considerable evidence that withholding feed from pigs for 16 to 36 h before slaughter effectively reduces longissimus muscle (LM) glycogen concentrations and elevates initial and ultimate muscle pH values, which, in turn, leads to the production of darker, more desirable colored pork with improved WHC of fresh pork [86]. However, short-duration feed withdrawal periods of 16 h or less have no appreciable effects on muscle glycogen reserves, postmortem pH decline, or fresh pork quality [39]. Moreover, it appears that withholding feed from RN-pigs for as long as 60 h prior to slaughter does not alter LM glycogen levels, indicating that preslaughter fasting, alone, is not an effective method of manipulating the abnormally high muscle glycogen reserves in pigs with this genetic mutation [18]. In addition to the beneficial effects on pork quality, preslaughter feed withdrawal also decreases pig mortality during transportation and lairage, reduces carcass contamination with pathogenic bacteria in response to puncture of the gastrointestinal tract, and produces less waste to be rendered and/or disposed [71].

**Glycogen-Reducing Diets.** Research has shown that feeding high-fat (17 to 19%), high-protein (19 to 25% CP) diets formulated with very low levels (<5%) of digestible carbohydrates will reduce muscle glycogen concentrations in pork LM at slaughter [15]. More importantly, 45-min, but not 24-h, postmortem muscle pH was elevated, and WHC was increased, in response to feeding these glycogen-reducing diets [81, 82]. The effects of glycogen-reducing diets on pork color are inconsistent, and there is little information to suggest cooked pork palatability is altered by feeding pigs high-protein/high-fat/low-carbohydrate diets prior to slaughter [15, 82].

**Other Dietary Modifications to Alter Postmortem Metabolism.** It is generally accepted that preslaughter stress affects muscle glycogen reserves and, ultimately, pork quality; so, it is plausible that modifying the pig’s response to a stressor could also modify muscle glycogen reserves. Supplementing swine diets with the amino acid tryptophan increases serotonin production, which has been shown to alleviate aggression in pigs and reduce circulating cortisol concentrations [47], and, more importantly, reduced the incidence of PSE pork [1]. Even though most of the recent research has failed to detect beneficial effects of dietary...
L-tryptophan supplementation on pork quality, Guzik and co-workers [47] demonstrated that pork from pigs fed 0.5% supplemental tryptophan for 5 d prior to slaughter received greater color scores and lower L* values than pork from minimally-handled pigs.

Magnesium (Mg) supplementation has also been shown to effectively reduce the stress response of pigs prior to slaughter and reduce the incidence of PSE pork [32]. More importantly, it has been regularly demonstrated that supplementing swine diets with Mg for as little as a week before slaughter will improve the WHC of fresh pork, regardless of Mg source [3]. Furthermore, research has shown that fresh pork color can be improved by either long- [5] or short-duration [32] Mg supplementation.

Within the body, creatine increases the bioavailability of phosphocreatine for cellular ATP production, especially in active muscle. This fact led researchers to test the supplementation of swine diets with creatine monohydrate to increase antemortem muscle phosphocreatine levels, thereby sparing muscle glycogen, and reducing the incidence of PSE pork. Initial pork LM pH values were increased by 5 d of supplementing swine diets with creatine monohydrate [107], and both James et al. [51] and Young et al. [107] reported that supplementing swine diets with creatine monohydrate reduced LM drip losses. Conversely, creatine supplementation does not appear to alter fresh pork color, marbling, or cooked pork palatability [16, 17, 51].

**Dietary Effects on Intramuscular Fat Content**

Intramuscular fat (IMF) content of pork plays an important role in consumers’ perceptions of cooked pork palatability [61], and it has been suggested that an IMF content between 2.5 and 3.0% is necessary for consumer acceptability of cooked pork [28]. Moreover, the majority of countries importing U. S. pork prefer IMF contents of at least 4%; however, the adoption of leaner swine genotypes by U. S. pig producers over the past two decades has reduced IMF contents to as low as 1.0%. Even though there are a number of swine genetic lines with the propensity for higher IMF deposition, there is a growing effort to increase the marbling/IMF content in today’s pork by manipulating swine nutrition.

**Dietary Protein and Amino Acid Effects on Pork IMF:** One strategy shown to effectively increase the IMF content of pork is reducing the crude protein (CP) and/or lysine content of swine diets (Table 1). When dietary CP levels were reduced in grower and finisher diets, IMF was increased 13.7 to 176.5% [42, 105], whereas reducing the dietary lysine content in diets of growing-finishing pigs elevated IMF content 66.7 to 136.8% [19, 21]. Obviously, long-term exposure of pigs to CP- and/or lysine-deficient diets will affect gain

| Table 1. Effect of reduced crude protein (CP) and/or lysine on the intramuscular fat content (IMF) of fresh pork. |
|-----------------|------------------|------------------|------------------|
| **Reference** | **Dietary CP (lysine) content, %** | **Control** | **Reduced** | **IMF change (%)** |
| Essen-Gustavsson et al. [38] | 18.5 (0.96) | 13.1 (0.64) | + 66.7* |
| Castell et al. [22] | 17.6 (0.81) | 11.9 (0.48) | +150.0* |
| Goerl et al. [42] | 25.0 | 10.0 | +176.5* |
| Kerr et al. [53] | 16.0 (0.82) | 12.0 (0.55) | +103.6* |
| Cisneros et al. [24] | 14.0 (0.56) | 10.0 (0.40) | + 50.0* |
| Blanchard et al. [19] | 20.5 (1.05) | 16.6 (0.70) | +100.0* |
| Cameron et al. [21] | 26.2 (1.57) | 15.7 (0.56) | +136.8* |
| Nold et al. [73] | 13.0 to 19.0 | 12.0 to 18.0 | + 19.6* |
| Bidner et al. [18] | (0.64) | (0.48) | + 25.7* |
| Wood et al. [105] | 20.0 (1.14) | 16.0 (0.68) | +13.4 to +54.6* |
| Teye et al. [91] | ~ 21.0 | ~18.0 | +64.7* |

*On an as-fed basis.

*Represents the percent change from the IMF content of pork from pigs fed the control diet (an asterisk [*] indicates a statistically significant [P < 0.05] difference from the control).

*Difference between control and treated diets was 1.6% CP in diets for boars, barrows, and gilts.

*The IMF change range is across all genders.

*Approximate CP levels because of the three different fat sources altered the CP content less than 0.5%.
and feed conversion efficiency detrimentally, but feeding lysine-reduced diets over the last 5 to 6 weeks of the finishing period had virtually no impact on performance and still IMF concentrations were increased in the LM [18, 24]. On the other hand, increasing CP and/or lysine levels in swine diets has been repeatedly shown to reduce IMF content of fresh pork. In fact, Johnston et al. [52] and Friesen et al. [40] observed linear reductions in LM marbling scores as the dietary lysine content increased from 0.54 to 1.4%.

Research out of the University of Illinois has shown that the addition of an extra 2.0% leucine in swine finishing diets increased pork marbling scores (20 to 30%) and IMF content in the LM (25 to 42%) and SM (18%), without altering pig performance [24]. It could be argued, however, that the increases in IMF were an indirect response to reductions in lysine intake caused by an amino acid imbalance incurred with the high levels of supplemental leucine rather than a direct effect of increasing dietary leucine levels 200%.

Feed and energy intake. Even though restricting feed intake of finishing pigs doesn’t affect muscle pH [59] or fresh pork color [86], feed restrictions of 75 to 80% ad libitum have been repeatedly shown to reduce IMF content between 8 and 27% [26, 59]. Interestingly, reducing the energy density of swine finishing diets does not alter IMF, or any other fresh pork quality attribute [60], nor is there evidence that the grain source incorporated in the diet affects marbling scores [87].

Fats and oils. Fats and oils have been used for decades to increase the caloric density of swine diets, but the effects of dietary fat levels and/or sources on pork IMF content are inconsistent. Feeding diets formulated with sunflower or canola oil has been shown to reduced LM marbling scores [68, 72]; however, Apple and others [12] observed that LM IMF content increased with increasing dietary corn oil, whereas LM IMF content was increased by approximately 25% in pigs fed diets containing 5% beef tallow [35]. For the most part, however, few studies have demonstrated an effect of dietary fats/oil on pork marbling scores [8, 37] or IMF content [69].

Conjugated linoleic acid (CLA) refers to a mixture of positional and geometric conjugated isomers of linoleic acid. Most synthetic CLA sources contain approximately 65% CLA isomers, and, since July, 2009, CLA is being marketed in the U. S. under the trade-name of Lutalin® (BASF SE, Ludwigshafen, Germany) for inclusion into swine and broiler diets. More importantly, there is substantial evidence that supplementing swine diets with CLA can increase LM marbling scores and/or IMF content (Table 2). Sun et al. [88] and Martin et al. [64] reported increases in IMF content ranging from as little as 12% to as much as 44%, whereas Wiegand et al. [100] demonstrated that incorporating 0.75% CLA in diets increased the IMF content in the LM of halothane-negative, halothane-carriers, and halothane-positive pigs by 17.8, 19.2, and 16.6% respectively.

Table 2. Effect of dietary conjugated linoleic acid (CLA) level on the intramuscular fat content (IMF) of fresh pork.

<table>
<thead>
<tr>
<th>Reference</th>
<th>CLA dose (%)</th>
<th>IMF change (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dugan et al. [33]</td>
<td>2.00</td>
<td>+ 22.2*</td>
</tr>
<tr>
<td>O’Quinn et al. [77]</td>
<td>0.50</td>
<td>+ 13.7</td>
</tr>
<tr>
<td>Wiegand et al. [100]</td>
<td>NN</td>
<td>0.75 + 17.8*</td>
</tr>
<tr>
<td></td>
<td>Nn</td>
<td>0.75 + 19.2*</td>
</tr>
<tr>
<td></td>
<td>nn</td>
<td>0.75 + 16.6*</td>
</tr>
<tr>
<td>Averette Gatlin et al. [14]</td>
<td>1.00</td>
<td>+ 18.8*</td>
</tr>
<tr>
<td>D’Souza &amp; Mullan [30]</td>
<td>Gilts</td>
<td>0.50 + 24.0*</td>
</tr>
<tr>
<td></td>
<td>Barrows</td>
<td>0.50 + 8.0</td>
</tr>
<tr>
<td>Tischendorf et al. [94]</td>
<td>2.00</td>
<td>+ 8.8</td>
</tr>
<tr>
<td>Wiegand et al. [102]</td>
<td>0.75</td>
<td>+ 25.9*</td>
</tr>
<tr>
<td>Migdal et al. [67]</td>
<td>2.00</td>
<td>+ 8.5</td>
</tr>
<tr>
<td>Sun et al. [88]</td>
<td>2.00</td>
<td>+ 12.5*</td>
</tr>
<tr>
<td></td>
<td>4.00</td>
<td>+ 29.2*</td>
</tr>
<tr>
<td>Martin et al. [64]</td>
<td>1.0</td>
<td>+ 30.8*</td>
</tr>
<tr>
<td></td>
<td>2.0</td>
<td>0.0</td>
</tr>
</tbody>
</table>

*Represents the percent change from the IMF content of pork from pigs fed the control diet (an asterisk [*] indicates a statistically significant [P < 0.05] difference from the control).
Vitamin A Supplementation. A derivative of vitamin A, retinoic acid, is involved in the regulation of adipose cell differentiation and proliferation, and, in theory, a retinoic acid deficiency may directly increase IMF content [29]. In fact, feeding cattle vitamin A-deficient diets increased LM marbling scores and/or IMF content without affecting performance or carcass composition ([45]. D’Souza et al. [31] also demonstrated that feeding vitamin A-restricted diets during the grower and finisher phases increased IMF content by almost 54%, whereas Olivares et al. [76] noted that feeding diets supplemented with 100,000 IU of vitamin A actually increased IMF in pigs with the genetic propensity for IMF, but not in high-lean genotypes. The evidence indicating that both vitamin A deficiencies and supranutritional dietary inclusion of vitamin A can increase pork IMF/marbling is promising; however, dietary inclusion levels, feeding durations, and interactive effects with other feedstuffs and feed additives are largely unknown, especially when fed to growing-finishing pigs.

Dietary Effects on Pork Fat Quality

The fatty acids in pork muscle and fat may be obtained from de novo synthesis from non-lipid substrates and the direct absorption of fatty acids from the pig’s diet. Glucose from the digestion of corn and barley, for example, will increase the proportion of saturated fatty acids (SFA) at the expense of polyunsaturated fatty acids (PUFA) absorbed from the oil fraction of concentrates [57]. However, as indicated previously, fat is routinely incorporated in swine diets to increase the energy density of the diet and reduce the content of dietary cereal grains, especially corn.

Dietary fat source and pork fat quality. The quality of the dietary fat source included in swine diets is dependent upon a number of factors, including iodine value (IV; a measure of the chemical unsaturation of the fat), titre (temperature at which a fat is completely solid), and melting point (temperature at which a fat is completely liquefied). Highly saturated fat sources, like tallow and lard, will have IV of 30 to 70 g of I/100 g of fat, titres of 32 to 47°C, and melting points of 45 to 50°C. Conversely, unsaturated oils from soybeans, canola, corn, sunflower, and safflower seeds will typically have IV greater than 100 g of I/100 g of fat, titre of less than 30°C, and melting points of 20°C, or less. Therefore, the fatty acid composition of pork fat depots will typically reflect the quality (i.e., fatty acid composition) of the fat and/or oil formulated into the diets.

Although there are apparent health benefits associated with the consumption of PUFA, increasing the polyunsaturation of pork fat leads to the development of soft fat. According to Whittington and co-workers [98], pork fat with a linoleic acid (C18:2n-6) content greater than 15% is classified as soft; thus, it is not surprising that feeding pigs fat sources high in C18:2n-6 content will also cause soft fat [68, 72] and pork bellies [9, 12]. Soft fat and pork bellies cause carcass handling and fabrication difficulties; reduced bacon yields; oily, almost opaque-appearing, unattractive products; reduced shelf-life; and, more importantly, discrimination by domestic consumers and export partners. Research has shown that belly thickness and firmness increased as the IV of the dietary fat source decreased from 80 to 20 [13]; so, feeding animal fats does not appear to depress fat and belly firmness/hardness [37] as severely as feeding plant oils. Interestingly, Shackelford et al. [85] reported that bacon from pigs fed sunflower, safflower or canola oil received much lower sensory scores for crispiness, chewiness, saltiness, flavor, and overall palatability than bacon from pigs fed diets devoid of added fat and diets formulated with tallow. Moreover, Teye and others [92] observed that pigs fed soybean oil-formulated diets product soft bacon and a greater number of low-quality, soft bacon slices.

There is growing evidence that between 50 and 60% of the change in the fatty acid composition of pork fat caused by manipulating the dietary fat source, inclusion level, or both, occurs during the first 14 to 35 d on the particular dietary fat source, and diminishes with a longer time on feed [104]. Apple et al. [6, 7] reported that the fatty acid profile of pork LM and subcutaneous fat was altered substantially within
the first 17.4 kg of BW gain, with IV of pork fat increasing almost 12 points during the first feeding phase in pigs fed 5% soybean oil (Table 3). In addition, Anderson and co-workers [2] found that the half-life of linolenic acid (C18:3n-3) in pork subcutaneous fat was almost 300 d; thus, the economic savings associated with increased efficiency during the grower phases, when high levels of fat are traditionally fed, may also cause damage to the fat quality of pigs at slaughter. Moreover, it is doubtful that removing all fat from the late-finishing diet or replacing an unsaturated fat source with tallow or a hydrogenated fat source will have dramatic effects on pork fat quality [9].

By-Products of Biofuel Production. In an attempt to reduce reliance upon fossil fuels considerable efforts have been made to generate biofuels from renewable resources. Ethanol production from corn, as well as sorghum and wheat, has increased substantially over the past 10 yr, leading to substantial supplies of dried distillers’ grains with solubles (DDGS) which can be incorporated in swine diets. The crude fat content of DDGS ranges between 10 and 15%, and the fat from DDGS has a high proportion of unsaturated fatty acids; thus, it is not surprising that feeding pigs high levels of DDGS increases the PUFA content and IV of pork subcutaneous fat [96, 106]. Moreover, the degree of polyunsaturation of fat in fresh pork bellies increases linearly with the amount of DDGS included in swine diets [96, 97], which leads to soft, pliable, undesirable fresh pork bellies [95, 97, 99]. Moreover, Weimer et al. [99] reported greater fat-lean separation with increased dietary DDGS, and Xu et al. [106] noted linear reductions in bacon fattiness and tenderness with increased dietary inclusion rates of DDGS, even though DDGS did not affect the crispiness, flavor, or overall acceptability of cooked bacon [99, 106].

New or recycled animal fats or vegetable oils can easily be converted into biodiesel, and, like DDGS, the major by-product of biodiesel production, glycerol, has received a great deal of interest as an energy source in swine diets. Mourot et al. [70] and Della Casa et al. [27] found that including 5 to 10% crude glycerol in swine diets increased the proportion of oleic acid (C18:1cis9) and all MUFA in pork backfat, whereas Mourot et al. [70] and Lammers et al. [56] observed reductions in C18:2n-6 in subcutaneous fat and muscle. Moreover, the reduction in fat polyunsaturation associated with feeding glycerol has been shown to produce firmer pork bellies [84].

Conjugated Linoleic Acid. Supplementing swine diets with CLA routinely increases the proportions of SFA, especially palmitic (C16:0) and stearic acid (C18:0), in both pork fat [34, 88] and muscle [64, 88]. There are conflicting results on the impact of CLA on the MUFA and PUFA composition of pork fat and muscle [63, 88]; however, the increases in SFA lead to reductions in IV [58] and firmer pork fat [34] and fresh bellies [58].

| Table 3. Interactive effect of dietary fat source and slaughter weight on the iodine value (IV) of the pork fat and muscle [6, 7]. |
|-----------------------------------------------|---------------|---------------|-----------------|-----------------|-----------------|
| Slaughter weight (kg)                          | 28.1          | 45.5          | 68.1            | 90.9            | 113.6           |
| Backfat                                        |               |               |                 |                 |                 |
| No fat                                         | 72.5<sup>def</sup> | 72.1<sup>def</sup> | 67.9<sup>ghi</sup> | 67.0<sup>f</sup> | 67.3<sup>ghi</sup> |
| Tallow                                         | 72.8<sup>ab</sup> | 70.5<sup>abc</sup> | 68.5<sup>ghi</sup> | 65.2<sup>f</sup> | 65.3<sup>g</sup> |
| Poultry fat                                      | 73.2<sup>de</sup> | 77.6<sup>e</sup> | 74.1<sup>d</sup> | 72.4<sup>def</sup> | 69.8<sup>ghi</sup> |
| Soybean oil                                      | 73.5<sup>d</sup> | 85.2<sup>a</sup> | 83.9<sup>ab</sup> | 85.7<sup>a</sup> | 82.6<sup>b</sup> |
| Longissimus muscle                               |               |               |                 |                 |                 |
| No fat                                         | 65.8<sup>b</sup> | 63.0<sup>de</sup> | 58.9<sup>g</sup> | 59.3<sup>a</sup> | 58.7<sup>a</sup> |
| Tallow                                         | 65.6<sup>bc</sup> | 63.3<sup>de</sup> | 62.2<sup>ef</sup> | 60.7<sup>ab</sup> | 59.3<sup>a</sup> |
| Poultry fat                                      | 65.2<sup>bcd</sup> | 67.2<sup>b</sup> | 63.6<sup>de</sup> | 61.8<sup>ef</sup> | 60.4<sup>g</sup> |
| Soybean oil                                      | 65.9<sup>b</sup> | 69.9<sup>a</sup> | 66.7<sup>b</sup> | 66.1<sup>b</sup> | 65.1<sup>bcd</sup> |

*<sup>-</sup>* <sup>a – j</sup> Within a tissue, means lacking a common superscript letter are different (<i>P</i> < 0.05).
Dietary Modifications on Lipid and Color Stability

It would be expected that any dietary modification that increases the PUFA content of pork would also increase the susceptibility of pork to lipid oxidation. Thus, a great deal of research has focused on either the feeding of antioxidants, especially vitamin E, as well as stimulating endogenous antioxidative enzymes via mineral supplementation.

**Vitamin E.** Vitamin E (α-tocopherol) is an antioxidant that protects cell membrane integrity and retards lipid oxidation, especially during refrigerated storage and/or retail display. So, it is not surprising that incorporating supranutritional levels of vitamin E in diets of growing-finishing swine may be the most widely tested nutritional modification to improve pork quality.

Research has repeatedly shown that feeding pigs an additional 100 to 200 mg/kg of dl-α-tocopheryl acetate effectively delays the onset of lipid oxidation in fresh whole-muscle pork cuts [20] and ground pork [79], as well as precooked [46] and cured pork products [25]. Vitamin E supplementation of cattle finishing diets not only slows the rate of discoloration but actually improves the color stability of fresh beef, but the vast majority of research has yet to prove any benefits of elevating the levels of vitamin E in swine diets with either dl-α-tocopheryl acetate [46, 79] or the natural-occurring stereoisomer, d-α-tocopheryl acetate [20], on fresh pork color or color stability during refrigerated storage.

**Vitamin C.** Vitamin C has antioxidant properties, and pigs typically produce adequate amounts of this water-soluble vitamin from D-glucose in the liver; yet, feeding ascorbic acid within 4 h of slaughter produced darker, redder pork [78]. However, neither short-term [75] nor long-term vitamin C supplementation [41] affected pork color or WHC. Furthermore, there is no evidence to suggest that supplementing swine diets with vitamin C improves the oxidative stability of LM lipids during storage or retail display [41], and, in fact, Ohene-Adjei and others [75] reported that feeding pigs diets formulated with elevated levels of vitamin C actually increased TBARS values of LM chops during refrigerated storage.

**Selenium.** Selenium (Se) is a component of the endogenous antioxidant enzyme glutathione peroxidase, and research has shown that serum glutathione peroxidase activity is increased by supplementing swine diets with either sodium selenite or a selenium-yeast compound [62]. Yet, the increased glutathione activity associated with supplemental Se does not equate into changes in fresh color and WHC [62] or lipid stability during storage of fresh pork [49].

**Manganese.** Manganese (Mn) and Mg are both divalent, transition metal cations that may be interchangeable in several biological functions; however, Mn is a required for the activation of superoxide dismutase, which is involved in the breakdown of superoxide free radicals; so, it was not surprising that TBARS values of fresh LM chops were reduced by dietary Mn supplementation [11], and the LM from pigs fed diets supplemented with 350 mg/kg of Mn were less discolored after 2 and 4 d [11] and 5, 6, and 7 d [83] of simulated retail display than the LM from non-supplemented pigs. Additional benefits of supplementing swine diets with Mn include increased LM pH and visual color scores, and reduced L* values of fresh pork LM [10, 11].

**Vitamin-Trace Mineral Removal.** There is growing sentiment among swine nutritionists that most grower-finisher diets are formulated to equal or, in most cases, exceed the NRC [74] requirements for vitamins and/or minerals. It is thought that reducing vitamins and minerals, especially during the last month of the finishing period, will reduce not only production costs but also excretion of phosphorus and other mineral elements into the environment [66]. Moreover, there is little evidence to suggest that removing all vitamins and trace minerals during the late-finishing phase will affect fresh pork color, marbling, or firmness, as well as Warner-Bratzler shear force (WBSF) values [23]. The lone disadvantage of vitamin and trace mineral removal may be that TBARS values were elevated during refrigerated storage by vitamin/trace mineral removal [23], whereas fortifying finishing diets with 150, 200, and 250% of the NRC [74] vitamin and trace minerals during the last few weeks before slaughter substantially reduced TBARS values during as much as 3 weeks of refrigerated storage [23, 48].
Dietary Modifications on Cooked Pork Palatability

Even though fresh pork color is the single most important factor in the purchasing decision of a consumer, their perception of cooked pork palatability will impact whether or not they purchase pork again. Therefore, it is vitally important that palatability is either not affected or improved by any dietary modification.

**Crude Protein/Lysine.** Shear force values of cooked LM chops increased almost 23% as CP content increased from 10 to 22% in the finishing diet [42]. Furthermore, Goodband et al. [43, 44] reported linear increases in WBSF values in cooked LM and SM chops as dietary lysine levels were elevated from 0.6 to 1.4% (Figure 2), whereas Apple et al. [4] observed a linear increase in WBSF values as the lysine-to-energy ratio of the late-finishing diet increased from 1.7 (0.56 to 0.59% lysine) to 3.1 g/Mcal (1.02 to 1.08% lysine). Goodband et al. [44] also noted decreased sensory panel myofibrillar and overall tenderness scores with increasing dietary lysine levels; yet, for the most part, elevating dietary lysine levels in swine diets does not affect juiciness or flavor intensity of cooked pork [43].

**Energy Content and Sources.** Reducing the energy density in diets of growing-finishing swine does not affect the palatability of pork [60]; however, LM chops from pigs fed ad libitum received greater tenderness scores and had lower WBSF values than pork from pigs fed at 75% [21] or 80% [19] ad libitum, even though neither total and soluble muscle collagen contents [59] nor myofibrillar fragmentation index (an indicator of postmortem proteolysis; [21]) were affected by dietary intake. Furthermore, a number of studies have shown that pork from pigs with ad libitum access to grower-finisher diets was rated higher for pork flavor [19, 21], flavor-liking, juiciness, and overall acceptability [21, 36] by trained sensory panelists.

The cereal grain source included in swine diets can create palatability differences. For example, cooked chops from wheat-fed pigs received higher flavor scores than chops from sorghum-fed pigs [65], whereas LM chops from pigs fed a 33%:67% or 67%:33% mixture of yellow and white corns received higher juiciness and flavor scores than chops from pigs fed yellow corn or white corn and barley, respectively [57]. Furthermore, McConnell et al. [65] reported that the LM from wheat-fed pigs had lower WBSF values and higher tenderness scores than the LM from sorghum-fed pigs, and Robertson et al. [80] noted that sensory panelists rated LM chops from barley-fed pigs more tender than chops from pigs fed corn or barley with triticale. Conversely, WBSF values [57, 87] and palatability scores [87] were similar among pigs fed yellow corn, white corn, wheat, barley, or triticale.
Feeding canola oil and/or fish oil has been shown to impart more abnormal odors and off-flavors, thereby reducing the overall acceptability of cooked pork [68]. However, there is no effect of animal fat sources on WBSF values [8, 12, 37, 68] or sensory panelists’ evaluations of tenderness, juiciness, or flavor intensity [37, 68]. Neither WBSF values nor palatability ratings of cooked LM chops have been affected by feeding pigs DDGS- [97, 99, 106] or glycerol-formulated diets [27, 56]. In addition, it doesn’t appear that supplementing swine diets with CLA affects WBSF values [33] or palatability scores [33, 34, 58, 100] of cooked pork LM chops or bacon.

**Compensatory Gain.** Compensatory growth is the accelerated growth rate that occurs in pigs having ad libitum access to feed after a period of severely restricted feed intake. The increase in protein degradation during the period of restricted intake does not appear to decrease during the realimentation period, which led Kristensen and co-workers [55] to hypothesize that high antemortem proteolytic activity would lead to a more rapid postmortem muscle tenderization. Interestingly, both Kristensen et al. [55] and Therkildsen et al. [93] found that the activities of both μ- and m-calpain, but not calpastatin, were increased in the LM from pigs afforded ad libitum access to feed following a period of restricted feed intake, and Therkildsen et al. [93] noted that the longer the period of ad libitum feed intake prior to slaughter the greater the μ-calpain activity. Total collagen content does not appear to be affected by compensatory growth, but there is evidence that the proportion of soluble collagen in the LM is actually increased by feed restriction followed by ad libitum feed intake [54, 55, 93]. However, WBSF values and sensory panel tenderness scores were only improved in pork from pigs with confirmed compensatory growth [55]; in other words, in studies where the length or severity of the feed restriction was insufficient to cause a significant reduction in growth rate, the period of ad libitum intake had little to no effect on cooked pork palatability, especially tenderness [50, 54].

**Vitamin D_{3}** Because of the well-established association between calcium and meat tenderness, it is generally accepted that increasing muscle calcium concentrations will increase postmortem calpain degradation of the cytoskeletal proteins and improve cooked meat tenderness. Vitamin D is involved in intercellular calcium mobilization and regulation, and feeding supranutritional levels of vitamin D_{3} to feedlot cattle was shown to elevate blood and muscle calcium levels and, more importantly, improve cooked beef tenderness [89]. Even though plasma and muscle calcium concentrations were increased over 125% by supplementing swine finishing diets with vitamin D_{3} [101], neither pork WBSF values [90, 101, 103], sensory panel tenderness ratings [90, 103], nor any other palatability attribute [90, 103] have been altered by supplemental vitamin D3. Interestingly, there is evidence that suggests that supplementing swine diets with supranutritional levels of vitamin D3 can cause improvements in fresh pork quality, including increased initial and ultimate muscle pH values, subjective color scores, and LM a* values, along with reductions in L* values and drip loss percentages [90, 103].

**Summary**

Pork quality is affected by a number of factors, but this review focused on the effects of modifying swine diets on traditional measures of pork lean quality (i.e., pH, color, firmness, and marbling/IMF content), as well as fat quality, shelf-life, and cooked pork palatability. Several “tried-and-true” dietary modifications were discussed, including feed withdrawal, restricted feed intake, CP/lysine nutrition, and the advantages of vitamin E supplementation on pork quality; however, this review also look into emerging concepts of altering swine nutrition to increase muscle pH and enhance pork color and WHC (glycogen-reducing diets), increase marbling (CLA supplementation), and improve tenderness (compensatory gain). It should be noted, however, that there is no proverbial “silver bullet” that can overcome inferior genetics and poor rearing environments, preslaughter handling, and/or inadequate harvest systems, and the added production costs associated with many of these nutritional strategies need to be weighed against the possibility of added value before implementation by swine producers.
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Frequently Asked Questions

The fatty acid composition of a fat source obviously affects the fatty acid composition of pork fat, but does the fat source affect carcass composition?

Research has routinely shown that elevating the amount of fat in the diet may increase backfat depths, but there is little evidence to suggest that one dietary fat source will affect fat-free lean yields differently than another.

What affect to feeding antibiotics have on pork quality?

To date, there is little information on the impact of feeding antibiotics on pork quality attributes; however, there is antidotal evidence that healthy pigs tend to produce “quality” pork. Moreover, a number of the dietary supplements, especially vitamins and minerals, which have been shown to enhance pork quality, have also been shown to promote swine health. Therefore, it is plausible that some of the noted benefits of these supplements and/or feed ingredients on pork quality could be attributed to improvements in swine herd health.

Should you include an antioxidant in swine diets?

It is not uncommon to see diets formulated with very low levels of an antioxidant to combat the limited amount of lipid oxidation that may occur during feed storage. Even though diets are not typically stored for long durations, those with high polyunsaturated fat contents can oxidize rapidly, resulting in the feeding of diets with oxidized fats. And, recent research out of the University of Illinois has shown that feeding pigs diets containing oxidized fats can reduce fresh pork shelf-life; however, Fernández-Dueñas and others (2009) noted that including a blend of synthetic antioxidants not only counteracted the negative effects of oxidize dietary fat on pork shelf-life but improved some cooked pork palatability attributes.

How can I combat the apparent negative effects of feeding high amounts of dried distillers’ grains with soluble?

A number of studies have shown that feeding as much as 30% dried distillers’ grains with solubles (DDGS) will not only impact fat quality but also reduce carcass yield, or dressing percent, up to 1%. It is apparent that removing DDGS from the late-finishing diet will recoup some, if not all, of the losses in carcass yield, but may have little to no impact on fat quality. Moreover, Stevens and co-workers (2009) at Purdue University noted that replacing DDGS with either beef tallow or choice white grease during the last 26 d before slaughter failed to reverse the effects of DDGS on pork quality. And, the results of White et al. (2009) indicated that supplementing 20 to 40% DDGS-diets with 0.6% conjugated linoleic acid (CLA) for only 10 days before slaughter improved pork belly firmness even though CLA had no appreciable effect on the fatty acid composition of the belly fat. It is plausible that longer durations of CLA-supplementation may alleviate some of the negative effects of DDGS on pork fat quality, but more research is needed before implementing this nutritional modification.
