

EFFECTS OF SORGHUM GRAIN AND SORGHUM DRIED DISTILLERS GRAINS  
WITH SOLUBLES ON THE COMPOSITION, QUALITY AND SENSORY  
ATTRIBUTES OF GROUND PORK

by

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## Abstract

A total of 48 carcasses were taken from a larger trial using 288 pigs (PIC TR4 × 1050, initially 58.9 kg) in a 73 d feeding study to determine the effects of sorghum dried distillers grains with solubles (S-DDGS) in sorghum- or corn-based diets on ground pork quality. The dietary treatments included: sorghum-based diets with 0, 15, 30, or 45% S-DDGS, a sorghum-based diet with 30% corn DDGS (C-DDGS) and a corn-based diet with 30% C-DDGS. Shoulders from 24 barrow and 24 gilt carcasses were ground and evaluated for proximate and fatty acid composition, iodine value (IV), objective color, thiobarbituric acid-reactive substances (TBARS), and sensory attributes. No finishing diet × gender interaction was detected for composition, fatty acid profile, color or TBARS ( $P > 0.05$ ). Pork from gilts contained less fat and more moisture ( $P < 0.001$ ), was less saturated with a greater IV and total percentage of PUFA ( $P < 0.01$ ), and also had a lower  $L^*$  value ( $P < 0.001$ ) and higher  $a^*$  value ( $P = 0.006$ ) than pork from barrows. Gender did not affect total color change ( $\Delta E$ ) from 0 to 120 h ( $P = 0.30$ ), TBARS ( $P = 0.08$ ), or sensory attributes ( $P \geq 0.32$ ). Finishing diet had no effect on total fat, moisture, or protein composition ( $P \geq 0.18$ ). Increasing S-DDGS resulted in a linear ( $P < 0.001$ ) decrease in SFA and MUFA and an increase ( $P < 0.01$ ) in PUFA and ground pork IV. Pork from pigs fed 30% S-DDGS had a greater percentage of MUFA ( $P = 0.01$ ) and a lower percentage of PUFA ( $P > 0.006$ ) and reduced IV ( $P = 0.03$ ) compared to pork from pigs fed the sorghum-based diet with 30% C-DDGS. Diet did not affect TBARS ( $P = 0.37$ ) or  $L^*$ ,  $a^*$ , or  $b^*$  values ( $P \geq 0.11$ ) but was shown to influence  $\Delta E$  ( $P = 0.01$ ) with pork from pigs fed sorghum grain and 30% S-DDGS having less total change than all other treatments. It is concluded that consumers will not be able to differentiate ground pork from pigs fed DDGS and that feeding sorghum grain and S-DDGS can be done without affecting ground pork quality.

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# **CHAPTER 1 - Review of Literature**

## **Introduction**

Statistics compiled by the Renewable Fuels Association (2011) indicate that the United States produced over 13 billion gallons of ethanol in 2010, up from the 10.6 billion gallons produced in 2009. This number will continue to rise in accordance with the Energy Independence and Security Act of 2007 (Public Law 110-140, 2007) to ensure that transportation fuel sold or introduced into commerce, on an annual average basis, contain at least 36 billion gallons of renewable fuel by the year 2022. With ever increasing grain biofuel production, a continuous need is presented to find the best use for those products which remain at the completion of milling and distillation.

The term “distillers grains” refers broadly to the co-products of the dry mill fuel and beverage ethanol process, with a majority of that product being marketed and used as dried distillers grains with solubles (DDGS; Distillers Grains Technology Council, 2005) to the livestock feed industry. Ethanol is most often sourced from corn grain; however, many other crops such as sorghum, wheat, and more recently cellulosic biomass, have been and are continually evaluated for use in this system. Specifically, the contributions and role of sorghum grains in the production of ethanol and livestock is of great interest to those in the plains regions as the states of Kansas, Texas, Oklahoma and Colorado are the leading producers of sorghum in the U.S. In recent years, sorghum’s use in the ethanol market has seen tremendous growth, with 30 to 35 percent of domestic sorghum going to ethanol production (United Sorghum Checkoff Program, 2011). It can then be agreed that sorghum DDGS have and will continue to present the livestock industry with yet another valuable feed resource option that, like all distillers grains co-products, should continue to be analyzed for optimization in its effects on animal performance as well as final meat product quality.

## **Utilization of DDGS in Swine Diets**

The use of distillers grains co-products has been evaluated and reviewed for use in the diets of many different livestock species including, but not limited to: beef cattle,



dairy cattle, poultry, swine and horses (Berger and Good, 2007; Bregendahl, 2008; Hill, 2007; Klopfenstein et al., 2008a,b; Schingoethe, 2008; Stein, 2008; Stein and Shurson, 2009). For the purposes of this review and the adjoining study, emphasis will be put on the utilization of DDGS in swine diets with a special interest in that work which has specifically assessed sorghum DDGS (S-DDGS).

### ***DDGS Composition and Digestibility***

Multitudes of studies are available with several thorough reviews being published and frequently referenced (Stein, 2008; Stein and Shurson, 2009) pertaining to the utilization of various forms of DDGS in multiple phases of the swine diet. Some points reviewing details of the general nutrient composition, energy and digestibility of predominantly corn DDGS (C-DDGS) from Stein and Shurson (2009), are summarized (Lackey, 2010) as follows:

- Average digestible energy (DE) and metabolizable energy (ME) similar to corn, net energy (NE) approximately 86% of corn NE.
- Phosphorus in DDGS is highly digestible for pigs, with an apparent total tract digestibility of 60% reported.
- The concentration of most amino acids (AAs) is 3X greater than corn, but the standard ileal digestibility of most AAs is approximately 10% less than in corn.
- The total dietary fiber levels in DDGS are approximately 3X greater than those in corn.
- The apparent total tract digestibility of dietary fiber is less than 50%, which results in reduced digestibility values for dry matter (DM) and NE values for DDGS.
- The report concluded that research on practical ways to enhance DM and energy digestibility, specifically by improving the digestibility of insoluble fiber fraction, could improve the feeding value of DDGS.

One study (Urriola et al., 2009) was found, up to the 2009 review, to have evaluated the concentration and standardized ileal digestibility (SID) of crude protein and AAs specifically in S-DDGS. It was concluded that values for the SID of lysine (64%) and crude protein (CP; 72.5%) for S-DDGS were within the same range as C-DDGS, *P*-value = 0.19 and 0.68, respectively, but that many of the remaining AAs were less

digestible ( $P < 0.05$ ) in S-DDGS (Urriola et al., 2009). Feoli (2008) presented data comparing S-DDGS and C-DDGS, concluding that S-DDGS had an equivalent DM and gross energy (GE) digestibility ( $P \geq 0.10$ ), and a reduced nitrogen digestibility ( $P = 0.002$ ) and DE (kcal/kg) ( $P = 0.02$ ) compared to C-DDGS. Also, it was shown from this study that pigs fed a corn-soybean based control diet exhibited a greater digestibility of DM ( $P < 0.001$ ), nitrogen ( $P < 0.02$ ) and GE ( $P < 0.001$ ) than pigs fed S-DDGS.

More recently, Sotak et al. (2010) performed a nutrient and composition analysis on a total of 21 samples from S-DDGS and sorghum/corn-DDGS (60-70% S-DDGS) from five ethanol plants in the Western Plains region. Descriptive statistic overall sample means for S-DDGS, on a DM basis, were: DM (89.5%), CP (34.2%), crude fat (10.5%), ash (4.4%), crude fiber (10.6%), average digestible fiber (26.4%), calculated DE (3,439 kcal/kg), calculated ME (3,205 kcal/kg), calculated NE (2,026 kcal/kg), isoleucine (1.37%), leucine (3.84%), lysine (0.88%), methionine (0.55%), threonine (1.04%), tryptophan (0.26%), valine (1.67%), calcium (0.01%), and phosphorous (0.72%). It was concluded that sorghum/corn mixed DDGS sample means were generally similar to the pure S-DDGS. Values for DM, CP, GE and DE were similar to those reported by Feoli (2008). These values are an excellent resource for producers and future researchers in formulating diets containing S-DDGS, and are beneficial to work that may look to further evaluate the digestibility of this feedstuff in swine.

### ***Finishing Pig Performance and Carcass Composition***

Much of the work done regarding performance and productivity of pigs fed DDGS has focused on inclusion rates. Stein and Shurson's (2009) compilation of almost 25 studies conducted over the past several decades soundly points to the conclusion that up to 20 or 30% DDGS can be safely included in nursery or finishing swine diets without altering growth performance and carcass composition as compared to pigs fed no DDGS. A majority of those studies reviewed reported no change in average daily gain (ADG) (18 of 25 studies), average daily feed intake (ADFI) (15 of 23 studies), gain to feed ratio (G:F) (16 of 25 studies), dressing percentage (10 of 18 studies), backfat depth (14 of 15 studies), carcass lean percentage (13 of 14 studies) or loin depth (12 of 14 studies) at DDGS inclusions ranging from 5 to 30%. Two of the 4 studies assessing belly thickness

found no change according to the inclusion of corn DDGS with the other two stating a reduction. In some studies in which poor performance appeared related to the use of DDGS, inclusion was confounded with an increase of dietary crude protein. It was also noted that most experiments reporting a reduced ADG also showed a reduction in ADFI. Hastad et al. (2005) concluded this was potentially due to pigs preferring corn-soybean diets over diets containing DDGS. A very recent, large scale cooperative study (Cromwell et al., 2011) across 9 universities evaluated a constant source of C-DDGS increased to 0, 15, 30 or 45% of the finishing diet. In this case, while ADG was linearly reduced ( $P = 0.03$ ) in pigs fed DDGS, ADFI and G:F were not affected. Additionally, backfat depth showed a linear reduction ( $P = 0.02$ ) with increasing DDGS, while loin muscle area was not affected.

Sorghum DDGS have been analyzed and/or included in several studies to assess contributions to pig performance. Senne et al. (1996) evaluated increasing levels of S-DDGS at 20, 40 or 60% of the finishing diet as compared to a corn-soybean meal based control; with results showing that pigs fed S-DDGS had a lower ADFI and percent fat free lean (%FFL) in addition to an increased hot carcass weight (HCW), G:F, last rib backfat (LRBF) and dressing percentage (DP). Following this, a comparison of S-DDGS to basic sorghum mash, at 98% and 97% of the total diet, respectively, found S-DDGS to result in a reduced ADG ( $P = 0.03$ ) and poorer G:F ( $P = 0.02$ ) compared to a strictly (97%) sorghum diet. This was stated as an expected difference as S-DDGS, compared to the parent grain source, had a greater fiber content and lower energy with no attempt to equalize ME across the diets (Senne et al., 1998).

More recently, several studies have utilized S-DDGS to evaluate additional feed ingredients for their effectiveness in diets with DDGS levels above the previously recommended limit of 30%. In one study, pigs fed diets of 40% S-DDGS with or without 5% beef tallow were compared to a corn-soybean meal based control (Feoli et al., 2007a). Being measured against the control, pigs fed S-DDGS exhibited slight but significant ( $P < 0.05$ ) reductions in ADG, ADFI, HCW and DP. Inclusion of S-DDGS was not recorded as altering percent carcass lean, backfat thickness or loin depth. This same pattern of results was replicated in similar work by Feoli et al. (2008a) via evaluation of finishing diets with 40% S-DDGS, with or without 5% beef tallow and palm oil, as

compared to a corn-soybean meal based control. Additionally, Feoli et al. (2008b) compared feed conditioning methods (standard steam vs. expander) of finishing diets containing 40% S-DDGS. Findings from this work showed the inclusion of S-DDGS to have no effect on carcass lean percentage, backfat thickness, or loin depth ( $P > 0.15$ ), while still contributing to a reduction in HCW ( $P = 0.001$ ) and DP ( $P = 0.03$ ).

Outcomes of these studies may suggest that the inclusion of S-DDGS in corn-soybean meal diets contributes to a drop in several swine performance attributes; however, as stated previously, reductions in ADG seen in conjunction with ADFI can potentially be explained by pigs showing a general preference for corn-soybean meal diets over diets containing DDGS (Hastad et al., 2005). Moreover, it should be remembered that these S-DDGS evaluations utilized inclusion levels of 40% within the respective diets; a usage well above the summarized recommended limit in order to avoid hindering finishing performance in the review by Stein and Shurson (2009).

Perhaps of greater interest is work by Feoli et al. (2007b) allowing for a comparison of S-DDGS to C-DDGS. Finishing pigs were fed either a corn-soybean meal base control, a high energy diet with 40% C-DDGS, a medium energy diet with 40% C-DDGS, or a medium energy diet with 40% S-DDGS. Similar to the previous S-DDGS studies, pigs fed DDGS compared to the control diet had slightly lower ADG ( $P = 0.003$ ), HCW ( $P = 0.001$ ) and DP ( $P = 0.003$ ); however, in this case pigs fed S-DDGS exhibited a slightly higher DP ( $P = 0.04$ ) compared to pigs fed C-DDGS, at 73.6 and 73.2%, respectively. Additionally, in a study (Feoli et al., 2008c) comparing pigs fed either a corn-soybean meal control, 30% C-DDGS or 30% S-DDGS all with and without enzymes, S-DDGS fed pigs had a higher ADFI ( $P = 0.004$ ) and poorer G:F ( $P = 0.02$ ) as compared to those pigs fed C-DDGS. No difference was seen in HCW, DP, carcass lean percentage, backfat depth, or loin depth. Pigs fed C-DDGS were noted as having a greater digestibility ( $P < 0.04$ ) of DM, protein (N) and GE, suggesting greater utilization of that feed consumed, and possibly explaining the reduced ADFI and G:F advantage seen in this study.

While select differences were noted in the resulting performance and growth of pigs fed S-DDGS compared to C-DDGS in the finishing diet, the compilation of these studies seems to suggest that equivalent usage levels of S-DDGS or C-DDGS is practical

and both can be equally tolerated by pigs to result in pork carcasses of similar composition.

### *Fat Quality Concerns*

A large majority of the studies conducted and reviewed regarding the effects of DDGS in swine diets conclude with the assessment of standard carcass yield characteristics. Dressing percentage, lean muscle percentage, backfat thickness, and belly thickness are traits that are usually measured and reported, understandably, due to the fact that these attributes would most directly influence efficient profitability of producers and packers. While select differences in some of these traits were noted in a few of the previously cited studies, it has largely been summarized and accepted that 20 or up to 30% DDGS, depending on diet quality, can be included in finishing diets without causing unfavorable changes in growth performance and carcass yield characteristics. However, when considering final pork quality attributes, feeding DDGS at these levels has been marked as cause for concern.

Fat quality affects both further processing characteristics and the ability of pork products to meet export specifications as softer pork fat and bellies result in carcass handling and fabrication difficulties, reduced bacon yields, unattractive products and reduced shelf life (Carr et al., 2005; NPPC, 2000). Fat quality, as measured by iodine value (IV), is an important attribute often evaluated at the conclusion of swine feeding trials. Iodine value is reported in g/100 g of sample and calculated according to the American Oil Chemists' Society (AOCS, 1998) equation using the following fatty acid concentrations and coefficients:  $IV = [C16:1] \times 0.95 + [C18:1] \times 0.86 + [C18:2] \times 1.732 + [C18:3] \times 2.616 + [C20:1] \times 0.785 + [C22:1] \times 0.723$ . Higher IV numbers indicate a more unsaturated fat profile and, consequently, softer fat. Published IV maximum thresholds for quality fat have ranged from 60 (Hugo and Roodt, 2007) to 74 (Boyd, 1997), with several reports presenting an IV = 70 as a maximum limit in order to avoid overly unsaturated pork carcass fat (Lea, 1970; Barton-Gade, 1987; NPPC, 2000).

It is well established that the fatty acid composition of pork is influenced by the composition of the diet (Averette Gatlin et al., 2002; Xu et al., 2010a). Dietary fatty acids pass through the digestive system unchanged (Nürnberg, 1998) and, depending on

the fatty acid, are transferred to carcass fat at a relatively high rate (Kloareg et al., 2007). Increases in dietary fats have also been noted to inhibit *de novo* fatty acid synthesis in favor of direct deposit into the adipose tissue (Farnwoth and Kramer, 1987; Chilliard, 1993). Observations of these actions assist in the explanation of manipulating carcass fat composition by careful selection of dietary fat sources and feed ingredients (Benz et al., 2010). Dried distillers grains with solubles have approximately 10% oil which contains an increased proportion of unsaturated fatty acids (UFA, 81%), including linoleic acid (C18:2, 54%), and a decreased concentration of saturated fatty acids (SFA) (Xu et al., 2010a). These less saturated dietary fat concentrations in DDGS are replicated in that fat which is deposited during growth in swine.

In order to test pork quality in relation to DDGS usage, Whitney et al. (2006) evaluated 240 pigs separated by high, medium and low initial body weights by feeding C-DDGS during finishing at 0, 10, 20 and 30% of a corn-soybean meal based diet. Soybean oil was added in low percentages to control dietary energy balance and dust. Findings showed that IV of belly fat increased linearly ( $P < 0.01$ ) with increasing dietary DDGS concentrations from 66.8 at 0% to 72.0 at 30%. Belly firmness, adjusted for thickness, was also reduced ( $P < 0.05$ ) for pigs fed 30% DDGS compared with pigs fed 0 or 20% DDGS. It was concluded that, although feeding up to 30% DDGS in the finishing diet did not have any effect on muscle composition, increasing DDGS did decrease the saturation of fatty acids and resulted in softer bellies that may negatively affect further processing traits. A review of DDGS in the swine diet by Stein and Shurson (2009) compiled this study and 2 others as evaluating belly firmness, all noting a similar increase in softness in conjunction with increasing DDGS concentrations in the finishing diet. Additionally, 7 similar studies evaluating increasing DDGS concentrations from 0 to 30% were sighted as finding an increase in carcass fat IV to greater than 70, due to inclusion of DDGS. More recently, Xu et al. (2010a) evaluated pigs fed 0, 20 or 30% DDGS and also stated increases in pork fat IV with increasing dietary DDGS, confirming that levels of 20 or 30% throughout the finishing phase is not an acceptable option if carcass fat quality is to be considered.

Much like C-DDGS, the inclusion of S-DDGS in the finishing diet should be treated with similar caution when considering fat quality implications. A series of studies

conducted by Feoli et al. (2007b, 2008a,c,d,e) utilized S-DDGS during finishing, and recorded the resulting carcass fat IV in addition to swine performance attributes. Initially, Feoli et al. (2007b) fed pigs a corn-soybean meal control or a control diet with 40% S-DDGS and 0, 2.5 or 5% beef tallow as a saturated fat source. Jowl fat IV means for control, S-DDGS with 0, 2.5 and 5% tallow were 68, 72, 73 and 74, respectively. This suggests that there is a deposition of softer fat in pigs fed S-DDGS ( $P < 0.001$ ) compared with pigs fed no DDGS, even with saturated fat added to the diet (Feoli et al., 2007b). In a following study, feeding 40% S-DDGS in the corn-soybean meal based finishing diet with and without 5% added tallow and palm oil resulted in higher IV for pigs fed S-DDGS ( $P < 0.001$ ) vs. the control diet with no DDGS (Feoli et al., 2008a). For the control, S-DDGS, S-DDGS + tallow and S-DDGS + palm oil diets, IV was 67, 73, 74 and 73, respectively. Similarly, when comparing pigs fed either no DDGS or 40% S-DDGS, both with and without 5% added stearic acid or coconut oil, pigs fed DDGS had a higher IV than control pigs, with the exception of those pigs fed added coconut oil. For the control, S-DDGS, S-DDGS + stearic acid, and S-DDGS + coconut oil diets, IV was 67, 72, 71 and 67, respectively (Feoli et al., 2008e). Given the results of these studies, S-DDGS would seem to operate in a similar fashion as other DDGS sources when included in swine finishing diets.

Sorghum DDGS, however, may offer an advantage over C-DDGS when considering final fat composition and quality. Further work by Feoli et al. (2008c) comparing pigs fed a corn-soybean meal-based diet finished with no DDGS, 30% C-DDGS or 30% S-DDGS, all with or without added enzymes, found pigs fed S-DDGS to have a lower jowl fat IV ( $P < 0.04$ ) than those fed C-DDGS. For pigs fed control, C-DDGS with enzymes, C-DDGS without enzymes, S-DDGS with enzymes and S-DDGS without enzymes, IV was 70.3, 80.4, 80.1, 74.6 and 74.3, respectively (Feoli et al., 2008d). While these IV numbers for S-DDGS fed pigs did not ultimately fall below the previously mentioned quality threshold of 70, they were certainly much closer to that value seen in the control animals than C-DDGS fed pigs.

Dietary fat is not the only factor effecting carcass fat composition and IV. Studies have shown that consideration also must be made for carcass sampling location comparing the belly, jowl or backfat (Benz et al., 2010; Xu et al., 2010a), as well as for

backfat thickness and total fat deposition (Gandemer, 2002). Knowledge of additional factors contributing to carcass fat IV prompted Bergstrom (2011) to conduct a meta-analysis of 21 studies to develop prediction equations for IV in pigs fed relatively constant dietary iodine products (IVP). Additionally, 6 separate studies were used to develop equations for pigs fed dietary IVP-reduction strategies, such as when pigs are fed reduced amounts of DDGS closer to the time of marketing. Backfat, belly fat, and jowl fat IV were all highly correlated among the experiments that measured the IV of the multiple fat depots ( $r \geq 0.88$ ;  $P < 0.001$ ). As expected, dietary concentrations of unsaturated fatty acids (UFA), especially polyunsaturated fatty acids (PUFA), were most important in predicting carcass fat IV for both constant- and reduced-IVP feeding strategies. Backfat and belly fat IV were both shown to drop in accordance with increasing values for ADG, final body weight (BW), BW range over feeding and backfat depth. Similarly, reduced jowl fat IV was also associated with increased backfat depth, contributing to the idea that pigs with a greater amount of fat deposition have a reduced carcass fat IV. Considering this, it was concluded that gender differences in fat IV and composition are also a function of the differences found between genders in subcutaneous fat depth and leanness, as described by Wood et al. (2008). In pigs fed with IVP-reduction strategies, backfat IV was found to be the most responsive to dietary changes and the characteristics of the beginning diet were seen as being the most important in predicting final carcass fat IV, suggesting that the fat deposition and composition in swine is not quickly altered from that which is initially established when higher dietary fat levels are introduced.

Using an IVP reduction strategy, Jacela et al. (2009) concluded that reducing 30% DDGS to 15 or 0% for diets from 3 to 6 wk before pigs were marketed did not totally alleviate the negative effects of DDGS on carcass fat IV; however, DDGS reduction did numerically reduce the IV compared with continuously feeding DDGS until marketing. Control pigs fed no DDGS had an average carcass fat IV over 3 locations of 67.8, while pigs removed from DDGS for 6, 3 or 0 wk prior to harvest had an average IV of 73.1, 73.3 and 74.8, respectively. In a similar, more recent study, Xu et al. (2010b) fed 0, 15 and 30% DDGS in the finishing diet, withdrawn for 0, 3, 6 or 9 wk prior to harvest. Their findings indicated that an inclusion of up to 30% DDGS had a minor effect on



growth performance and that the desired effects of reduced C18:2 content and IV was seen, and could be elicited with as little as a 3 wk withdrawal of DDGS prior to slaughter. Linear decreases ( $P \leq 0.001$ ) in IV were seen with increasing time of withdrawal for pigs fed both levels of DDGS, with all resulting IV means being below 70, with the exception of pigs fed 30% DDGS with no withdrawal time.

This work makes a point that increasing withdrawal time of DDGS prior to harvest may be an option to reduce final carcass fat IV; however, Jacela et al. (2009) importantly notes that feed cost/pig was highest ( $P < 0.05$ ) when 0% DDGS was fed in the diet or was withdrawn for 6 wk and that feed cost/pig linearly decreased ( $P < 0.01$ ) the longer DDGS was left in the diet. From an economical standpoint, the advantage of including and leaving DDGS in the diet is evident and work will continue to progress in a way that looks to maximize their use while minimizing negative pork quality effects.

### ***Opportunity for Sorghum Grains***

A point of interest, and importance to this review, is that every feeding trial referenced thus far has utilized a corn-soybean meal based control diet compared with percentage DDGS diet(s), formulated with the same corn-soybean meal base. In looking for continued ways to maintain DDGS in the diet, and with knowledge that sorghum has a lower oil content than corn, Benz et al. (2011) compared the use of sorghum- and corn-based diets in finishing pigs. One hundred twenty pigs were fed either sorghum- or corn-grain based diets with 0, 2.5 or 5% added choice white grease and were monitored for growth performance and fat quality characteristics. From a performance perspective, pigs fed sorghum-based diets had an increased ADG ( $P < 0.01$ ) and equivalent ADFI ( $P = 0.15$ ) and G:F ( $P = 0.90$ ) compared with corn fed pigs, while also maintaining virtually equivalent ( $P < 0.09$ ) DP, 10<sup>th</sup> rib backfat and percent carcass lean. Most interestingly, pigs fed sorghum-based diets had reduced ( $P < 0.01$ ) IV and percent C18:2 in jowl fat and backfat samples compared to corn fed pigs. Sorghum- vs. corn-fed backfat IV means and sorghum- vs. corn-fed jowl fat IV means were 63.9 vs. 65.8 and 68.3 vs. 70.3 g/100g, respectively. These results would suggest that substituting sorghum for corn in diets for finishing pigs can be an effective way to reduce IV without affecting growth.

The feeding value of sorghum compared to corn in finishing swine diets noted by Benz (2011) is supported by Shelton et al. (2004) and Johnston et al. (1998) and

summarized well by Tokach et al. (2011) with the conclusion that sorghum can be used to replace corn without affecting growth performance in finishing pigs. Given this more recent realization of the potential for sorghum grain-based diets and the opportunity they present to assist in the control of pork carcass fat quality issues, additional research is warranted in order to detail the influence of feeding sorghum grains with DDGS on pork quality attributes.

## **Retail Pork Quality**

Where an information gap exists in an attempt to understand the full effects of the inclusion of DDGS in the swine diet, is at the level of the pork consumer. Dietary inclusion strategies for all distillers grains sources and variations must continue to be evaluated and refined; however, those feedstuffs and usage values which are found to meet expectations at the production and packing house level must also be validated via assessment of final meat quality attributes, specifically those that may influence consumer purchase and consumption.

Many, if not most, quality aspects and interests have applications to several different species; however, as stated earlier, special interest will be taken in this review to consider work pertaining to the pork industry.

## ***Meat Color***

Color is considered by many as the most important factor influencing initial consumer purchase of meat products and, consequently, has been the focus of much research throughout the history of the meat industry, especially in the recent decade. Mancini and Hunt (2005) provided an excellent review of the factors that contribute to variations in meat color and those that are of more recent interest to researchers. Simply put, the protein myoglobin is largely responsible for the appearance of common meat colors, while the proteins hemoglobin and cytochrome C also contribute to a lesser extent. Myoglobin's contribution can most easily be recognized when comparing meat sourced from livestock of different species and ages. Beef has the highest concentration of myoglobin, and therefore is the darkest when compared to meat from lamb or pork, in the same way that meat from older animals is regarded as having a greater myoglobin concentration (Seideman, 1984). This concentration difference helps describe color

intensity comparisons, but a more basic level of understanding of myoglobin chemistry is needed to differentiate true color changes that occur in meat; Mancini and Hunt (2005) review this well.

Within myoglobin's hydrophobic pocket is contained a heme ring structure with a centrally located iron atom capable of forming 6 bonds. It is the ligand bound to the sixth position and the valence of the iron that dictate the resulting meat color.

Deoxymyoglobin (DMb), oxymyoglobin (OMb) and metmyoglobin (MMb) are the three most basic forms of the myoglobin pigment observed in fresh meat applications.

Deoxymyoglobin is present when no ligand is bound to the heme ring and the iron is in a ferrous ( $\text{Fe}^{2+}$ ) state. This pigment is most often associated with a purplish-red or purplish-pink color and largely can be seen in that product which is in a vacuum packaged state. Oxymyoglobin is formed when meat is then exposed to oxygen ( $\text{O}_2$ ), causing product "bloom" and oxygenation of the heme iron, filling the 6<sup>th</sup> position with an  $\text{O}_2$  molecule while maintaining the valence state of the iron. This reaction results in the bright red or reddish-pink color often associated with fresh meat cuts. Lastly, MMb is responsible for the brownish, discolored state of meat products and has been detailed as being present at very low oxygen levels. Metmyoglobin is largely formed due to oxidation of the ferrous heme iron to a ferric ( $\text{Fe}^{3+}$ ) state (Livingston and Brown, 1982).

Many aspects of basic myoglobin chemistry and muscle biology have been detailed as contributing to the formation of and transition between pigment states, including: NADH concentrations and MMb reducing activity (Bekhit et al., 2000; 2003) the activity location within the muscle structure (Sammel et al., 2002; Bekhit et al., 2004) and glycolytic potential (Hamilton et al., 2003). These molecular level explanations, in turn, develop as a result of many application level adjustments, such as the animal's genetics, diet, pre-harvest handling and final carcass management. These aspects will be discussed later; however, it is helpful to first review how color is measured and compared.

### ***Color Perception***

Hunter Associates Laboratory, Inc. (2008) provides an excellent series of educational, technical and application notes detailing the many factors that contribute to

color perception, development and testing. These materials are available and can be accessed through the Hunter Associates Lab archive and were used to assist in the following description of color science.

Color perception, in a very simple sense, consists of an object reflecting a visible light source to an observer. Observations can be interpreted by a subjective source (ex. human visual panel) which utilizes predetermined standards and examples to assign color values, or by an objective source (ex. spectrophotometer or colorimeter), which provides a standardized illumination and specified observance area (2° or 10° standard observer) in which to read the amount of reflectance. Standard illuminants refer to the type of light provided for an objective reading and can be differentiated according to their unique composition of wavelengths within the visual spectrum ranging from 400 to 700 nm. D65, A10, C and F are possible illuminants utilized when sampling meat products for color (Brewer et al., 2001). Objective (instrumental) color measurements are recorded using some form of the Commission Internationale l'Eclairage (CIE) tristimulus values X, Y and Z. These values take into account the type of illumination and the reflectance of the sample and are calculated from the CIE Standard Observer reflectance curve functions established in 1931. A similar unit of objective measurement utilizes the CIE L\*, a\* and b\* values, also referred to as CIE LAB. These are most often obtained using a colorimeter containing a 10° standard observer and are commonly used to report color values of meat products. L\* values measure product "lightness" and range from 0 (black) to 100 (white); a\* values measure "redness" with positive and negative values indicating red and green reflectance, respectively; while b\* values measure "yellowness" with positive and negative values indicating yellow and blue reflectance, respectively. Mancini and Hunt (2005) reference studies utilizing CIE XYZ and CIE L\*a\*b\* forms as both being effective for measuring meat color, clarifying that variable selection is experimentally specific and dependant on the project objectives.

### ***Pork Color***

Pork is frequently evaluated and graded with a subjective system utilizing the Pork Quality Standards established by the NPPC (1999), which describe pork on a scale from pale pinkish-gray or white to dark purplish-red with number values of 1 to 6,

respectively. This system is well used and accepted, however, objective measurements in addition to pH have also been employed over the past decade with great benefit to describing pork quality (Stetzer and McKeith, 2003).

Meat pH is an attribute which has been marked as having a clear influence on, and relationship with, final product color. This connection is recognized by pH differences that can be seen in pork discounted as pale, soft and exudative (PSE) or dark, firm and dry (DFD); conditions reported in a survey of US pork packers as occurring in an average of 15.5 and 1.9% of carcasses, respectively (Stetzer and McKeith, 2003). To test pork pH and color, Brewer et al. (2001) selected 78 pork carcasses from a variety of genetic backgrounds to result in a range of pH values from 5.13 to 7.15, covering the spectrum of potential pork pH values including PSE and DFD meat. Five muscles were removed from each carcass and sampled for 24 h ultimate pH, visual pink color intensity according to Japanese Color Standards for pork, and instrumental color utilizing 2 colorimeters and several varying illuminants to compare CIE  $L^*a^*b^*$  values. Results indicated that as pH increased across the range of sampled values, visual pink color intensity also increased (improved) with a correlation coefficient of 0.81. Additionally, correlation equation analysis across the full pH range determined that a two-factor model using  $L^*$  and  $a^*$  values from the *longissimus lumborum* 10<sup>th</sup> rib cross section was the most accurate ( $R^2 = 0.69$ ) in explaining visual pink color intensity. This would make sense as pink color intensity should be a value of product lightness ( $L^*$ ) and redness ( $a^*$ ).

The relationship between color and pH was also expected and explained by a known relationship between pH and water holding capacity. Briefly, as pH decreases and approaches the product isoelectric point, less water is retained within the muscle structure and more is made available on the meat cut surface to reflect and scatter light. This results in a lighter appearing product. Via the opposite action, as pH increases and distances itself from the product isoelectric point, more water is bound within the meat structure. This results in less surface moisture and light reflectance giving the appearance of a darker, dryer product and consequently, a more intense “concentrated” pink color. This study provides an excellent example of how visual preferences and differences in pork color can be quantified with an analytical measurement system.

In addition to pH, the components that contribute to the development of an individual meat product's final color are numerous. Several additional components that stretch across the many phases of the pork industry are briefly discussed. Genetically, Brewer et al. (2004) detailed that different breed lines and crosses of pigs affect visual panel lightness and pinkness as well as CIE  $a^*$  of loin chops. Of similar interest is work which denotes certain pigs as having the halothane gene or n allele; genetics that are associated with easily stressed pigs prior to harvest, resulting in a higher incidence of PSE (Fisher et al., 2000) and consequently lighter colored, less desirable pork (Channon et al., 2000). Also related to pre-harvest handling, Gentry et al. (2004) found pigs born and reared outdoors to have redder loins than those born and raised indoors. While the true effects of rearing environment were questioned, additional differences between treatments were noted regarding muscle fiber type, as pigs raised outdoors had an increased percentage of oxidative fibers and a decrease in glycolytic fibers. Oxidative fibers are rich in myoglobin, contain a large number of mitochondria, present high enzymatic activity and are present at higher concentrations in 'red' muscles (Renner, 1990); an appropriate name as they appear redder in color. During harvest, Channon et al. (2000) noted higher stress stunning styles such as electrical stunning as being detrimental to pork color when compared to a low stress, CO<sub>2</sub> stunning; however, this was also related to the presence of prior mentioned halothane genetics and stressful handling before the stunning process.

Lastly, after harvest, Hamilton et al. (2003) evaluated individual carcass glycolytic potential, a measure of the capacity for anaerobic metabolism according to those substances that are available in muscle to be converted to lactic acid during rigor. Glycolytic potential was found to be inversely related to color quality of loin chops due to the ability for greater lactic acid development and a lower ultimate pH, resulting in lighter colored pork, as described earlier. These particular aspects of pork production as they influence color are accepted by many, but should continue to be tested in conjunction with future evaluations. They are important to understand and remember in order to approach further color work with a full perspective of the potential results.

### ***Gender***

One aspect that has received mixed attention regarding its affect on pork color is gender. Latorre et al. (2003) correctly states that there is much research indicating that meat color, as determined by visual scores, objective parameters and myoglobin content, is independent of gender. Their study evaluating pork from pigs of differing genetic backgrounds and genders found pork from barrows to be redder and have a more intense color than pork from gilts, a conclusion that was cited as being both supported and countered by other researchers. Nold et al. (1999) evaluated 12 muscles from carcasses of boars, barrows and gilts finished to either 100 or 110 kg with high and low protein diets. Results found pork from 100 kg boars and barrows to have a higher ( $P < 0.001$ ) L\* than gilts harvested at the same weight, while at 110 kg, boars had a lower ( $P < 0.05$ ) L\* than gilts and barrows. The latter outcome was more expected as past research has indicated that intact males are generally expected to have a greater myoglobin concentration and darker meat than castrates of the same species and age (Seideman et al, 1984). Additionally, pork from boars was determined to be less red (lower a\*,  $P < 0.05$ ) and less yellow (lower b\*,  $P < 0.05$ ) than gilts and barrows. This difference was thought to be partially explained by Goerl et al. (1995) who attributed lower a\* and b\* pork values to a decrease in pigmentation for pigs with a higher lean growth potential.

Much more recently, Bergstrom (2011) conducted a series of trials that evaluated subjective and objective color of *longissimus* (LM) chops held in 7 d retail display from barrows and gilts fed varying levels of a dietary supplement and ractopamine HCl. In one trial, subjective evaluation with trained panelists found chops from gilts to be less discolored on d 3 and 7 of display and overall, when compared to chops from barrows. Similarly, objective measurements (CIE L\*a\*b\*, 10°, D65) described the linear decrease ( $P < 0.001$ ) in a\* values over 7 d to be greater for barrows than gilts, and total color change ( $\Delta E$ ) over display to be less for gilts than barrows at values of 2.4 and 2.9, respectively. This suggests that LM chops from gilts have a longer color life when compared to chops from barrows. In a following experiment, Bergstrom (2011) also found LM chops from gilts to be less discolored ( $P < 0.001$ ) from d 4 to 6 of retail display, when compared to chops from barrows. The researcher noted in this case that differences were potentially related to the concept of LM diameter as, Miller et al. (1975) and Larzul et al. (1997) reported that the cross-sectional area of all myofibers was greater

in LM from gilts. Miller et al. (1975) also noted that animals possessing large muscle fibers are often rapid growing and muscular. Although pigs with a high feed intake grow faster and deposit mainly fat, pigs with a high growth rate have a higher intake capacity and deposit mostly protein (Latorre et al., 2008). Latorre et al. (2008) found that ADG and ADFI are negatively correlated with  $a^*$  values in meat and summarize that a rapid increase in muscle cell size, as occurs during finishing growth, might dilute mitochondria and cause a shift to a more glycolytic system. An overall less oxidative muscle system would potentially decrease initial pork redness but would assist in explaining product with greater color stability. The relationship between muscle fiber type and color stability is generally known (Lanari and Cassens, 1991) in that muscles with a high oxidative metabolism have low color stability. Renner (1990) summarizes well in stating that slow-twitch oxidative fibers are rich in myoglobin, contain a large number of mitochondria, present high enzymatic activity and are present at higher concentrations in “red” muscles. Additionally, “red” fibers are also able to oxidize fat, and the more unsaturated lipid content of red than white muscles influences their susceptibility to oxidative rancidity, and consequently, discoloration. Similar to this concept, Gentry et al. (2004) reported reduced percent type IIA (oxidative intermediate, fast) fibers and increased percent type IIB/X (glycolytic) fibers in LM of pigs raised indoors as compared to pigs raised outdoors. Chops from those pigs raised indoors were also found to have a less dark, grayish-pink subjective color, decreased  $a^*$  values (reduced redness) and a tendency for less discoloration during 4 d of retail display.

The reasoning behind this perspective does seem plausible; however, the true relationship between fiber composition and growth performance is still unclear (Latorre et al., 2008) and it is important to restate that both the reports of Miller et al. (1975) and Larzul et al. (1997) clarify that no muscle fiber type differences were found according to gender in their respective studies. Further work detailing the differential development of fiber types could still prove valuable, as Gentry (2004) concluded that selection for decreased percentages of IIB/X fibers, reducing the cross sectional area of glycolytic cells, could lead to improved meat quality by decreasing the rate and extent of postmortem pH decline.



One additional factor to consider regarding the effect of gender on pork color relates to the prior mentioned knowledge that gilts are typically leaner than barrows and have a reduced subcutaneous fat cover (Wood et al., 2008). This is important when considering carcass chilling immediately following harvest, the details of which are reviewed well by Huff-Lonergan and Page (2001). Briefly, following the point of exsanguination the body system is no longer able to deliver oxygen to muscle cells or remove that heat which they produce. This can lead to increases of internal muscle temperature and, more importantly, a shift in the muscular system to anaerobic glycogen utilization, producing lactate, which in turn lowers muscle pH to its typical meat levels around 5.6. If pH drops too quickly at an elevated temperature, this leads to the development of PSE pork as detailed previously. In research set to evaluate pork quality between genetic lines, Carr et al. (2006) found barrow carcasses to have a higher ( $P = 0.03$ ) mean temperature over 24 h compared with gilts (15.4 vs. 14.9°C) and also a greater ( $P < 0.018$ ) LM L\* value, detailing product as lighter. The initial difference in temperature was attributed to increased fat levels in barrows, hindering carcass cooling and consequently increasing L\* values through greater light reflectance from surface level free water and denatured proteins from a slightly extended heat storage period.

In summary, while there are many conflicting reports regarding the true presence of color differences between barrows and gilts, several new ideas detailing potential explanations have been made. With these in mind, future work considering color differences due to gender should first reflect on product attributes that could also explain standard pig to pig variation such as pH, fat cover, muscle type and myoglobin concentration due to age.

### ***Dried Distillers Grains with Solubles***

Data pertaining to the affects of DDGS on pork color is less prevalent and has only more recently been included in the pork quality analyses of swine feeding trials. Whitney et al. (2006) allotted 240 pigs randomly by weight and gender to 10 pens and fed a corn-soybean meal based diet with either 0, 10, 20 or 30% high quality C-DDGS. High quality DDGS was procured from an ethanol plant built after 1990 and was analyzed to have increased and more consistent levels of fat, lysine, and ME than C-DDGS from older plants. Among other traits, LM chops were evaluated for subjective

color (NPPC, 1999) and objective lightness (CIE L\*, D65 illuminant). Chops from pigs fed all levels of C-DDGS were evaluated as similar for subjective color ( $P = 0.24$ ) with mean scores ranging from 3.05 to 3.17, qualifying all pork as reddish-pink. Similarly, CIE L\* values for all dietary treatments were equivalent ( $P = 0.32$ ) with means ranging from 54.3 to 55.8. In addition to color attributes, pork was also noted as displaying no differences regarding ultimate pH, drip loss and cooking loss. This led to the conclusion that DDGS in the swine diet did not have any meaningful effect on pork muscle quality. Supporting these results, Xu et al. (2010a) finished pigs on increasing levels of C-DDGS at 0, 10, 20 and 30% and found no difference between LM chop visual (subjective) color score over all C-DDGS inclusion levels ( $P = 0.65$ ). In opposition to the prior study, CIE a\* and b\* (illuminant D65, 10° standard observer) values were also recorded and found to decrease ( $P < 0.05$ ) in conjunction with increased C-DDGS levels in the diet. As a point of caution, reported a\* values in this instance ranged from -0.83 to -1.24, readings that would suggest the LM chops were actually more green than red. Considering subjective evaluation of these same chops (NPPC, 1999) resulted in values from 2.9 to 3.03, detailing color as approximately reddish pink, the validity of this color data is severely discounted from a practical standpoint.

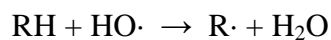
In further support of Whitney et al. (2006), Widmer et al. (2008) finished pigs with either 0, 10 or 20% DDGS as well as other corn distillers grains co-products and found no differences in subjective color, CIE L\*, CIE a\*, drip loss or purge due to dietary inclusions of these feedstuffs. Given this information and the similar results found between multiple studies, it seems reasonable to side with the original conclusion of Whitney et al. (2006) in stating that up to 30% DDGS can be included in the swine diet without any meaningful effect on pork muscle quality, including color.

At this time, while several previously reviewed studies have utilized S-DDGS in feeding trial experiments, none have reported pork quality attributes related to color. If S-DDGS are expected to perform in a similar fashion as C-DDGS regarding their influence on pork color, then no effects should be seen; however, this is a gap in research knowledge that needs to be verified.

## *Oxidation and Shelf Life*

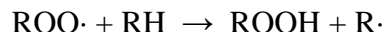
Many stages of meat production have been discussed thus far regarding those factors which contribute to basic meat quality, especially that of pork. However, even with extensive quality control, testing and understanding of the optimum production and processing techniques, an improper display environment can significantly devalue a meat product to the point that it may not sell. Oxidation is recognized by most in the meat and muscle foods industry as one of, if not the main factor limiting the overall quality and acceptability of meat and meat products. This most often refers to the oxidative rancidity attributed to the peroxidation of lipids, but also is a major concern regarding the oxidative change in meat color pigments, mentioned previously. Many comprehensive reviews of the stages, mechanisms and catalysts involved in the lipid peroxidation process have been published. A brief summary is compiled here from the reviews of Morrissey et al. (1998) as well as Min and Ahn (2005).

Oxidation in meat foods is a concern as it leads to discoloration, drip loss, off-odor and off-flavor development as well as the production of potentially toxic compounds. The free radical chain reaction is traditionally regarded as operating across three steps described as initiation, propagation and termination. Additionally, Morrissey et al. (1998) breaks the development of lipid oxidation down to its presence in three phases of meat production: 1) the production of reactive oxygen species and antioxidant defense mechanisms *in vivo*, or in the living animal, 2) internal and external influences occurring during harvest or immediately post-slaughter and 3) stimuli due to final product handling, processing, storage and cooking. From a chemical standpoint, initiation occurs in fat with the removal of a hydrogen molecule from a methylene group within a lipid molecule. This is often catalyzed by a hydroxyl radical (HO·) or a similar reactive oxygen species such as a superoxide anion radical (O<sub>2</sub><sup>·-</sup>), hydroperoxyl radical (HO<sub>2</sub>·) or hydrogen peroxide (H<sub>2</sub>O<sub>2</sub>). The catalytic action of these individual compounds, in addition to the similar action of iron-oxygen complexes, is discussed in greater detail by Min and Ahn (2005). An example initiation reaction is as follows:



Subsequently, the fatty acyl radical (R·) then reacts rapidly with oxygen (O<sub>2</sub>) to form a peroxy radical (ROO·). This radical is more highly oxidized than the fatty acyl radical

or the fatty acid itself and will preferentially oxidize other unsaturated fatty acids and propagate the chain reaction.



Lipid hydroperoxides (ROOH) formed in the propagation reaction are both products of oxidation and substrates for further reaction with  $\text{Fe}^{2+}$  and  $\text{Cu}^+$  to yield additional  $\text{ROO}\cdot$  as well as alkoxy radicals ( $\text{RO}\cdot$ ). These components often initiate further chain reactions resulting in the formation of ethane and pentane as well as aldehydes such as hexanal, malondialdehyde and 4-hydroxynonenal which can contribute to Maillard-type complexes, altering flavors.

Polyunsaturated fatty acids, both isolated and those incorporated into the lipid, have consistently been recognized as being more susceptible to the actions of oxidation as they are readily attacked by free radicals, while monounsaturated fatty acids (MUFAs) and SFAs are more resistant (Halliwell and Chirico, 1993). Horwitt (1986) reported relative oxidation rates of fatty acids containing 1, 2, 3, 4, 5, or 6 double bonds as 0.025, 1, 2, 4, 6, and 8, respectively. This clear propensity for more unsaturated fatty acids to oxidize leads to greater rancidity as display time increases (Wood et al., 2003). Malonaldehyde (MDA) is a product of the autoxidation of polyunsaturated fatty acids and reacts with the 2-thiobarbituric acid (TBA) reagent to produce a pink complex with an absorbance at 532 nm, the concentration of which can be read with a spectrophotometer as an objective measurement of oxidation (Shahidi and Pegg, 1994). Although there are many assays available for assessing the oxidative status of meat and meat products, the TBA test by Tarladgis et al. (1960), and similar variations, is widely used for this purpose. Malonaldehyde and similar products are also referred to in testing and literature as 2-thiobarbituric acid-reactive substances, or TBARS, and are generally reported as mg of MDA per kg of sample (mgMDA/kg). A threshold range of TBARS numbers for detecting off-odors in ground pork by trained panelists was originally established at approximately 0.5 – 1.0 (Tarladgis et al., 1960). Additionally, gas chromatography has also been used as a way to measure compounds emitted by fresh and cooked meat in an effort to find correlations that may relate to product oxidation. Pegg and Shahidi (1994) noted that hexanal generation has been successfully used as a means of evaluation of the oxidative state of red meats from different species as well as from

fish; moreover, hexanal has been cited as the most prominent volatile compound in cooked meat with the amount being directly proportional to TBARS values, and inversely proportional to flavor acceptability (Calkins and Hodgen, 2007). Considerations regarding flavor will be discussed in a later section.

### ***Pre-harvest***

Since more unsaturated fatty acids have been found to be more susceptible to lipid oxidation, more pressure is placed on live animal production, especially in the swine industry, to minimize those practices that result in pork with an unnecessary quantity of PUFA, as detailed previously. Feeding of DDGS certainly falls into this category. Leick et al. (2010) fed 0, 15, 30, 45 or 60% C-DDGS and evaluated enhanced (salt and phosphate) anterior blade chops stored in modified atmosphere packages (80% oxygen/20% carbon dioxide) under fluorescent lighting. From an oxidation perspective, chops were found to have statistically equivalent TBARS values at 0, 7 and 14 d of storage, but at 21 d, those chops from pigs finished on 30, 45, and 60% C-DDGS had greater TBARS values when compared to product from pigs finished with 0 and 15%. Overall, d 21 TBARS values ranged from approximately 0.30 to 0.57 mgMDA/kg. This suggests that DDGS included at levels greater than 30% would result in product with retail oxidation concerns. More specifically, Xu et al., (2010a) fed 10, 20 and 30% C-DDGS and noted no differences in LM chop TBA values when product was stored in vacuum for 28 d and displayed in oxygen permeable overwrap for 3 d. Comparatively, chops in the first study contained much higher percentages of the PUFA C18:2 than the later study, even at overlapping DDGS inclusion rates. Pigs in the Leick et al. (2010) trial were fed 0, 15, 30 and 45% DDGS and had belly fat samples with C18:2 percentages of roughly 25, 30, 32 and 37%. Comparatively, pigs in the Xu et al. (2010a) trial were fed 0, 10, 20 and 30% DDGS and had belly fat samples with approximately 9, 12, 15 and 17% C18:2. Leick et al. (2010) acknowledged that fat analyses were overall more unsaturated than expected, with cause being attributed to the inclusion of yellow grease for supplemental fat rather than choice white grease. These conclusions support the work of Teye et al. (2006) stating increases in TBA values due to increased concentrations of the fatty acid C18:2. The conclusions of these studies emphasize the importance of producers knowing the composition of their ingoing feed ingredients and recognizing the impact it can have in

altering final retail quality. With this in mind, while the increased inclusion of a particular feedstuff may significantly increase unsaturation of lipids, it may not mean that the quantity of the unsaturated fatty acids is enough to influence pork oxidation shelf life, as in the case of Xu et al. (2010a).

Of additional interest, no literature was found regarding the final lipid oxidation of pork sourced from pigs finished on sorghum grains or sorghum distillers products.

### ***Harvest and Processing***

There are many intrinsic and extrinsic factors that contribute to the development of oxidation products during and after both slaughter and further processing. The influence of rigor state and ultimate pH are valuable, basic, meat quality quantifications. They have been assessed for their affect on oxidation by evaluating ground light and dark meat from both pre- and post-rigor pork as well pre- and post-rigor ground pork from pigs applied an epinephrine injection prior to harvest (Judge and Aberle, 1980; Yasosky et al., 1984). Pre-rigor pork has a higher ultimate pH than standard post-rigor product and has been found to have reduced TBA values, describing it as less susceptible to oxidation. Additionally, dark muscles are noted as being more susceptible to oxidation than light muscles as they showed greater TBA values after 3, 7 and 10 d of refrigeration. This increase in oxidation for dark muscles was potentially attributed to either the greater myoglobin pigment concentration, with a higher presence of heme proteins and associated iron, or the increased content of phospholipids, which have been noted as being a primary contributor to the oxidation process (Wilson et al., 1976). Allen et al. (1967) summarized that phospholipids, as measured by lipid phosphorus content, are associated and structurally involved in membranous cell components, leading to the reduced cholesterol/lipid phosphorus ratio that is associated with muscles which are involved in a greater amount of physical activity.

Independent of rigor and muscle type, as theorized, meat products simply having a higher ultimate pH are less susceptible to lipid oxidation, with a critical limit of a pH > 6.1 being needed to obtain maximum oxidation prevention (Yasosky et al., 1984). Similarly, Cheah and Ledward (1997) evaluated minced pork over 8 d of refrigerated storage and observed greater TBARS values in product with a pH of 5.5 to 4.9 compared to control product with a pH of 6.1. Following the same pattern, no difference in

oxidation was seen for product with an increased pH of 6.5 or 6.9. Seideman et al. (1984) detailed that low pH environments cause denaturation of the globin moiety and removal of oxygen from the heme, promoting metmyoglobin formation. Additionally, Faustman and Cassens (1990) note that a reduced pH will accelerate the protonation of bound oxygen and favor the release of superoxide anion, a previously mentioned contributor to the oxidation chain reaction.

Regardless of muscle state, oxygen availability to the final product is one of the most important factors influencing the development of lipid peroxidation in both raw and cooked meats. It almost goes without saying that oxygen molecules must be available in order for the problematic, free radical development of reactive oxygen species (ROS), mentioned previously. Ahn et al. (1993) evaluated ground turkey patties formulated from either breast meat or a turkey meat mixture (breast, leg and mechanically deboned turkey meat (MDTM)) with added oxidation catalyst solutions of FeCl<sub>2</sub>, hemoglobin or salt. Patties were cooked with 1/3 of each treatment being “hot packed” and vacuum packaged immediately after cooking, 1/3 being “cold packed” and vacuumed after 3 h of refrigeration post cooking and the final 1/3 being stored in oxygen permeable polyethylene sandwich bags. All samples were stored at 4°C and evaluated for oxidative rancidity via TBARS values at 0, 1, 3 and 7 d of storage. With limited oxygen contact after cooking, as in hot or cold vacuum packaging, the TBARS values of patties were much lower than those of loose packaging and did not increase much during storage. However, TBARS values of cold packed product were higher ( $P < 0.05$ ) than those of hot packed product with the difference being attributed to the reduced oxygen exposure time of hot packed patties. Overall, it was concluded that TBARS values of patties with prooxidants such as ionic iron, hemoglobin, salt or a combination, indicated that the catalytic effect of these compounds became highly significant only when oxygen was freely accessible to the patties during storage. Similarly, the differences between turkey meat blocks in total fat, fatty acid composition and lipid class became highly significant ( $P < 0.01$ ) only when cooked patties were exposed to storage oxygen. These findings support previous work detailing the role of oxygen molecules in the oxidation chain reaction and provide an excellent example of the care which must be taken to minimize oxygen exposure during the processing chain in order to prevent undesired lipid

oxidation. Mechanical processes such as grinding, chopping, flaking, and mechanical deboning of meat are processing instances that disrupt the integrity of membranes and expose the phospholipids to not only molecular oxygen but also oxidative enzymes, heme-pigments and metal ions (Ahn et al., 1993). Products such as ground pork can be especially susceptible to oxidation, due to the incorporation of oxygen and trace metals during grinding (Phillips et al., 2001). Wanous et al. (1989) outlined that, in the instance of ground pork or fresh sausage, increased grinder wear over time results in the equipment becoming less capable of shearing meat which increases product temperature, promotes smearing and contributes to minute amounts of iron deposition within the product.

### *Display*

The pathways and concerns of the oxidation process not only pertain to lipids but also to meat color components. This becomes most apparent during retail display at the point of purchase, when consumers ultimately decide which products meet their perceived standards of quality and which do not. The basic color transition due to oxidation is discussed earlier and results from the shift of the red OMb pigment to a brown “discolored” MMb pigment. From a molecular perspective, Seideman et al. (1984) details that any condition which results in the initial deoxygenation of OMb, subsequently causing the globin moiety to lose its ability to protect the heme group, consequently contributes to the spontaneous oxidation of the heme iron from  $Fe^{2+}$  to  $Fe^{3+}$ . This promotes discoloration and reduces retail color life. Comparatively, lipid oxidation is catalyzed by the same factors that oxidize myoglobin pigments to metmyoglobin; however, since lipid oxidation occurs at a slower comparative rate than discoloration or microorganism growth, it is usually not the major determinant of shelf-life in traditional overwrapped, air-permeable retail packages (Zhao et al., 1994). The mechanisms and interactions of lipid and color oxidation are complex and an important segment of the meat retail sector which has received attention. Faustman and Cassens (1990) are some of many to present a review with evidence supporting lipid oxidation as a promoter of pigment oxidation, while Baron and Andersen (2002) reviewed more recent studies presenting the potential mechanisms by which muscle pigments induce lipid oxidation. Both conditions develop under the basic oxidation reaction processes, so it is



understandable that they would compete and interact for those resources which both prevent or promote retail quality deterioration.

Seideman et al. (1984) summarized that the conditions influencing both lipid and color oxidation can include environments with a low pH, high temperatures, ultraviolet light and particularly low oxygen tensions. The influence of pH as well as oxygen have been noted and the reduction of storage temperatures has long been recognized as an oxidation prevention technique. This mechanism is outlined well in a review by Kanner (1994). Basically, heat disrupts muscle cell structure, degrades proteins, inactivates enzymes and releases oxygen from oxymyoglobin. Additionally, high temperatures decrease the activation energy for oxidation and break down pre-formed hydroperoxides to free radicals. These processes all work to propagate lipid peroxidation and accelerate discoloration. Kropf (1980) references a multitude of early studies, all finding increased oxidation rates in multiple meat products coinciding with increases in storage and display temperature.

The final component to consider in a retail environment is the presence of light, which could arguably be considered the primary factor in defining a product as being in display, as meat in storage is often not purposefully held in highly lit areas for long periods of time. The effect of light on lipid oxidation has been demonstrated in food systems such as oils, butter, milk and meat (Martínez et al., 2007). Whang and Peng (1988) evaluated the affect of fluorescent light at an intensity of 3,767 lux on ground pork and turkey held at 4°C for 6 d. Results revealed greater peroxide values ( $P < 0.01$ ) for that product held under light, when compared to comparable samples held in the dark. It was concluded that there were indeed photosensitized mechanisms within the ground meat which contributed to the initiation of oxidation products upon the absorption of light. Additionally, the inhibitory effect of several antioxidant compounds in lighted and dark treatments confirmed the involvement of the free radical pathway thought to be induced by light exposure.

A heavily referenced review by Kropf (1980) took particular interest in reviewing data in order to summarize those characteristics of display lighting that should be scrutinized most heavily for influence on meat appearance. Special attention was given to types of lighting, light intensity and temperature of display due to light, as well as

packaging. Differences in light type are the exact same concept as illuminant differences discussed previously regarding color perception. A light source is simply the natural occurrence of a standardized illuminant. Light sources, or illuminants, are compared regarding the range of wavelengths they emit. The visible light spectrum ranges from approximately 400 to 700 nanometers (nm) with the arrays of ultraviolet (UV) and infrared (IR) wavelengths being immediately below and above this spectrum, respectively. In addition, colorants such as pigments or dyes, in the object, selectively absorb some wavelengths while reflecting or transmitting others (HunterLab, 2001). This ultimately determines how the product is viewed.

Barbut (2001) evaluated beef, pork and chicken under fluorescent (FL), incandescent (IN) and metal halide (MH) light sources, finding product from all species under IN lighting to be most appealing to a visual panel, with a more red color. Product under FL and MH lighting was rated as similar in acceptability, and considerably less desirable than IN displayed meats. It was noted that the IN lighting provided a much greater luminance in the red region of the visible spectrum ( $> 570$  nm) than the FL and especially MH lighting. This supports the recommendation of Kropf (1980), stating meat display light sources should be reasonably rich in the red part of the spectrum as lighting with a close fit to the natural reflectance pattern of a product results in a more appetizing appearance.

Calkins et al. (1986) placed overwrapped LM chops under cool flood incandescent (CF), deluxe cool white fluorescent (DCW), cool white fluorescent Sulyn coated (CWSC) and warm fluorescent (WW) lights. One series received light exposure around the clock for 24 h, while a second series was only allowed light exposure for 12 h and was covered for the remaining 12 h of a particular day. Light type and exposure time were found to have no effect on TBARS over 5 d of retail display; however, chops under DCW light were rated as more desirable ( $P < 0.05$ ) by visual panelists, while that product housed under CWSC and WW light was evaluated as the least desirable. These preferences were noted as significant; however, overall panel scores for mean chop desirability under all light sources only ranged from 5.04 to 5.26, with a score of 8 being required to describe product as “extremely desirable”, showing that all products in this study were not highly desirable in appearance. Chops under most light types showed a

percentage decrease in DMb and an increase in MMb during display, marking product as discolored. Interestingly, product under CF lighting had a much more rapid accumulation of MMb, which was attributed to a product surface temperature increase of 2 - 8°C compared to product under all other light treatments. Overall, visual color panel concluded that the best and most preferred color rendition of pork was associated with DCW and CF lighting, however, substantial concerns were raised regarding product temperature and pigment oxidation increases due to CF lighting.

This data for pork contrasts with previously reviewed conclusions from Kropf (1980) and Barbut (2001) which found beef and pork displayed under warm white and IN lighting to be more preferred. Certainly, visual panel scores for desirability obtained by Barbut (2001) were more positive than those previously noted. Beef round steaks and pork chops in that study were scored at approximately 8.0 and 8.3 for the most preferred IN light treatment, respectively, on a scale with 10 as the highest possible value. Also, reflectance curves presented by both Kropf (1980) and Barbut (2001) seem to firmly back the idea that red meats under lighting with a greater yellow/orange/red spectrum concentration have a preferential appearance. These light sources and their emitted wavelengths are perhaps more easily distinguished and defined by their specified color temperatures as measured by degrees Kelvin (K). Lights with a higher color temperature, such as the D65 illuminant (6500 K) and cool white fluorescent lighting (~4200 K) shed increasing levels of “blue” light while those with lower color temperatures, such as warm white fluorescent or incandescent (~2900 K) emit more “red” light (HunterLab, 2008).

Kropf (1980) also reviewed data detailing product temperature increase due to intense retail light displays, referencing engineering figures which stated that deluxe FL lighting radiates approximately 1/5 as much heat as incandescent lamps at equal intensities. In general, low light intensities that do not increase surface temperature do not discolor meat (Seideman et al., 1984), while greater light intensities contribute to reduced color stability. This emphasizes the consideration that must be given to the strength of light sources to increase heat energy output, even with equal intensities at product level.

More recently, consideration has been given to the influence of specific wavelengths, especially UV wavelengths at around 300 – 400 nm. Martínez et al. (2007)

reviewed that UV-light is more effective than visible light in inducing oxidation of lipids and pigments, and that its presence in FL lighting is small, but needs to be taken into account for its affect in meat display environments. Their study found fresh pork sausage samples displayed in the dark to have no difference ( $P > 0.05$ ) in  $a^*$  or TBARS values when compared to samples displayed under 1000 lx of fluorescent lighting equipped with a polycarbonate UV filter. The highest TBARS values over 16 d of display were associated with product exposed to standard FL tube lighting. It was concluded that use of standard supermarket FL lighting was deleterious to the display life of fresh pork sausage, reducing it from 12 to 8 d, primarily due to discoloration, while use of FL lighting with a UV filter sustained shelf life to 12 d. Use of a “low-UV” color balanced FL light, did not prevent discoloration either.

These results supported work by Andersen and Skibsted (1991), who evaluated pork patties with and without 1% salt, a known oxidizer, packaged with a polyethylene UV-light barrier. Product was stored for 31 d at approximately  $-18^{\circ}\text{C}$  with half the product under 700 lux of fluorescent lighting and the other half under black plastic to block all light. Product temperature between treatments was not recorded. As anticipated, product which was formulated with salt, housed under lighting and packaged with no UV-light protection, resulted in pork patties with the lowest average Hunter  $a$  value and the greatest oxidative rancidity as measured by TBARS analysis. Consequently, patties without added salt that were held in the dark and packaged with a UV-light barrier film, exhibited an increased, more preferred, Hunter  $a$  value and the lowest TBARS. Initially, a slight lag phase was noted for TBARS, while discoloration began almost immediately and progressed steadily throughout storage; however, when lipid oxidation was in full progress, the TBARS value of product exposed to light without any UV-light protection increased at a rate almost double of that compared to products stored in dark. It was concluded that the UV-light barrier in the packaging material gave complete protection against light-induced lipid oxidation and partial protection against light induced discoloration.

Overall, the factors contributing to a meat products color stability and lipid oxidation shelf life are numerous. Effort on the part of producers and processors to provide an initially higher quality product to retail will undoubtedly allow for a greater

product display life; however, once in display it is the role of the retailer to ensure an optimal environment. Lighting and case setups that provide the proper spectrum of light, so as to emphasize the products natural color characteristics, are most preferred. Consideration must be taken, though, to minimize unnecessary light exposure and increased intensities which can increase a product's holding temperature, quickening the rate of color and lipid oxidation, consequently reducing display life and the opportunity for purchase by the consumer.

### *Sensory*

Once a product has been purchased, it then needs to provide a pleasant eating experience once consumed. Understanding the eating qualities of pork is a very important component of improving pork's competitiveness. As new pork products are produced, as new genetics and management and/or nutritional practices are developed, or as new technologies are implemented that may affect pork eating attributes, understanding of the eating qualities and consumer acceptance of the end product is needed (Miller, 2008). Considering the overall challenge of defining meat palatability, Calkins and Hodgen (2007) acknowledge that tenderness has played a large role in the overall acceptability of meat products by consumers, but state that it has become increasingly apparent that flavor also needs to be addressed. Holding tenderness constant, flavor has been found to be the most important factor affecting consumers' meat buying habits and preferences (Sitz et al., 2005). The flavor and aroma of meat products has been studied at numerous levels and it is widely recognized that the contributing compounds are many in number and interact in unique ways. Mottram (1998) compiled an extensive and thorough review of the origin, development and relationship of the major compounds which have been recognized as contributing to meat flavor. To summarize, cooked meat contains a complex mixture of volatile compounds, derived from both lipid- and water-soluble precursors. These provide roasted, boiled, fatty and species-related flavors, as well as the characteristic meaty aromas associated with all cooked meats. During cooking, the Maillard reaction between amino acids and reducing sugars and the thermal degradation of lipids are the primary means of flavor and aroma development. Specifically, the fatty tissues provide species characteristics, while the lean

tissues contain precursors for the meaty flavors associated with all cooked meats. Compared to the other mainstream red meats of beef and lamb, pork has a more unsaturated fatty acid profile, most noticeably seen when comparing levels of linoleic acid (C18:2; Enser, 1996). Given the role that fat has been shown to play in developing species specific flavors, it seems that adjustments to that fat which is presented to the cooking process would also result in adjustment to the final flavor profile.

As mentioned previously, it is well known that the fat composition of swine diets specifically influences the composition of that fat which is deposited during growing and finishing (Averette Gatlin et al., 2002). Given the previous thought regarding meat flavor development, it would seem that this could cause potential flavor differences in the end product; however, conclusions regarding the true flavor influence of pork with different fatty acid profiles are mixed. Calkins and Hodgen (2007) noted studies which worked to adjust the fat profile of pigs through feeding high oleic acid (C18:1) feedstuffs with findings of both improved palatability (Rhee et al., 1990) and no affect (Myer et al., 1992). Similarly, Larick et al. (1992) increased dietary linoleic acid (C18:2) content from roughly 1.5 to 6% in swine diets, increasing the C18:2 content of the resulting pork. The researchers found no differences in trained panel evaluation of pork flavor for ground patties. This supported similar work which found no flavor or color influence of pork chops due to increased compositional levels of linoleic acid.

Interestingly, Larick et al. (1992) did note increased levels of volatile compounds such as pentanal and hexanal during cooking of high C18:2 pork patties. Higher levels of these compounds, as mentioned previously, are usually associated with increased lipid oxidation and off-flavors in meat; however, this was not the case, supporting work from six other studies which altered the fatty acid composition of pork through dietary changes and found no differences in the resulting pork flavor. The fact that fatty acid adjusted pork was not shown to have off-flavors or noticeable changes to pork flavor was thought to be explained by work from Melton (1990), which hypothesized that oxidative rancidity may be a part of acceptable or intense pork flavor, due the fact that pork naturally contains more linoleic acid than other meats. Simply, compounds that develop and would be off-flavors in other meats are potentially expected in pork, and could therefore be considered as defining the flavor rather than altering it.

As detailed in an earlier section regarding the feeding of DDGS and fat quality concerns, much of the pork processing industry push back to the increased usage of distillers grains products in swine diets is in response to a more unsaturated fatty acid profile. This is certainly a viable concern for manufacturing parameters, but given the prior information, may present less of a concern for consumer palatability attributes.

Research regarding the effects of DDGS on growth and performance of pigs is plentiful, but data detailing the resulting palatability and sensory attributes is not extensive. A review of research looking at the inclusion of DDGS and other distillers co-products in the swine diet by Stein (2008) references only one study, conducted by Widmer et al. (2008), which included an assessment of the palatability of pork from pigs fed DDGS. Researchers in that instance, fed 84 pigs 1 of 7 dietary treatments including a corn-soybean meal based control, diets containing 10 or 20% C-DDGS and diets containing high or low levels of high-protein DDGS or corn germ. Palatability of cooked LM chops and bacon was determined over a series of trained panel sessions. Small numerical differences were noted, with LM tenderness decreasing at 10% DDGS and increasing at 20% inclusion (quadratic,  $P < 0.05$ ). Additionally, trends (linear,  $P \geq 0.08$ ) were noted for a slight increase in pork flavor intensity and decrease in off-flavor intensity. No effect was seen on LM chop juiciness concerning the use or increase of C-DDGS. Considering this loin muscle data as well as the similar bacon analysis, it was concluded that there was no difference in overall acceptability of pork from pigs fed distillers co-products as compared to pork from pigs fed a corn-soybean meal diet, at tested levels. It was conjectured that it is unlikely consumers will be able to tell whether or not the pork they are eating comes from a pig fed distillers co-products.

Previously mentioned work by Xu et al. (2010a) also evaluated sensory attributes of LM chops and bacon from pigs fed 10, 20 or 30% C-DDGS on a corn-soybean meal-based control. Findings from this study supported the conclusions of Widmer et al. (2008) with data stating no differences ( $P > 0.30$ ) in flavor intensity, off-flavor, tenderness, juiciness or overall acceptability of LM chops from pigs fed 0 to 30% DDGS.

No literature was found regarding the palatability of pork from pigs finished with sorghum or S-DDGS; however, given the specific data detailing the feeding of other distillers co-products and the conclusions regarding the uniqueness of pork fat and flavor,

it would seem unlikely that the use of sorghum distillers products in swine diets would contribute to a decline in quality regarding sensory attributes.

Physical characteristics contributing to pork palatability, such as texture and juiciness, are more straight forward than aspects surrounding flavor components, especially when considering ground product. Generally, as fat level decreases in ground beef, tenderness and juiciness sensory scores follow, and decrease as well (Kregel et al., 1986). The same is true in pork. Reitmeier and Prusa (1987) formulated pork patties at fat levels of 4, 9, 18 and 23%, and cooked product to end point temperatures of both 71° and 77°C before presenting them to trained panelists. As expected, the moisture (%) content of patties decreased as fat (%) increased and those patties formulated at the two highest fat levels received the most preferred scores for tenderness and juiciness ( $P < 0.001$ ). Additionally, it was noted that final endpoint temperature did not affect sensory attributes. These results were noted as supporting findings by Keeton et al. (1983) which generally noted an increase in preferred tenderness and juiciness for pork patties with 30% fat compared to patties with approximately 20% fat.

The influence of fat is important to remember when conducting sensory evaluation, especially of higher fat ground products like pork patties. Clearly if a feeding regimen were to result in a higher or lower pork fat composition, it should be expected that sensory attributes such as juiciness and texture would follow a similar pattern. Additionally, gender has already been mentioned as contributing to compositional differences, with barrows usually being fatter than gilts at equal points of marketing. Regarding gender, the feeding trial conducted by Xu et al. (2010a) also compared barrows and gilts. Loin muscle chops were evaluated from 32 barrow and 32 gilt carcasses and were deemed equivalent ( $P > 0.45$ ) for flavor intensity, off-flavor, tenderness, juiciness and overall acceptability. These results support previous work (Stein et al., 2006) which evaluated barrows and gilts for palatability of both LM chops and ground pork patties. Trained panel assessment found no affect according to gender on LM ( $P \geq 0.17$ ) tenderness, juiciness, pork flavor intensity and off-flavors or ground pork patty ( $P \geq 0.09$ ) texture, juiciness, pork flavor intensity, and off-flavors.



Overall, while there are processing concerns resulting from the feeding of distillers co-products to swine, the resulting compositional differences that develop are not seen as carrying through to hinder retail pork palatability.

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## **CHAPTER 2 - Effects of Sorghum Grain and Sorghum Dried Distillers Grains with Solubles on the Composition, Quality and Sensory Attributes of Ground Pork.**

### **Abstract**

A total of 48 carcasses were taken from a larger trial using 288 pigs (PIC TR4 × 1050, initially 58.9 kg) in a 73 d feeding study to determine the effects of sorghum dried distillers grains with solubles (S-DDGS) in sorghum- or corn-based diets on ground pork quality. The dietary treatments included: sorghum-based diets with 0, 15, 30, or 45% S-DDGS, a sorghum-based diet with 30% corn DDGS (C-DDGS) and a corn-based diet with 30% C-DDGS. Shoulders from 24 barrow and 24 gilt carcasses were ground, packaged and evaluated for proximate and fatty acid composition, iodine value (IV), objective color, thiobarbituric acid-reactive substances (TBARS), and sensory attributes. No finishing diet × gender interaction was detected for composition, fatty acid profile, color or TBARS ( $P > 0.05$ ). Pork from gilts contained less fat and more moisture ( $P < 0.001$ ), was less saturated with a greater IV and total percentage of PUFA ( $P < 0.01$ ), and also had a lower CIE L\* value ( $P < 0.001$ ) and higher CIE a\* value ( $P = 0.006$ ) than pork from barrows. Gender did not affect total color change from 0 to 120 h ( $P = 0.30$ ), TBARS ( $P = 0.08$ ), or sensory attributes ( $P \geq 0.32$ ) of ground pork. Finishing diet had no affect on total fat, moisture, or protein composition ( $P \geq 0.18$ ). Increasing S-DDGS resulted in a linear ( $P < 0.001$ ) decrease in SFA and MUFA and an increase ( $P < 0.01$ ) in PUFA and ground pork IV. Pork from pigs fed 30% S-DDGS had a greater percentage of MUFA ( $P = 0.01$ ) and a lower percentage of PUFA ( $P > 0.006$ ) and reduced IV ( $P = 0.03$ ) compared to pork from pigs fed a sorghum-based diet with 30% C-DDGS. Diet did not affect TBARS ( $P = 0.37$ ) or objective color CIE L\*, a\*, or b\* values ( $P \geq 0.11$ ) but was shown to influence total color change ( $P = 0.01$ ) with pork from pigs fed sorghum grain and 30% S-DDGS having less total change than all other dietary treatments. Ground pork patties from all treatments were characterized with similar sensory descriptors. Overall, increasing dietary S-DDGS during finishing resulted in ground pork having a linear increase in unsaturated fatty acids. Utilization of S-DDGS compared to an

equal level of C-DDGS resulted in pork with a more saturated fatty acid profile and reduced IV; however, no differences were observed for oxidative rancidity, color or sensory attributes.

Keywords: color, dried distillers grains with solubles, pork, sensory, sorghum, TBARS

## **Introduction**

Dried distillers grains with solubles (DDGS), largely processed from corn (C-DDGS), have been a popular feed ingredient in swine diets over the past decade due to its increasing availability (DTGC, 2005) and opportunity for diet cost savings (Jacela et al., 2009). The use of sorghum grains in ethanol has grown to include 30 to 35% of the domestically grown sorghum resulting in an interest from producers to use S-DDGS in the plains states such as Kansas (USCP, 2011). In general, DDGS are fed at 20 to 30% of the diet as many studies have been reviewed to show these levels do not detrimentally affect growth performance (Stein and Shurson, 2009). However, feeding at these levels has been shown to hinder pork quality and result in a more unsaturated fatty acid profile and consequently, increases in iodine value (IV), linoleic acid (C18:2), and total percent PUFA (Whitney et al., 2006; Stein, 2008; Stein and Shurson, 2009). This leads to softer fat, fabrication difficulties, reduced bacon yields, unattractive products, and reduced shelf life (NPPC, 2000; Carr et al. 2005). While many diets fed are corn-soybean meal-based, Benz et al. (2011) found pigs fed sorghum-based diets to have a lower IV than pigs fed corn. Because sorghum grains are largely recognized as being able to replace corn in finishing diets without affecting growth performance (Johnston et al., 1998; Shelton et al., 2004; Tokach et al., 2011), they may offer an opportunity to assist in the control of pork fat quality issues and allow for the inclusion of DDGS at higher, more economically preferred levels. Additionally, the work detailing the influence of DDGS on consumer evaluated quality issues such as color and sensory attributes is not extensively detailed. Therefore, the objective of this study was to determine the effects of increasing sorghum DDGS (S-DDGS) in sorghum- or corn-based diets on ground pork composition, fatty

acid profile, and sensory attributes as well as retail display objective color and oxidative rancidity.

## **Materials and Methods**

### ***Animal Background***

The Kansas State University (KSU) Institutional Animal Care and Use Committee approved procedures used in this experiment. A total of 288 finishing pigs (PIC TR4 × 1050, initially 58.9 kg) were utilized as part of a 73 d feeding study (IACUC# 2772.20) at the KSU Swine Teaching and Research Center to determine the effects of increasing S-DDGS in sorghum- or corn-based diets on resulting ground pork quality, sensory attributes, and retail display life. Pigs were allotted to 1 of 6 dietary treatments, in a completely randomized design based on initial pen weight. The dietary treatments included: sorghum-based diets with S-DDGS included at 0, 15, 30, or 45%, a sorghum-based diet with 30% C-DDGS and a corn-based diet with 30% C-DDGS.

There were 8 pigs per pen and 6 replications per treatment, resulting in 36 total pens. Each pen provided 2.44 m<sup>2</sup> per pig and had slatted floors, one 5-hole self-feeder and a cup waterer. Throughout the trial, pigs had ad libitum access to feed and water. All treatment diets were in meal form and fed in 3-phases (Appendix A).

At the conclusion of the feeding trial, the heaviest barrow and gilt were selected from each pen with each being humanely harvested on 1 of 2 dates at the KSU Meat Laboratory. Pigs were allocated to harvest dates so that there were an equal number of barrows and gilts from each diet.

### ***Ground Pork Processing***

A total of 48 carcasses were used from those pigs harvested at the KSU Meat Laboratory for production of ground pork to be utilized in all subsequent evaluations in this study. Twenty four pigs were randomly selected from each of the 2 harvest dates so that within a single harvest date there were a total of 4 pigs selected from each of the 6 diet treatments (2 barrows and 2 gilts), with each pig being sourced from a different original finishing pen.

Approximately 48 h postmortem, Institutional Meat Purchase Specifications (IMPS) Item No. 403 pork shoulders (AMS, 2010) were separated from the right and left carcass halves, fabricated to remove the scapula, ribs, humerus and vertebrae, and were trimmed to an external average fat thickness of 0.64 cm. Shoulders were placed in cooler storage ( $2.2 \pm 1^\circ\text{C}$ ) prior to further processing. At approximately 72 h postmortem both shoulders from each carcass were trimmed of any noticeable blood splash and then ground through a 1.27 cm plate (grinder model 4732, The Hobart Mfg. Co., Troy, OH). Pork was then ground (grinder model 1556, Biro Mfg. Co., Marblehead, OH) through a bone collection plate to a final diameter of 0.32 cm and temperature of 4.4 to 6.1°C.

Following the final grind of both shoulders from each carcass, ultimate pH was recorded (glass tip probe model FC 200; meter model HI 9025, Hanna Instruments, Woonsocket, RI) before seven 0.45 kg packages were prepared for retail display simulation; 0.9 kg of product was removed for sensory evaluation, vacuum packaged and placed in frozen storage ( $-28.9^\circ\text{C}$ ); and 0.45 kg was removed, frozen ( $-80^\circ\text{C}$ ) and submitted to the KSU Analytical Services Lab for compositional analysis.

### ***Composition***

One, 0.45 kg sample of ground pork from each carcass was vacuum packaged, frozen ( $-80^\circ\text{C}$ ) and submitted to the KSU Analytical Chemistry Laboratory. Approximately 0.22 kg of each sample was finely cubed, frozen in liquid nitrogen, pulverized (blender model 51BL32, Waring Commercial, Torrington, CT) and returned to frozen storage prior to analysis. Duplicate samples were evaluated for moisture and crude fat (AOAC Official Method: PVM-1:2003 Meat), crude protein (AOAC Official Method: 990.03) and fatty acid profile analyses (Sukhija and Palmquist, 1988). Fatty acid profile data is reported as a percent of the total fatty acid content. Additionally, iodine value (IV) was calculated according to (AOCS, 1998) with the following equation:  $[\text{C16:1}] \times 0.95 + [\text{C18:1}] \times 0.86 + [\text{C18:2}] \times 1.732 + [\text{C18:3}] \times 2.616 + [\text{C20:1}] \times 0.785 + [\text{C22:1}] \times 0.72$ , where brackets indicate concentration.

### ***Retail Display***

Retail display packages were prepared by placing 0.45 kg of product on a 1S styrofoam tray (Dyne-A-Pak, Inc., LAVAL, QC, Canada) with an absorbent pad and



polyvinyl chloride (PVC) overwrap film (Borden Packaging and Industrial Products, North Andover, MA) with an oxygen permeability flow rate of 23,250 mL O<sub>2</sub>/m<sup>2</sup>/24 h. Immediately after packaging, all products were removed from light and held below 4.0°C for no more than 1 h until all packages were ready to be placed in the retail display cases.

In order to facilitate application of retail lighting treatments, 2 identical, open-top retail display cases (unit model DMF8, Tyler Refrigeration Corp., Niles, MI) in the KSU Meat Color Lab were each equipped with a different light source. Preliminary work involving comparisons of retail display light sources at KSU has set equal operation temperatures prior to turning on lighting, allowing for any differences in display environment temperature to be attributed to the light source. It is important to note and emphasize that one of the goals of this study was to evaluate the main effect of only light source. With this in mind, the retail display environment was established so as to equilibrate all variables, including display temperature, with the exception of the variable of interest: light source. To accomplish this, 1 case was set under 10 fluorescent tube bulbs (Sylvania/F032/835/Eco, 3500K; Osram Sylvania, Danvers, MA) with the second case set under 10 light emitting diode (LED) tube bulbs (EnergyLED E1N5KLHC3-S4, 3500K; Altair Exchange Corp., Canoga Park, CA). Care was taken to ensure that both sets of lights were of an equivalent manufactured color temperature (3500 Kelvin) and were adjusted above the display cases to emit an average light intensity of 2,152 ± 208 lux. Prior to product placement in the cases, water bags were placed in each case to imitate product load, and light fixtures were turned on and allowed to warm up for 48 h. After the acclimation period, cases were monitored for 48 h and adjusted to operate at an equivalent average temperature of 1.6 ± 1.5°C as measured in the product display area (model RD-TEMP-XT, Omega Engineering, Inc., Stamford, CT).

From the 7 packages of ground pork retained from each pig, 1 was randomly allocated to be sampled at 0 h and not placed in retail display, with the other 6 going to the display treatments. Of those six, 3 were placed under fluorescent lighting and sampled during either h 12-24, 36-72, or 84-120; and 3 were placed in the LED lit case to be sampled during the same time intervals. Specifically, from the 3 samples within each case, 1 package was evaluated for analytical color at 12 and 24 h, then vacuum packaged and frozen (-80°C); a second was evaluated at 36, 48, 60 and 72 h, then removed, vacuum

packaged and frozen; and the third was evaluated at 84, 96, 108 and 120 h of display at which point it was removed, vacuum packaged and frozen. Remaining packages after each evaluation time were rotated within the case to account for any location specific variations in temperature and light intensity. Color values were obtained from the mean of 2 random readings per package using a HunterLab Miniscan EZ colorimeter (model 4500L, 31.8 mm-diameter aperture, 10° standard observer, Illuminant A10, Hunter Associates Laboratory, Inc., Reston, VA). Color data recorded included CIE L\* (lightness), a\* (redness) and b\* (yellowness) values from a spectral reflectance range of 400 – 700 nm. Additionally, total color change ( $\Delta E$ ) was calculated according to Minolta (1998) with the following equation:  $\sqrt{[(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2]}$ .

Oxidative rancidity was evaluated on all retail packages from each pig after frozen storage (-80°C) following the conclusion of the second display repetition. Thiobarbituric acid-reactive substances (TBARS) were performed as described by Buege and Aust (1978) and modified according to the AMSA (2011). The top 0.5 - 1.5 cm layer of product was cut from each ground pork package, finely cubed, frozen in liquid nitrogen, pulverized (blender model 51BL32, Waring Commercial, Torrington, CT) and returned to frozen storage (-80°C) until all samples had been prepped. Duplicate 0.5 g samples were weighted out in disposable 15 mL polypropylene centrifuge tubes (Nalge Nunc International, Rochester, NY) and thoroughly mixed (Touch Mixer model 232, speed 10, Fisher Scientific, Fair Lawn, OH) with 2.5 mL of thiobarbituric acid (TBA) stock solution containing 0.375% TBA (MP Biomedicals, LLC, Solon, OH), 15% trichloroacetic acid (Fisher Scientific, Fair Lawn, OH) and 0.25N hydrochloric acid (Fisher Scientific, Fair Lawn, OH). Samples, including a blank standard tube containing only 2.5 mL of TBA stock solution, were then boiled (100°C) in a water bath (Versa-Bath model 139, Fisher Scientific, Fair Lawn, OH) for 10 min, cooled in tap water (24°C) for 10 min and centrifuged (model J2-21, rotor model JA-14, Beckman-Coulter, Fullerton, CA) at 5000 × g for 10 min. Samples were then filtered (Autovial 5, glass microfilter with polypropylene housing, 0.45 µm pore size, Whatman, Inc., Piscataway, NJ), to obtain a clear supernatant, into disposable 1.5 mL cuvetes (Fisherbrand, methacrylate, Fisher Scientific, Fair Lawn, OH). Supernatant absorbance (A) was read at 532 nm against the blank solution with a spectrophotometer (model U-2010 UV/Vis,

Hitachi High Technologies America, Inc., Naperville, IL). TBARS values (mg malonaldehyde (MDA)/kg of meat) were calculated using an extraction coefficient of  $156,000 \text{ M}^{-1} \text{ cm}^{-1}$  (Sinhuber and Yu, 1958) as follows:

$$\text{TBA}(\text{mg}/\text{kg}) = \text{sample } A_{532} \times \frac{1 \text{ M chromagen}}{156,000} \times \frac{1 \text{ mol/L}}{\text{M}} \times \frac{0.003 \text{ L}}{0.5 \text{ g meat}} \times \frac{72.07 \text{ g MDA}}{\text{mole}} \times \frac{1000 \text{ mg}}{\text{g}} \times \frac{1000 \text{ g}}{\text{kg}}$$

### ***Temperature Log Data Adjustments***

Retail case temperature was monitored throughout both display periods utilizing a temperature logger (model RD-TEMP-XT, Omega Engineering Inc., Stamford, CT) placed within each case to record the actual display environment temperature at the product level. While the purpose and goal of the retail display segment of this study was to evaluate fluorescent vs. LED light sources by equilibrating all other variables associated with the display environment, equal temperatures between cases was not maintained.

Fluctuations in temperature can certainly be expected in open retail display storage, however; differences in this instance are of a great enough magnitude to warrant an explanation of the potential interpretations of data that might, but cannot statistically be, attributed to the applied light treatments. Temperature data logs are presented in Appendix B. Perhaps of greatest influence is the significant temperature increase which can be seen during the second display repetition in the fluorescent case starting at approximately 27 h.

With this in mind, it must be clarified that the desired light treatment did not align with the stated study protocol and cannot be assessed. Therefore, the main and interactive effects of light were removed from the analysis with TBARS and CIE L\*, a\* and b\* values, as well as calculated  $\Delta E$  being averaged over both cases.

Data detailing cooked pork patty sensory attributes and ground pork crude fat, moisture, crude protein and fatty acid profile composition were obtained separate from retail display product were not affected by the above detailed temperature deviations.

### ***Sensory Evaluation***

The KSU Institutional Review Board (IRB) approved sensory panel studies used in this experiment. Sensory panelists consisting of previously approved faculty, staff and

students of KSU were trained prior to testing during 2 preliminary round table discussions held with the purpose of refining and acclimating panelists to the product attributes, descriptors and scales to be used during testing. Ground pork from each of the 24 pigs selected within a harvest date was allocated to 1 of 4 panels such that 6 pigs were evaluated during a single session, 1 from each dietary treatment and 3 of each gender. Individual panel sessions consisted of at least 6 and no more than 8 trained panelists, secluded in partitioned booths under red filtered lighting.

Pork was removed from frozen storage (-28.9°C) 36 h prior to its allocated session and thawed in vacuum package at 3.3°C. Patties were formed and prepared for sampling (AMSA, 1995). Specifically, four, 113.5 g (scale model EP2102C, Ohaus Corporation, Pine Brooks, NJ) ground pork patties (GPP) from each pig were press formed simultaneously using a plastic, 6-hole meat patty mold 1.27 cm in thickness. Patties were kept cool (3.3°C) prior to cooking. All 4 patties were placed on a preheated electric griddle (model 106733Wal-Mart Stores, Inc., Bentonville, AK) and turned every 2 min until cooked to an internal temperature of 71°C (thermocouple type T, 30 gauge, Omega Engineering, Stamford, CT; Doric model 245, Vas Engineering, San Diego, CA). Cooked GPP from a single pig were each cut into 6 equal pieces and held in individual double boiler pans during panel sampling.

During each session, panelists were first presented an identical warm-up sample and were asked to share their evaluation with the other panelists in order to facilitate a brief panel calibration. This was followed by a randomly ordered presentation of the 6 samples to each panelist with each person being given 2 GPP pieces from a single pig at once. Between each sample, panelists cleansed their pallet with a piece of apple, saltine cracker and filtered water, consumed in that order. Panelists were asked to evaluate each GPP sample on a numerical scale from 1- 8 for the following attributes, scoring to the 0.5 point:

Pork Aroma:	1= extremely weak	8 = extremely Strong
Off Aroma:	1= none	8 = abundant
Pork Flavor:	1= extremely bland	8 = extremely Intense
Juiciness:	1= extremely dry	8= extremely juicy
Texture:	1= extremely soft	8 = extremely hard

Off Flavor: 1 = none 8 = abundant

A sensory form is presented in Appendix C. Data was averaged over panelists to obtain a single value for each sample attribute within a panel session.

### *Statistical Analysis*

Data analyses were conducted utilizing the MIXED procedure of SAS (SAS Institute Inc., Cary, NC). Main and interactive means were obtained with the LSMEANS statement and compared with the PDIFF option if the F statistic was significant ( $P < 0.05$ ). Statistical code is presented in Appendix D.

Color and TBARS data were analyzed as a randomized complete-block with a split-plot. Pig served as the whole plot experimental unit and was blocked by harvest date, while package served as the split-plot experimental unit. Due to the split plot design, the Kenward-Roger degrees of freedom adjustment was used in the model statement.

Sensory data were analyzed as a randomized incomplete-block as not each diet  $\times$  gender combination was presented during each panel session. Pig was used as the experimental unit, blocked by panel session (incomplete-block) and harvest date.

Data for pH, moisture, crude fat, crude protein, fatty acid concentration and total color change were analyzed as a randomized complete-block with pig serving as the experimental unit being blocked by harvest date.

## **Results and Discussion**

### *Composition*

There were no diet  $\times$  gender interactive effects observed for ground pork percent moisture, protein, or fat, fatty acid profile or ultimate pH (data not shown), therefore only compositional main effect data is presented and discussed. Data detailing this specific interaction is lacking as none of the literature reviewed discussed the feeding of S-DDGS to finishing barrows and gilts. Many reports are available regarding the feeding of C-DDGS during finishing; however, Xu et al. (2010) was the only work reviewed that analyzed barrows and gilts fed 0 to 30% C-DDGS. In this case, no interaction was

detected ( $P > 0.05$ ) for last rib backfat depth, percent fat-free lean, backfat and belly fat fatty acid profile, or loin muscle fatty acid profile. It is determined that feeding DDGS to barrows and gilts results in pork of a similar composition.

Increasing dietary S-DDGS from 0 to 45% had no effect ( $P > 0.05$ ) on percent fat, moisture, or protein (Table 2.1). A review of DDGS in swine diets by Stein and Shurson (2009) clearly summarizes the accepted idea that up to 20 or 30% DDGS can be included in finishing diets without causing unfavorable changes in growth performance and carcass yield characteristics; however, considering pork quality issues, feeding DDGS at these levels has been marked as a cause for concern.

As expected in the current study, finishing diet was shown to influence ground pork fatty acid profile (Table 2.2, 2.3). It is well established that the fatty acid profile of pork is influenced by the composition of the diet (Averette Gatlin et al., 2002). In the case of swine, dietary fatty acids pass through the digestive system unchanged (Nürnberg, 1998) and, depending on the fatty acid, are transferred to carcass fat at a relatively high rate (Kloareg et al., 2007). Iodine value is a common attribute used to assess fat saturation, with a threshold of an IV = 70 being established by many as a maximum limit in order to avoid overly unsaturated pork carcass fat (Lea, 1970; Barton-Gade, 1987; NPPC, 2000). Overly unsaturated pork fat is a concern, as it leads to softer fat, fabrication difficulties, reduced bacon yields, unattractive products, and reduced shelf life (NPPC, 2000; Carr et al., 2005). An initial comparison of ground pork from pigs finished on both of the diets containing 30% C-DDGS revealed equivalent ( $P > 0.05$ ) levels of all fatty acids, fatty acid ratios and IV with the exception of myristic acid (C14:0), which was slightly higher ( $P < 0.05$ ) in pork from the sorghum grain-based diet. This suggests that use of sorghum grain does not result in a fatty acid profile advantage compared to corn grain when finishing with an equal level of C-DDGS. Sorghum grains are largely recognized as being able to replace corn grains in finishing diets without affecting growth performance (Johnston et al., 1998; Shelton et al., 2004; Tokach et al., 2011). Performance effects are supported by Benz et al. (2011); however, researchers in that instance found pigs fed sorghum grain with 30% C-DDGS to have a reduced ( $P < 0.01$ ) IV and percent C18:2 levels in jowl and belly fat samples compared to pigs fed corn grain with same level of C-DDGS. It was concluded from this that sorghum grains offered an

advantage over traditional corn based diets in reducing final pork fat IV when feeding C-DDGS. The ground pork data in the current study support at least an equivalency of sorghum and corn grain based DDGS diets to influence fatty acid profile, but not an advantage, emphasizing the need for further research in evaluating corn vs. sorghum grain bases in swine diets utilizing DDGS.

A comparison of diets containing S-DDGS vs. C-DDGS at 30% was made. In this case, ground pork from pigs fed with S-DDGS had a higher percentage of oleic acid (C18:1n9c;  $P = 0.005$ ) and MUFA ( $P = 0.01$ ) and a lower percentage of total C18:2 ( $P = 0.004$ ) and PUFA ( $P = 0.006$ ), a lower PUFA:SFA ratio ( $P = 0.01$ ), and a lower IV ( $P = 0.03$ ) than pork from pigs finished with 30% C-DDGS. Similarly, Feoli et al. (2008a) reported jowl fat IV from pigs fed 30% S-DDGS to be reduced ( $P < 0.04$ ) from about 80.4 to 74.4 when compared to pigs fed 30% C-DDGS. None of the treatments in that study resulted in an IV below the desired level of 70, however, the IV of S-DDGS pigs were certainly much closer to control pigs fed no DDGS, which had a mean IV of 70.3. This supports the idea that feeding S-DDGS in place of C-DDGS results in a more saturated, higher quality fat profile.

Linear trends in conjunction with an increasing percentage of S-DDGS from 0 to 45% were observed for many fatty acids, including percent increases ( $P < 0.001$ ) in linoleic acid (C18:2n6c),  $\alpha$ -linolenic acid (C18:3n3), eicosadienoic acid, (C20:2), total PUFA and IV; as well as percent decreases ( $P < 0.01$ ) in palmitic acid (C16:0), palmitoleic acid (C16:1), oleic acid (C18:1n9c), vaccenic acid (C18:1n7), total SFA, and total MUFA. Increasing the inclusion of DDGS in the swine diet has consistently been shown to decrease fat profile saturation. Whitney et al. (2006) fed C-DDGS at 0, 10, 20 and 30% and reported an increase in IV from 66.8 at 0% to 72.0 at 30%. The DDGS review of Stein and Shurson (2009) detailed 7 similar studies that fed up to 30% C-DDGS, all reporting significant decreases in fat saturation and increases in IV to greater than 70. More recently, Xu et al. (2010) fed 0, 10, 20 and 30% C-DDGS and reported increased backfat IV of 58.2, 63.3, 68.4 and 72.4, respectively. Coinciding with this, levels of C18:2 were also shown to increase in fat samples and in loin muscle (LM) chops, understandably, as PUFA such as C18:2 are important in predicting carcass fat IV (Bergstrom, 2011). Results from feeding S-DDGS are similar to those found regarding

the feeding of C-DDGS. A series of studies conducted by Feoli et al. (2007, 2008a,b,c,d) evaluated fat supplements in S-DDGS diets and reported an increase in carcass fat IV according to the introduction of S-DDGS, when compared to corn-soybean meal based control diets. Overall, the current data agree with the literature in concluding that increasing S-DDGS during finishing results in a more unsaturated fatty acid profile.

Gender affected the composition (Table 2.6) of ground pork. Barrows contained more fat and less moisture ( $P < 0.001$ ) than ground pork from gilts. It is well known that gilts are leaner than barrows at similar slaughter weights (Averette Gatlin, 2002), an attribute with which the current data agree. Additionally, regarding fatty acid profile compared to gilts, ground pork from barrows contained a higher ( $P \leq 0.01$ ) percentage of palmitic acid (C16:0), oleic acid (C18:1n9c), and MUFA, as well as a lower ( $P \leq 0.01$ ) percentage of linoleic acid (C18:2n6c), total C18:2 fatty acids,  $\alpha$ -linolenic acid (C18:3n3), total PUFA, and IV (Table 2.7). In general, ground pork from barrows was more saturated than product originating from gilts. A recent meta-analysis by Bergstrom (2011) of the factors contributing to carcass fat IV confirmed that reduced backfat, belly fat and jowl fat IV are all associated with increased backfat depth. Because barrows were fatter than gilts, as expected, these findings agree with the expectation that pork from barrows should be more saturated than similar product from gilts due to an increase in total carcass fat.

### ***Retail Display***

No 2- or 3-way interactions were observed among retail display hour, finishing diet and gender regarding ground pork color or oxidation during 120 h of retail display (Appendix E). As expected, there was a decrease (linear and quadratic,  $P < 0.0001$ ) in ground pork L\*, a\* and b\* values according to an increase in display hour (Table 2.8). Additionally, TBARS were dependent on h of storage, with the least oxidation being observed at 24 h and the most at 120 h. Oxidation in muscle foods is a concern as it leads to discoloration, drip loss, off odor and off flavor development as well as the production of potentially toxic compounds (Morissey et al., 1998). Polyunsaturated fatty acids, both isolated and those incorporated into lipids, have consistently been recognized as being more susceptible to the actions of oxidation than MUFA or SFA (Halliwell and Chirico,



1993). Horwitt (1986) reported relative oxidation rates of fatty acids containing 1, 2, 3, 4, 5 and 6 double bonds as being 0.25, 1, 2, 4, 6, and 8, respectively. This clear propensity for more UFA to oxidize leads to greater rancidity as display time increases (Wood et al., 2003).

Recognizing the effect of increasing S-DDGS to increase (linear,  $P < 0.001$ ) C18:2 percent and IV in the present study, it could be expected that TBARS might follow a similar pattern; but this was not the case. Finishing diet was found to have no effect ( $P = 0.37$ ) on overall ground pork TBARS (Table 2.4), suggesting that the use of sorghum grain and the use of S-DDGS does not alter final product oxidation when compared to corn grain and C-DDGS. No data was found detailing the influence of DDGS, regardless of source, on ground pork; however, a similar finding of no TBARS difference was reported by Xu et al. (2010) for LM chops from pigs fed 0, 10, 20 and 30% C-DDGS after vacuum storage for up to 28 d and 3 d retail display (oxygen permeable overwrap). In opposition, Leick et al. (2010) fed pigs 0, 15, 30, 45 and 60% C-DDGS, evaluating enhanced blade chops in retail display for 21 d, and found equivalent TBARS values during retail display d 0, 7 and 14 for pork from all diets, but increased values at d 21 for chops from pigs fed 30, 45 and 60% DDGS. Contradiction in this case is explained by the conclusion of Teye et al. (2006) detailing an increase in TBA values due to increased concentrations of C18:2. Belly fat samples from the study of Leick et al. (2010) contained 25 to 37% C18:2, while similar samples from the study of Xu et al. (2010) only contained 9 to 17% C18:2. Also, considering that LM chops from the latter study only contained between 6.8 and 9.5% C18:2, it would seem that pork evaluated in the Xu et al. (2010) study did not contain a high enough level or percent change in C18:2 to result in oxidation differences between dietary treatments. Ground pork C18:2 concentrations for increased S-DDGS levels in the present study were similar to those reported for LM chops by Xu et al. (2010); therefore, the same conclusion is applied to the current data regarding S-DDGS and the absence of TBARS variation.

Finishing diet did not influence CIE L\*, a\*, or b\* values of ground pork (Table 2.4); however, it was found to affect ( $P = 0.01$ )  $\Delta E$ . Pork from pigs fed sorghum grain with 30% S-DDGS had less  $\Delta E$  during display compared to all other diets. The reasoning for this single diet difference is unclear. It is concluded that, compared to corn

grain and the use of C-DDGS, feeding sorghum and S-DDGS does not alter ground pork color or retail color life given the detailed display parameters. Lack of dietary DDGS influence on pork color supports previous results which found no difference in LM chop subjective color score (Whitney et al., 2006; Xu et al., 2010) or CIE L\*, a\* and b\* values (Whitney et al., 2006; Widmer et al., 2008) when feeding up to 30% C-DDGS. Xu et al. (2010) did note decreases in a\* and b\* values of LM chops according to increasing dietary C-DDGS; however, reported a\* values in that instance ranged from -0.83 to -1.24, detailing chops as more green than red. Considering subjective color scores (NPPC, 1999) of the same chops ranged from 2.9 to 3.03, describing product as approximately reddish-pink, the practicality of objective color data from Xu et al. (2010) is questioned.

Gender had no effect on TBARS ( $P = 0.08$ ) or  $\Delta E$  between 0 to 120 h ( $P = 0.30$ ); however, pork from gilts did have a lower L\* value ( $P < 0.001$ ), higher a\* value ( $P = 0.004$ ), and slightly lower b\* value, quantifying it as darker, more red and slightly less yellow (Table 2.6). This supports the conclusion that the production of ground pork from gilts results in a darker red display color. A simple explanation for this difference is that, remembering proximate composition, ground pork from gilts contained about 5% less fat. A lower total fat content resulting in less physical white colored tissue could easily be seen as resulting in a visually darker product with a greater percentage of lean red tissue available to reflect light and present a redder color. In general, gender has received mixed attention regarding its affect on pork color. Opposing the current findings, Latorre (2003) detailed pork from barrows as having a higher a\* value and c\* (chroma) value, describing pork as being redder and having a more intense color, a conclusion that was cited as being both supported and countered. There is much research indicating that meat color, as determined by visual scores, objective parameters and myoglobin content, is independent of gender (Latorre, 2003), although intact males and older animals are generally expected to have a greater myoglobin concentration and darker meat than castrates of the same species (Seideman et al., 1984). Many aspects of basic myoglobin chemistry and muscle biology have been detailed as contributing to the formation of and transition between the muscle pigment states which allow color perception, including: NADH concentrations and metmyoglobin (MMb) reducing activity (Bekhit et al., 2000; 2003), the activity location within muscle structure (Sammel et al., 2002; Bekhit et al.,

2004) and muscle glycolytic potential (Hamilton et al., 2003). Given the complex interactions of these mechanisms, the growth and processing stages that influence them and the inconsistent attribution of gender to affect pork color, it would seem that potential lean color differences could more properly be explained by basic biochemical differences from pig to pig.

### *Sensory Evaluation*

Considering sensory attributes, a diet  $\times$  gender interaction was shown to affect ( $P = 0.01$ ) pork aroma only (data not shown); however, significant interactive pork aroma mean scores only ranged from 5.4 to 5.8, categorizing all products as having a similar, “slightly strong” pork aroma. Independently, gender had no effect on any sensory attributes (Table 2.6), supporting previous research stating no difference in the tenderness, juiciness, pork flavor or off flavor of both LM chops (Xu et al., 2010; Stein et al., 2006) and GPP (Stein et al., 2006) sourced from barrows and gilts.

Diet was found to only slightly influence texture and off aroma (Table 2.5;  $P \leq 0.05$ ) with GPP from pigs finished on 0, 15, 30, and 45% S-DDGS being described as having a “slightly soft” texture, while GPPs from pigs finished on diets containing 30% C-DDGS were categorized as “moderately soft.” Although descriptively different, GPP from C-DDGS pigs were statistically ( $P > 0.05$ ) equivalent to product from 15 and 30% S-DDGS fed pigs on the sorghum based diet. Pork sourced from all finishing diets was evaluated as having *no* off-flavor, with GPP from pigs fed 15 and 30% S-DDGS having the least off-flavor. Overall, small significant differences in sensory attributes were noted, but the use of sorghum grain in addition to the inclusion of 0 to 45% S-DDGS, when compared to corn grain or C-DDGS, was not seen as altering the flavor profile of GPP. Product from all pigs was predominantly described as having a “slightly strong” pork aroma with “no” off-aroma, a “slightly intense” pork flavor with “no” off flavor, and a “slightly soft” texture while being “slightly” juicy.

No literature was found regarding the palatability of pork from pigs finished with sorghum grain or S-DDGS and data detailing the resulting palatability and sensory attributes of pork from pigs fed C-DDGS is not extensive. A thorough review of the use of DDGS in swine diets by Stein (2008) references only the study of Widmer et al.

(2008) as assessing the palatability of pork from swine fed DDGS. Researchers in that instance found slight numerical differences in LM chop tenderness and trends (linear,  $P \geq 0.08$ ) for small increases in pork flavor and decreased off flavor in pork from pigs fed C-DDGS included at 0, 10 and 20%. No differences were noted for LM chop juiciness or overall acceptability. More recently, Xu et al. (2010) supported this, reporting no differences ( $P > 0.30$ ) in flavor intensity, off flavor, tenderness, juiciness or overall acceptability of LM chops from pigs fed 0, 10, 20 and 30% C-DDGS. It was largely concluded, and is supported by the current study, that consumers will not be able to differentiate pork from pigs fed distillers co-products.

As mentioned previously, it is well known that the fat composition of swine diets specifically influences the composition of that fat which is deposited during growing and finishing (Averette Gatlin et al., 2002). Specifically, the fatty tissues provide species characteristics, while the lean tissues contain precursors for the meaty flavors associated with all cooked meats (Mottram, 1998). Compared to the other mainstream red meats of beef and lamb, pork has a more unsaturated fatty acid profile, most noticeably seen when comparing levels of linoleic acid (C18:2; Enser, 1996). Given the role that fat has been shown to play in developing species specific flavors, it seems that adjustments to that fat which is presented to the cooking process would also result in adjustment to the final flavor profile; however, conclusions regarding pork flavor differences due to fatty acid profile are mixed. Calkins and Hodgen (2007) noted studies which worked to adjust the fat profile of pigs through feeding high oleic acid (C18:1) feedstuffs with findings of both improved palatability (Rhee et al., 1990) and no effect (Myer et al., 1992). Similarly, Larick et al. (1992) increased dietary linoleic acid (C18:2) content from roughly 1.5 to 6% in swine diets, increasing the C18:2 content of the resulting pork. In that case researchers found no differences in trained panel evaluation of pork flavor of GPP. This supported similar work which found no flavor or color influence of pork chops due to increased compositional levels of linoleic acid. Interestingly, Larick et al. (1992) did note increased levels of volatile compounds such as pentanal and hexanal during cooking of high C18:2 pork patties. Higher levels of these compounds are usually associated with increased lipid oxidation and off-flavors in meat (Calkins and Hodgen, 2007); however, this was not the case, supporting work from 6 other studies which altered the fatty acid

composition of pork through dietary changes and found no differences in the resulting pork flavor. The fact that fatty acid adjusted pork was not shown to have off-flavors or noticeable changes to pork flavor is thought to be explained by work from Melton (1990), which hypothesized that oxidative rancidity may be a part of acceptable or intense pork flavor, due the fact that pork naturally contains more linoleic acid than other meats. Simply, compounds that develop and would be off-flavors in other meats are potentially expected in pork, and could therefore be considered as defining the flavor rather than altering it.

### **Implications**

Fatty acid profile differences were noted according to the inclusion and increase of S-DDGS in the swine finishing diet and should be expected to decrease carcass fat saturation. Sorghum DDGS could offer an advantage over traditional C-DDGS, in the sense that a more saturated fatty acid profile was noted for ground pork from S-DDGS fed pigs, compared to those pigs fed an equal amount of C-DDGS. Nevertheless, these alterations did not carry through to affect final ground pork quality attributes concerning oxidative rancidity and trained panel sensory analysis. It is concluded that consumers will not be able to differentiate pork from pigs fed distillers co-products and that feeding sorghum grain and S-DDGS can be done without affecting ground pork quality.

**Table 2.1 Main effect of dietary grain and DDGS<sup>1</sup> source on ground pork proximate composition**

Grain source	Diet						SE	<i>P</i> -value	
	Sorghum	Sorghum	Sorghum	Sorghum	Sorghum	Corn		Diet	Linear <sup>3</sup>
DDGS source	---	Sorghum	Sorghum	Sorghum	Sorghum	Corn			
DDGS level	---	15%	30%	45%	30%	30%			
Attribute <sup>2</sup> (n = 48)									
Moisture, %	62.2	63.4	62.1	63.9	61.5	62.6	0.936	0.27	---
Crude protein, %	18.6	18.8	18.0	18.8	18.3	18.1	0.279	0.18	---
Crude fat, %	17.9	16.8	18.8	16.1	19.2	18.0	1.15	0.25	---
pH	5.8	5.9	6.0	5.9	5.9	5.9	0.063	0.46	---

<sup>1</sup> Dried distillers grains with solubles.

<sup>2</sup> Ground pork was made from both shoulders from each of 48 pigs, 8 per dietary treatment (4 barrows and 4 gilts).

<sup>3</sup> Linear effect of sorghum DDGS from 0 to 45%.

**Table 2.2 Effect of dietary grain and DDGS<sup>1</sup> source on ground pork fatty acid composition<sup>2</sup>**

	Diet							SE	P-value	
	Grain Source	Sorghum	Sorghum	Sorghum	Sorghum	Sorghum	Corn		Diet	Linear <sup>3</sup>
	DDGS Source	---	Sorghum	Sorghum	Sorghum	Corn	Corn			
DDGS Level	---	15%	30%	45%	30%	30%				
Fatty acid, wt % (n = 48)										
Myristic acid (C14:0)		1.5 <sup>a</sup>	1.4 <sup>ab</sup>	1.4 <sup>ab</sup>	1.4 <sup>b</sup>	1.4 <sup>a</sup>	1.4 <sup>b</sup>	0.024	0.03	**
Palmitic acid (C16:0)		24.6 <sup>a</sup>	24.0 <sup>ab</sup>	24.1 <sup>ab</sup>	23.0 <sup>d</sup>	23.8 <sup>bc</sup>	23.1 <sup>cd</sup>	0.230	< 0.001	***
Palmitoleic acid (C16:1)		2.8 <sup>a</sup>	2.7 <sup>a</sup>	2.4 <sup>b</sup>	2.4 <sup>b</sup>	2.4 <sup>b</sup>	2.3 <sup>b</sup>	0.10	0.005	***
Margaric acid (C17:0)		0.44	0.45	0.47	0.49	0.52	0.46	0.027	0.29	
Stearic acid (C18:0)		12.8	12.3	12.7	11.8	12.3	12.0	0.308	0.20	
Oleic acid (C18:1n9c)		40.8 <sup>a</sup>	39.7 <sup>b</sup>	39.4 <sup>bc</sup>	38.3 <sup>cd</sup>	37.7 <sup>d</sup>	38.1 <sup>d</sup>	0.397	< 0.001	***
Vaccenic acid (C18:1n7)		4.0 <sup>a</sup>	3.9 <sup>a</sup>	3.7 <sup>b</sup>	3.6 <sup>b</sup>	3.5 <sup>b</sup>	3.4 <sup>b</sup>	0.086	< 0.001	***
Linoleic acid (C18:2n6c)		9.4 <sup>c</sup>	11.4 <sup>b</sup>	11.9 <sup>b</sup>	14.7 <sup>a</sup>	14.3 <sup>a</sup>	15.1 <sup>a</sup>	0.540	< 0.001	***
Total C18:2 <sup>4</sup>		9.5 <sup>c</sup>	11.6 <sup>b</sup>	12.0 <sup>b</sup>	14.9 <sup>a</sup>	14.4 <sup>a</sup>	15.2 <sup>a</sup>	0.546	< 0.001	***
$\alpha$ -linolenic acid (C18:3n3)		0.57 <sup>b</sup>	0.63 <sup>b</sup>	0.61 <sup>b</sup>	0.77 <sup>a</sup>	0.63 <sup>b</sup>	0.64 <sup>b</sup>	0.034	0.01	***
Arachidic acid (C20:0)		0.20	0.21	0.21	0.20	0.21	0.20	0.013	0.83	
Eicosenoic acid (C20:1)		0.76	0.78	0.78	0.78	0.75	0.77	0.026	0.95	
Eicosadienoic acid (C20:2)		0.48 <sup>c</sup>	0.57 <sup>b</sup>	0.59 <sup>b</sup>	0.69 <sup>a</sup>	0.69 <sup>a</sup>	0.73 <sup>a</sup>	0.026	< 0.001	***
Arachidonic acid (C20:4n6)		0.10 <sup>b</sup>	0.11 <sup>ab</sup>	0.10 <sup>b</sup>	0.13 <sup>a</sup>	0.10 <sup>b</sup>	0.11 <sup>b</sup>	0.007	0.04	*

<sup>1</sup> Dried distillers grains with solubles.

<sup>2</sup> Ground pork was made from both shoulders of each of 48 pigs, 8 per dietary treatment (4 barrows and 4 gilts).

<sup>3</sup> Linear effect of sorghum DDGS from 0 to 45% \*( $P < 0.05$ ), \*\*( $P < 0.01$ ), \*\*\*( $P < 0.001$ ).

<sup>4</sup> Total C18:2 fatty acids = [% C18:2n6t] + [% C18:2n6c] + [% C18:2, 9c11t] + [% C18:2, 10t12c] + [% C18:2, 9c11c] + [% C18:2, 9t11t].

<sup>a</sup> Within a row, means without a common superscript differ ( $P < 0.05$ ).

**Table 2.3 Effect of dietary grain and DDGS<sup>1</sup> source on ground pork fatty acid profile totals and ratios<sup>2</sup>**

	Diet							SE	P-value	
	Grain Source	Sorghum	Sorghum	Sorghum	Sorghum	Sorghum	Corn		Diet	Linear <sup>3</sup>
	DDGS Source	---	Sorghum	Sorghum	Sorghum	Corn	Corn			
DDGS Level	---	15%	30%	45%	30%	30%				
Total fatty acids, wt % (n = 48)										
SFA		39.9 <sup>a</sup>	38.9 <sup>ab</sup>	39.4 <sup>a</sup>	37.3 <sup>c</sup>	38.9 <sup>ab</sup>	37.6 <sup>bc</sup>	0.446	0.002	**
MUFA		49.0 <sup>a</sup>	47.8 <sup>ab</sup>	46.9 <sup>bc</sup>	45.7 <sup>cd</sup>	45.0 <sup>d</sup>	45.2 <sup>d</sup>	0.491	< 0.001	***
PUFA		11.1 <sup>c</sup>	13.4 <sup>b</sup>	13.8 <sup>b</sup>	16.9 <sup>a</sup>	16.3 <sup>a</sup>	17.2 <sup>a</sup>	0.615	< 0.001	***
UFA:SFA, ratio <sup>4</sup>		1.5 <sup>c</sup>	1.6 <sup>bc</sup>	1.5 <sup>c</sup>	1.7 <sup>a</sup>	1.6 <sup>bc</sup>	1.7 <sup>ab</sup>	0.031	0.002	***
PUFA:SFA, ratio <sup>5</sup>		0.28 <sup>c</sup>	0.35 <sup>b</sup>	0.35 <sup>b</sup>	0.46 <sup>a</sup>	0.42 <sup>a</sup>	0.46 <sup>a</sup>	0.020	< 0.001	***
Iodine Value (IV)		60.2 <sup>c</sup>	62.8 <sup>b</sup>	62.7 <sup>b</sup>	67.1 <sup>a</sup>	65.3 <sup>a</sup>	66.9 <sup>a</sup>	0.788	< 0.001	***

<sup>1</sup> Dried distillers grains with solubles.

<sup>2</sup> Ground pork was made from both shoulders of each of 48 pigs, 8 per dietary treatment (4 barrows and 4 gilts).

<sup>3</sup> Linear effect of sorghum DDGS from 0 to 45% \*( $P < 0.05$ ), \*\*( $P < 0.01$ ), \*\*\*( $P < 0.001$ ).

<sup>4</sup> Unsaturated fatty acids (UFA):SFA ratio = [MUFA + PUFA]/ SFA.

<sup>5</sup> PUFA:SFA ratio = PUFA / SFA.

<sup>a</sup> Within a row, means without a common superscript differ ( $P < 0.05$ ).



**Table 2.4 Main effect of dietary grain and DDGS<sup>1</sup> source on ground pork retail display life**

Grain source DDGS source DDGS level	Diet						SE	P-value	
	Sorghum	Sorghum	Sorghum	Sorghum	Sorghum	Corn		Diet	Linear <sup>8</sup>
	---	Sorghum	30%	45%	Corn	Corn			
Attribute <sup>2</sup> (n = 336)									
TBARS <sup>3</sup>	0.35	0.37	0.36	0.38	0.40	0.40	0.042	0.37	---
CIE L* <sup>4</sup>	60.1	60.2	61.0	60.5	61.1	60.8	0.745	0.66	---
CIE a* <sup>5</sup>	17.7	17.5	18.3	18.1	17.7	17.7	0.197	0.11	0.04
CIE b* <sup>6</sup>	17.5	17.5	17.9	17.5	17.6	17.5	0.240	0.14	---
$\Delta E^7$	8.7 <sup>a</sup>	8.9 <sup>a</sup>	7.3 <sup>b</sup>	8.5 <sup>a</sup>	8.9 <sup>a</sup>	9.3 <sup>a</sup>	0.92	0.01	---

<sup>1</sup> Dried distillers grains with solubles.

<sup>2</sup> Seven packages from each of 48 pigs, 8 per diet (4 barrows and 4 gilts) were held in retail display for 5 d (120 h).

<sup>3</sup> Thiobarbituric acid-reactive substances, mg of malonaldehyde / kg meat.

<sup>4</sup> Measure of lightness; 0 = black, 100 = white.

<sup>5</sup> Higher positive values indicate greater redness, negative values = greenness.

<sup>6</sup> Higher positive values indicate greater yellowness; negative values = blueness.

<sup>7</sup> Total color change from h 0 to 120 =  $\sqrt{[(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2]}$ .

<sup>8</sup> Linear effect of sorghum DDGS from 0 to 45%.

<sup>a</sup> Within a row, means without a common superscript differ ( $P < 0.05$ ).

**Table 2.5 Main effect of dietary grain and DDGS<sup>1</sup> source on ground pork sensory attributes**

Grain source DDGS source DDGS level	Diet						SE	P-value	
	Sorghum	Sorghum	Sorghum	Sorghum	Sorghum	Corn		Diet	Linear <sup>9</sup>
	---	Sorghum	30%	45%	Corn	Corn			
Attribute <sup>2</sup> (n = 48)									
Pork aroma <sup>3</sup>	5.7	5.6	5.6	5.8	5.7	5.7	0.088	0.09	---
Off aroma <sup>4</sup>	1.2	1.1	1.1	1.2	1.2	1.3	0.087	0.29	---
Pork flavor <sup>5</sup>	5.4	5.4	5.6	5.6	5.5	5.4	0.14	0.60	---
Juiciness <sup>6</sup>	5.4	5.6	5.7	5.7	5.8	5.7	0.11	0.25	---
Texture <sup>7</sup>	4.3 <sup>a</sup>	4.1 <sup>abc</sup>	4.0 <sup>bc</sup>	4.1 <sup>ab</sup>	3.9 <sup>c</sup>	3.9 <sup>c</sup>	0.10	0.02	---
Off flavor <sup>8</sup>	1.3 <sup>ab</sup>	1.2 <sup>b</sup>	1.2 <sup>b</sup>	1.4 <sup>a</sup>	1.4 <sup>ab</sup>	1.4 <sup>a</sup>	0.072	0.05	---

<sup>1</sup> Dried distillers grains with solubles.

<sup>2</sup> Ground pork from each of 48 pigs, 8 per treatment (4 barrows and 4 gilts), were analyzed during 8 trained panel sessions.

<sup>3</sup> Scale of 1-8: 1 = Extremely weak, 8 = Extremely strong.

<sup>4</sup> Scale of 1-8: 1 = None, 8 = Abundant.

<sup>5</sup> Scale of 1-8: 1 = Extremely bland, 8 = Extremely intense.

<sup>6</sup> Scale of 1-8: 1 = Extremely dry, 8 = Extremely juicy.

<sup>7</sup> Scale of 1-8: 1 = Extremely soft, 8 = Extremely hard.

<sup>8</sup> Scale of 1-8: 1 = None, 8 = Abundant.

<sup>9</sup> Linear effect of sorghum DDGS from 0 to 45%.

<sup>a</sup> Within a row, means without a common superscript differ ( $P < 0.05$ ).

**Table 2.6 Effect of gender on ground pork quality**

Composition <sup>1</sup>	Gender			P-value
	Barrow	Gilt	SE	Gender
Moisture, %	60.7 <sup>b</sup>	64.6 <sup>a</sup>	0.689	< 0.001
Crude protein, %	18.1 <sup>b</sup>	18.8 <sup>a</sup>	0.161	0.004
Crude fat, %	20.3 <sup>a</sup>	15.3 <sup>b</sup>	0.806	< 0.001
pH	5.9	5.9	0.052	0.46
Retail display <sup>2</sup>				
TBARS <sup>3</sup>	0.39	0.36	0.038	0.08
CIE L* <sup>4</sup>	61.4 <sup>a</sup>	59.8 <sup>b</sup>	0.624	< 0.001
CIE a* <sup>5</sup>	17.6 <sup>b</sup>	18.1 <sup>a</sup>	0.114	0.006
CIE b* <sup>6</sup>	17.7 <sup>a</sup>	17.4 <sup>b</sup>	0.221	0.01
$\Delta E$ <sup>7</sup>	8.7	8.4	0.88	0.30
Sensory attribute <sup>8</sup>				
Pork aroma <sup>9</sup>	5.7	5.7	0.076	0.41
Off aroma <sup>10</sup>	1.2	1.2	0.070	0.69
Pork flavor <sup>11</sup>	5.5	5.5	0.11	0.92
Juiciness <sup>12</sup>	5.6	5.7	0.084	0.32
Texture <sup>13</sup>	4.1	4.0	0.069	0.81
Off flavor <sup>14</sup>	1.3	1.3	0.043	0.57

<sup>1</sup> Ground pork was made from both shoulders from each of 48 pigs, 24 barrows and 24 gilts.

<sup>2</sup> Seven packages from each of 48 pigs, 24 barrows and 24 gilts, were held in retail display for 5 d (120 h).

<sup>3</sup> Thiobarbituric acid-reactive substances, mg of malonaldehyde / kg meat.

<sup>4</sup> Measure of lightness; 0 = black, 100 = white.

<sup>5</sup> Higher positive values indicate greater redness, negative values = greenness.

<sup>6</sup> Higher positive values indicate greater yellowness; negative values = blueness.

<sup>7</sup> Total color change from h 0 to 120 =  $\sqrt{[(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2]}$ .

<sup>8</sup> Ground pork from each of 48 pigs, 24 barrows and 24 gilts, were analyzed during 8 trained panel sessions.

<sup>9</sup> Scale of 1-8: 1 = Extremely weak, 8 = Extremely strong.

<sup>10</sup> Scale of 1-8: 1 = None, 8 = Abundant.

<sup>11</sup> Scale of 1-8: 1 = Extremely bland, 8 = Extremely intense.

<sup>12</sup> Scale of 1-8: 1 = Extremely dry, 8 = Extremely juicy.

<sup>13</sup> Scale of 1-8: 1 = Extremely soft, 8 = Extremely hard.

<sup>14</sup> Scale of 1-8: 1 = None, 8 = Abundant.

<sup>a</sup> Within a row, means without a common superscript differ ( $P < 0.05$ ).

**Table 2.7 Effect of gender on ground pork fatty acid profile<sup>1</sup>**

Fatty acid, wt %	Gender		SE	P-value
	Barrow	Gilt		
Myristic acid (C14:0)	1.4	1.4	0.014	0.04
Palmitic acid (C16:0)	24.1	23.4	0.133	< 0.001
Palmitoleic acid (C16:1)	2.6	2.4	0.055	0.04
Margaric acid (C17:0)	0.47	0.48	0.016	0.66
Stearic acid (C18:0)	12.3	12.4	0.178	0.79
Oleic acid (C18:1n9c)	39.4	38.6	0.229	0.01
Vaccenic acid (C18:1n7)	3.7	3.6	0.057	0.15
Linoleic acid (C18:2n6c)	12.0	13.6	0.312	< 0.001
Total C18:2 <sup>2</sup>	12.1	13.7	0.316	0.001
$\alpha$ -linolenic acid (C18:3n3)	0.60	0.68	0.020	0.01
Arachidic acid (C20:0)	0.20	0.21	0.011	0.73
Eicosenoic acid (C20:1)	0.79	0.75	0.015	0.14
Eicosadienoic acid (C20:2)	0.59	0.66	0.015	0.003
Arachidonic acid (C20:4n6)	0.10	0.12	0.005	0.002
Other	1.5	1.6	0.042	0.03
SFA	39.0	38.3	0.257	0.08
MUFA	47.2	46.0	0.286	0.01
PUFA	13.9	15.7	0.356	< 0.001
UFA:SFA, ratio <sup>3</sup>	1.6	1.6	0.177	0.08
PUFA:SFA, ratio <sup>4</sup>	0.36	0.41	0.011	0.002
Iodine Value (IV)	63.2	65.2	0.455	0.004

<sup>1</sup> Ground pork was made from both shoulders of each of 48 pigs, 24 barrows and 24 gilts.

<sup>2</sup> Total C18:2 fatty acids = [% C18:2n6t] + [% C18:2n6c] + [% C18:2, 9c11t] + [% C18:2, 10t12c] + [% C18:2, 9c11c] + [% C18:2, 9t11t].

<sup>3</sup> Unsaturated fatty acids (UFA):SFA ratio = [MUFA + PUFA]/ SFA.

<sup>4</sup> PUFA:SFA ratio = PUFA / SFA.

**Table 2.8 Ground pork TBARS and objective color from 0 to 120 h of retail display<sup>1</sup>**

Item (n = 336)	Hour											SE	P-value			
	0	12	24	36	48	60	72	84	96	108	120		Hour	Lin <sup>2</sup>	Quad <sup>3</sup>	
TBARS <sup>4</sup>	0.37 <sup>b</sup>	---	0.27 <sup>a</sup>	---	---	---	0.38 <sup>b</sup>	---	---	---	0.49 <sup>c</sup>	0.04	*	*	*	
Objective color																
CIE L* <sup>5</sup>	63.4 <sup>a</sup>	61.8 <sup>b</sup>	61.9 <sup>b</sup>	61.0 <sup>c</sup>	60.3 <sup>d</sup>	59.8 <sup>e</sup>	59.4 <sup>fg</sup>	59.8 <sup>ef</sup>	59.8 <sup>ef</sup>	59.2 <sup>g</sup>	60.6 <sup>cd</sup>	0.610	*	*	*	
CIE a* <sup>6</sup>	22.5 <sup>a</sup>	20.1 <sup>b</sup>	19.1 <sup>c</sup>	18.1 <sup>d</sup>	17.9 <sup>e</sup>	17.7 <sup>f</sup>	17.2 <sup>g</sup>	16.6 <sup>h</sup>	16.0 <sup>i</sup>	15.8 <sup>j</sup>	15.1 <sup>k</sup>	0.115	*	*	*	
CIE b* <sup>7</sup>	19.0 <sup>a</sup>	18.0 <sup>b</sup>	17.5 <sup>de</sup>	17.7 <sup>c</sup>	17.4 <sup>ef</sup>	17.6 <sup>d</sup>	17.5 <sup>de</sup>	17.5 <sup>de</sup>	17.2 <sup>f</sup>	17.3 <sup>f</sup>	16.6 <sup>g</sup>	0.228	*	*	*	

<sup>1</sup> Two packages from each of 48 pigs was sampled at each hour.

<sup>2</sup> Linear effect for hour from 0 to 120.

<sup>3</sup> Quadratic effect for hour from 0 to 120.

<sup>4</sup> Thiobarbituric acid-reactive substances, mg malonaldehyde/ kg meat.

<sup>5</sup> Measure of lightness; 0 = black, 100 = white.

<sup>6</sup> Higher positive values indicate greater redness, negative values = greenness.

<sup>7</sup> Higher positive values indicate greater yellowness; negative values = blueness.

<sup>a</sup> Within a row, means without a common superscript differ ( $P < 0.05$ ).

\*  $P < 0.0001$ .

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## **Appendix A - Dietary Treatments**

**Table A.1 Phase 1 Diet Composition (as fed basis)<sup>1</sup>**

Item	Grain Source DDGS <sup>2</sup> Source DDGS Level	Sorghum ---	Sorghum Sorghum 15%	Sorghum Sorghum 30%	Sorghum Sorghum 45%	Sorghum Corn 30%	Corn Corn 30%
<b>Ingredient, %</b>							
Sorghum		76.2	63.1	50.2	36.9	51.05	17.25
Soybean meal (46.5% CP)		20.85	19.25	17.45	15.85	16.5	17.25
Corn		---	---	---	---	---	50.3
Sorghum DDGS		---	15	30	45		---
Corn DDGS		---	---	---	---	30	30
Monocalcium P (21% P)		0.9	0.55	0.2	---	0.25	0.3
Limestone		0.9	1.03	1.15	1.3	1.2	1.2
Salt		0.35	0.35	0.35	0.35	0.35	0.35
Vitamin premix		0.15	0.15	0.15	0.15	0.15	0.15
Trace mineral premix		0.15	0.15	0.15	0.15	0.15	0.15
Lysine HCl		0.31	0.31	0.31	---	0.31	0.29
DL-Methionine		0.12	0.08	0.04	---	0.01	---
L-Threonine		0.08	0.04	0.01	---	0.02	0.02
<b>Total</b>		<b>100</b>	<b>100</b>	<b>100</b>	<b>100</b>	<b>100</b>	<b>100</b>
<b>Calculated analysis</b>							
<b>Standardized ileal digestible amino acids, %</b>							
L-lysine		0.94	0.94	0.94	0.94	0.94	0.94
Isoleucine: lysine		62	68	73	79	68	67
Methionine: lysine		35	33	31	29	29	30
Met & Cys: lysine		58	58	58	58	58	59
Threonine: lysine		60	60	60	64	60	60
Tryptophan: lysine		17	17	17	17	17	17
Valine: lysine		70	78	86	94	81	80
Total lysine, %		1.03	1.06	1.09	1.12	1.11	1.11
Crude Protein, %		17.1	19.3	21.4	23.5	20.8	20.7
ME kcal/lb		1,484	1,457	1,430	1,400	1,488	1,505
Ca, %		0.6	0.59	0.58	0.6	0.58	0.59
P, %		0.55	0.54	0.53	0.55	0.53	0.54
Available P, %		0.27	0.27	0.27	0.31	0.27	0.27

<sup>1</sup> Diets were fed in meal form from d 0 to 28 of the experiment.

<sup>2</sup> Dried distillers grains with solubles.

**Table A.2 Phase 2 Diet Composition (as fed basis)<sup>1</sup>**

Grain Source	Sorghum	Sorghum	Sorghum	Sorghum	Sorghum	Corn	Corn
DDGS <sup>2</sup> Source	---	Sorghum	Sorghum	Sorghum	Sorghum	Corn	Corn
DDGS Level	---	15%	30%	45%	30%	30%	30%
Item							
<b>Ingredient, %</b>							
Sorghum	79.85	66.8	53.75	40.45	54.8	---	---
Soybean meal (46.5% CP)	17.3	15.7	14.05	12.3	12.95	13.85	---
Corn	---	---	---	---	---	---	53.9
Sorghum DDGS	---	15	30	45	---	---	---
Corn DDGS	---	---	---	---	30	30	---
Monocalcium P (21% P)	0.85	0.48	0.10	---	0.15	0.20	---
Limestone	0.9	1.03	1.15	1.3	1.18	1.15	---
Salt	0.35	0.35	0.35	0.35	0.35	0.35	---
Vitamin premix	0.15	0.15	0.15	0.15	0.15	0.15	---
Trace mineral premix	0.15	0.15	0.15	0.15	0.15	0.15	---
Lysine HCl	0.29	0.28	0.28	0.28	0.28	0.28	---
DL-Methionine	0.09	0.05	0.01	---	---	---	---
L-Threonine	0.07	0.03	---	---	---	---	---
<b>Total</b>	<b>100</b>	<b>100</b>	<b>100</b>	<b>100</b>	<b>100</b>	<b>100</b>	<b>100</b>
<b>Calculated analysis</b>							
<b>Standardized ileal digestible amino acids, %</b>							
L-lysine	0.83	0.83	0.83	0.83	0.83	0.83	0.83
Isoleucine: lysine	64	70	76	82	70	68	---
Methionine: lysine	34	31	29	30	30	32	---
Met & Cys: lysine	58	58	58	61	60	63	---
Threonine: lysine	60	60	62	66	61	61	---
Tryptophan: lysine	17	17	17	17	17	17	---
Valine: lysine	73	81	90	99	85	84	---
Total lysine, %	0.91	0.94	0.97	1.0	0.99	1.0	---
Crude Protein, %	15.8	17.9	20.1	22.2	19.5	19.4	---
ME kcal/lb	1,484	1,457	1,430	1,399	1,489	1,508	---
Ca, %	0.58	0.56	0.55	0.59	0.54	0.55	---
P, %	0.53	0.51	0.50	0.54	0.49	0.50	---
Available P, %	0.25	0.25	0.25	0.30	0.25	0.25	---

<sup>1</sup> Diets were fed in meal form from d 28 to 56 of the experiment.

<sup>2</sup> Dried distillers grains with solubles.

**Table A.3 Phase 3 Diet Composition (as fed basis)<sup>1</sup>**

Grain Source	Sorghum	Sorghum	Sorghum	Sorghum	Sorghum	Corn
DDGS <sup>2</sup> Source	---	Sorghum	Sorghum	Sorghum	Corn	Corn
DDGS Level	---	15%	30%	45%	30%	30%
<b>Item</b>						
<b>Ingredient, %</b>						
Sorghum	83.35	70.3	57.25	43.8	58.2	---
Soybean meal (46.5% CP)	13.55	11.9	10.25	8.55	9.2	10.1
Corn	---	---	---	---	---	57.3
Sorghum DDGS	---	15	30	45	---	---
Corn DDGS	---	---	---	---	30	30
Monocalcium P (21% P)	0.75	0.4	0.05	---	0.1	0.15
Limestone	0.88	1	1.13	1.3	1.18	1.15
Salt	0.35	0.35	0.35	0.35	0.35	0.35
Vitamin premix	0.13	0.13	0.13	0.13	0.13	0.13
Trace mineral premix	0.13	0.13	0.13	0.13	0.13	0.13
Lysine HCl	0.26	0.25	0.25	0.25	0.26	0.23
DL-Methionine	0.07	0.03	---	---	---	---
L-Threonine	0.06	0.02	0.02	0.01	---	---
Chromic Oxide	0.5	0.5	0.5	0.5	0.5	0.5
Total	100	100	100	100	100	100
<b>Calculated analysis</b>						
<b>Standardized ileal digestible amino acids, %</b>						
L-lysine	0.71	0.71	0.71	0.71	0.71	0.71
Isoleucine: lysine	65	73	80	87	73	71
Methionine: lysine	33	31	30	33	33	34
Met & Cys: lysine	58	58	60	66	65	66
Threonine: lysine	62	62	67	70	63	63
Tryptophan: lysine	17	17	17	17	17	17
Valine: lysine	76	86	96	106	90	89
Total lysine, %	0.78	0.81	0.84	0.87	0.86	0.87
Crude Protein, %	14.3	16.4	18.6	20.7	18	17.9
ME kcal/lb	1,478	1,451	1,424	1,392	1,482	1,502
Ca, %	0.54	0.53	0.52	0.58	0.52	0.53
P, %	0.49	0.48	0.47	0.52	0.47	0.47
Available P, %	0.23	0.23	0.23	0.3	0.23	0.23

<sup>1</sup> Diets were fed in meal form from d 56 to 73 of the experiment.

<sup>2</sup> Dried distillers grains with solubles.

## Appendix B - Display Case Temperature Logs

Figure B.1 Week 2 Fluorescent Lighting Display Case Temperature Log

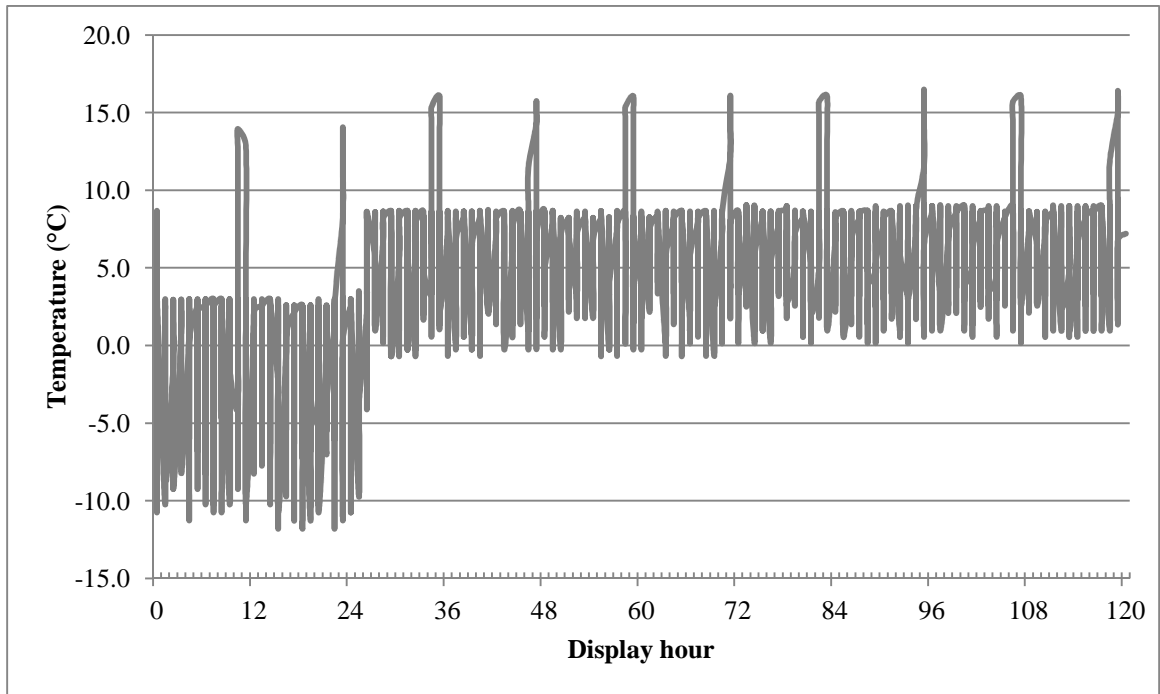
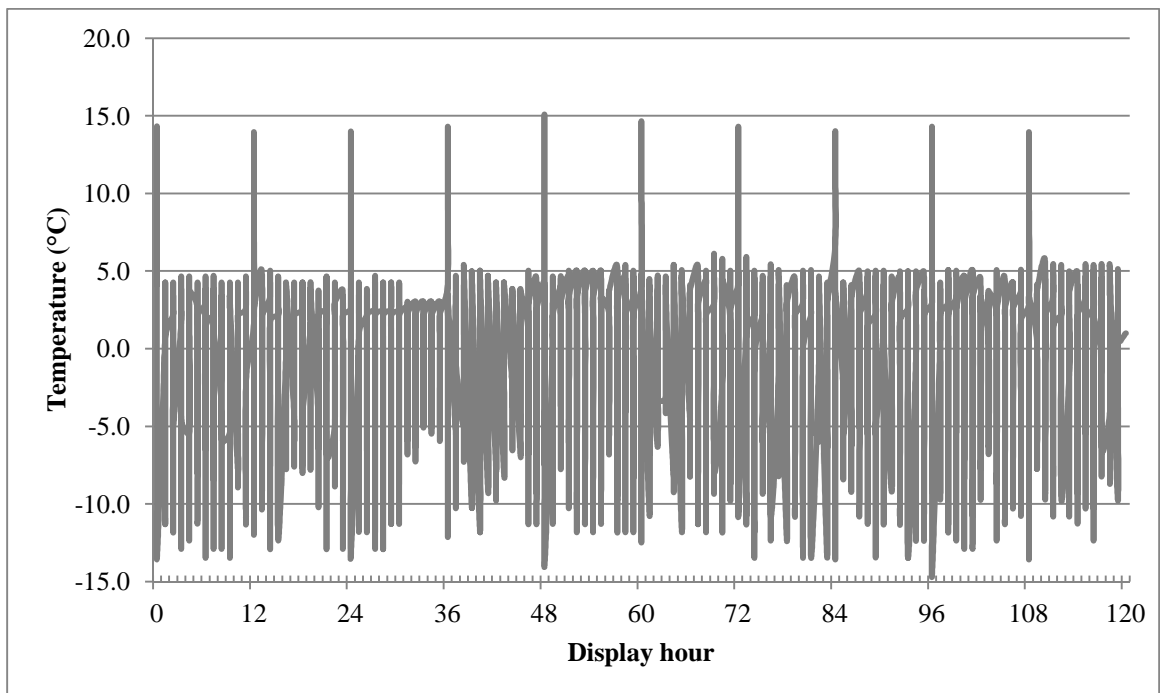


Figure B.2 Week 2 Light Emitting Diode Display Case Temperature Log



## Appendix C - Sensory Evaluation Form

Kansas State University - Sensory Panel Evaluation - Ground Pork

Study: Skaar/Houser

Time: \_\_\_\_\_

Name: \_\_\_\_\_

SAMPLE	PORK AROMA	OFF AROMA	OFF AROMA DESCRIPTOR	PORK FLAVOR	JUICINESS	TEXTURE	OFF-FLAVOR	OFF FLAVOR DESCRIPTOR
WU								
A								
B								
C								
D								
E								
F								
	8. Extremely strong 7. Very strong 6. Moderately strong 5. Slightly strong 4. Slightly weak 3. Moderately weak 2. Very weak 1. Extremely weak	8. Abundant 7. Moderately abundant 6. Slightly abundant 5. Moderate 4. Slight 3. Traces 2. Practically none 1. None	Examples: bitter burnt sour sweet grain boar taint other	8. Extremely intense 7. Very intense 6. Moderately intense 5. Slightly intense 4. Slightly bland 3. Moderately bland 2. Very bland 1. Extremely bland	8. Extremely juicy 7. Very juicy 6. Moderately juicy 5. Slightly juicy 4. Slightly dry 3. Moderately dry 2. Very dry 1. Extremely dry	8. Extremely hard 7. Very hard 6. Moderately hard 5. Slightly hard 4. Slightly soft 3. Moderately soft 2. Very soft 1. Extremely soft	8. Abundant 7. Moderately abundant 6. Slightly abundant 5. Moderate 4. Slight 3. Traces 2. Practically none 1. None	Examples: bitter burnt sour sweet grain boar taint other



## Appendix D - Statistical Code

### Proximate Composition

The following code was used to obtain main and interactive treatment means and standard errors, pair wise comparisons, and linear and quadratic orthogonal polynomial contrasts. Variables analyzed included percent crude protein, percent crude fat, percent moisture, pH, percent fatty acid profile (for individual and combination fatty acid variables), iodine value (IV), and total color change ( $\Delta E$ ).

```
options nocenter;
title 'Other FAs';
data FAprofile;
input Kdate PigID Diet$ Gender$ ... variables... C18_2TOT otherFA;
datalines;
...
...
;
proc mixed;
class Diet Gender Kdate;
model otherFA = Diet Gender Diet*Gender;
random Kdate;
lsmeans Diet Gender Diet*Gender/pdiff;
contrast 'linear A B C D' Diet -3 -1 1 3 0 0;
contrast 'quad A B C D' Diet 1 -1 -1 1;
run;
quit;
```

## TBARS

The following code was used to obtain main and interactive treatment means and standard errors, pair wise comparisons, and linear and quadratic orthogonal polynomial contrasts. Variables analyzed included TBARS (mgMDA).

```
options nocenter;
title 'TBARS NL';
data TBARS;
input Kdate Hour Light$ PigID Package Diet$ Gender$ mgMDA;
datalines;
...
...
;
proc mixed maxfunc=300 maxiter=100;
class Kdate Hour Light PigID Diet Package Gender;
model mgMDA = Hour|Diet|Gender/ddfm=kr;
random Kdate PigID(Kdate);
lsmeans Hour|Diet|Gender/pdiff;
contrast 'linear A B C D' Diet -3 -1 1 3 0 0;
contrast 'quad A B C D' Diet 1 -1 -1 1;
contrast 'linear time' Hour -0.059793 -0.033218 0.019931 0.0730804;
contrast 'quad time' Hour 0.0506186 -0.028639 -0.069268 0.0472885;
run;
quit;
```

The following was used to obtain the coefficients for linear and quadratic orthogonal polynomial 'hour' contrasts, as TBARS sampling times were unequally spaced.

```
proc iml;
a = {0 24 72 120};
b = {48 96 96 96};
coeff = orpol (a,2,b);
print a;
print b;
print coeff;
run;
quit;
```

## Color

The following code was used to obtain main and interactive treatment means and standard errors, pair wise comparisons, and linear and quadratic orthogonal polynomial contrasts. Variables analyzed included L\*, a\* and b\*.

```
options nocenter;
title 'LSTAR NL';
data color;
input Kdate Hour Light$ Package PigID Diet$ Gender$ L a b;
datalines;
...
...
;
proc mixed;
class Kdate Hour Light PigID Diet Gender Package;
model b = Hour|Diet|Gender;
random Kdate PigID(Kdate) Package(Kdate PigID);
lsmeans Hour|Diet|Gender/pdiff;
contrast 'linear A B C D' Diet -3 -1 1 3 0 0;
contrast 'quad A B C D' Diet 1 -1 -1 1;
contrast 'linear hr 0 to 120' Hour -5 -4 -3 -2 -1 0 1 2 3 4 5;
contrast 'quad hr 0 to 120' Hour 15 6 -1 -6 -9 -10 -9 -6 -1 6 15;
run;
quit;
```

## Sensory

The following code was used to obtain main and interactive treatment means and standard errors and pair wise comparisons. Variables analyzed included pork aroma, off aroma, pork flavor, juiciness, texture and off flavor.

```
options nocenter;
title 'PORK AROMA';
data sensory;
input Kdate Panel PigID Diet$ Gender$ pork_aroma off_aroma pork_flavor juice texture
off_flav;
datalines;
...
...
;
proc mixed;
class Kdate Panel Diet Gender;
model off_flav = Diet Gender Diet*Gender;
random Kdate Panel(Kdate);
lsmeans Diet Gender Diet*Gender/pdiff;
run;
quit;
```

## Appendix E - Interactive Display Data

**Table E.1 Effect of grain and DDGS<sup>1</sup> source with hour on ground pork lightness<sup>2</sup>**

Item	Hour											SE	P-value <sup>3</sup>	
	0	12	24	36	48	60	72	84	96	108	120			
<b>L*<sup>4</sup></b>														
S-0S <sup>5</sup>	62.8	61.2	61.4	60.3	59.8	58.9	59.3	59.2	59.4	58.6	60.5	0.836	1.0	
S-15S <sup>6</sup>	62.7	61.8	62.2	60.1	59.7	59.2	58.8	59.1	59.2	59.0	60.4			
S-30S <sup>7</sup>	63.8	62.0	62.1	61.4	60.8	60.2	60.1	60.0	60.4	59.3	60.9			
S-45S <sup>8</sup>	63.1	61.6	61.6	60.9	60.6	60.0	59.5	59.4	59.6	59.1	60.1			
S-30C <sup>9</sup>	63.9	62.1	62.2	62.0	60.7	60.5	59.4	60.2	60.0	59.8	60.9			
C-30C <sup>10</sup>	63.8	62.2	61.8	61.3	60.5	60.0	59.6	60.2	59.9	59.6	60.5			

<sup>1</sup> Dried distillers grain with solubles.

<sup>2</sup> Two packages from each of 48 pigs (8 per diet) were sampled each hour.

<sup>3</sup> Interactive effect of diet × hour.

<sup>4</sup> Lightness; 0 = black, 100 = white.

<sup>5</sup> Sorghum grain with 0% sorghum DDGS.

<sup>6</sup> Sorghum grain with 15% sorghum DDGS.

<sup>7</sup> Sorghum grain with 30% sorghum DDGS.

<sup>8</sup> Sorghum grain with 45% sorghum DDGS.

<sup>9</sup> Sorghum grain with 30% corn DDGS.

<sup>10</sup> Corn grain with 30% corn DDGS.

## E.2 Effect of grain and DDGS<sup>1</sup> source with hour on ground pork redness<sup>2</sup>

Item	Hour											SE	P-value <sup>3</sup>	
	0	12	24	36	48	60	72	84	96	108	120			
<b>a*<sup>4</sup></b>														
S-0S <sup>5</sup>	22.5	20.0	19.0	17.9	17.6	17.4	16.9	16.6	15.9	15.8	14.7	0.282	0.60	
S-15S <sup>6</sup>	22.5	19.8	18.8	18.2	17.7	17.6	17.2	16.0	15.7	15.0	14.6			
S-30S <sup>7</sup>	22.3	20.6	19.3	18.4	18.2	18.0	17.4	17.0	16.7	16.8	16.3			
S-45S <sup>8</sup>	22.4	20.1	19.2	18.5	18.1	18.0	17.5	17.0	16.3	16.1	15.3			
S-30C <sup>9</sup>	22.5	20.3	19.3	17.9	18.1	17.5	17.4	16.2	15.6	15.4	14.9			
C-30C <sup>10</sup>	22.7	19.9	19.1	18.0	17.9	17.4	17.1	16.5	15.8	15.7	14.8			

<sup>1</sup> Dried distillers grain with solubles.

<sup>2</sup> Two packages from each of 48 pigs (8 per diet) were sampled each hour.

<sup>3</sup> Interactive effect of diet × hour.

<sup>4</sup> Positive values = redness; negative values = greenness.

<sup>5</sup> Sorghum grain with 0% sorghum DDGS.

<sup>6</sup> Sorghum grain with 15% sorghum DDGS.

<sup>7</sup> Sorghum grain with 30% sorghum DDGS.

<sup>8</sup> Sorghum grain with 45% sorghum DDGS.

<sup>9</sup> Sorghum grain with 30% corn DDGS.

<sup>10</sup> Corn grain with 30% corn DDGS.

### E.3 Effect of dietary grain and DDGS<sup>1</sup> source with hour on ground pork yellowness<sup>2</sup>

Item	Hour											SE	P-value <sup>3</sup>	
	0	12	24	36	48	60	72	84	96	108	120			
<b>b*</b> <sup>4</sup>														
S-0S <sup>5</sup>	18.9	17.9	17.4	17.6	17.1	17.3	17.3	17.5	17.2	17.3	16.6	0.280	0.70	
S-15S <sup>6</sup>	18.9	18.0	17.5	17.7	17.1	17.4	17.4	17.2	17.3	17.0	16.6			
S-30S <sup>7</sup>	19.0	18.4	17.7	17.9	17.7	18.0	17.7	17.7	17.6	17.6	17.1			
S-45S <sup>8</sup>	18.9	17.8	17.4	17.8	17.3	17.6	17.5	17.6	17.0	17.1	16.3			
S-30C <sup>9</sup>	19.1	18.1	17.6	17.6	17.5	17.5	17.6	17.4	17.3	17.3	16.4			
C-30C <sup>10</sup>	19.4	17.9	17.4	17.5	17.5	17.5	17.5	17.3	17.1	17.3	16.5			

<sup>1</sup> Dried distillers grain with solubles.

<sup>2</sup> Two packages from each of 48 pigs (8 per diet) were sampled each hour.

<sup>3</sup> Interactive effect of diet × hour.

<sup>4</sup> Positive values = yellowness; negative values = blueness.

<sup>5</sup> Sorghum grain with 0% sorghum DDGS.

<sup>6</sup> Sorghum grain with 15% sorghum DDGS.

<sup>7</sup> Sorghum grain with 30% sorghum DDGS.

<sup>8</sup> Sorghum grain with 45% sorghum DDGS.

<sup>9</sup> Sorghum grain with 30% corn DDGS.

<sup>10</sup> Corn grain with 30% corn DDGS.

#### E.4 Effect of dietary grain and DDGS<sup>1</sup> source with hour on ground pork oxidation<sup>2</sup>

Item	Hour											SE	P-value <sup>3</sup>	
	0	12	24	36	48	60	72	84	96	108	120			
TBARS <sup>4</sup>														
S-0S <sup>5</sup>	0.334	-	0.249	-	-	-	0.371	-	-	-	0.425	0.0518	0.95	
S-15S <sup>6</sup>	0.370	-	0.272	-	-	-	0.375	-	-	-	0.482			
S-30S <sup>7</sup>	0.376	-	0.243	-	-	-	0.373	-	-	-	0.454			
S-45S <sup>8</sup>	0.390	-	0.279	-	-	-	0.376	-	-	-	0.488			
S-30C <sup>9</sup>	0.409	-	0.284	-	-	-	0.388	-	-	-	0.529			
C-30C <sup>10</sup>	0.367	-	0.285	-	-	-	0.380	-	-	-	0.572			

<sup>1</sup> Dried distillers grain with solubles.

<sup>2</sup> Two packages from each of 48 pigs (8 per diet) were sampled each hour.

<sup>3</sup> Interactive effect of diet × hour.

<sup>4</sup> Thiobarbituric acid-reactive substances, mg malonaldehyde / kg meat.

<sup>5</sup> Sorghum grain with 0% sorghum DDGS.

<sup>6</sup> Sorghum grain with 15% sorghum DDGS.

<sup>7</sup> Sorghum grain with 30% sorghum DDGS.

<sup>8</sup> Sorghum grain with 45% sorghum DDGS.

<sup>9</sup> Sorghum grain with 30% corn DDGS.

<sup>10</sup> Corn grain with 30% corn DDGS.



**Table E.5 Effect of gender with time on ground pork color and oxidation<sup>1</sup>**

Hour	CIE L* <sup>2</sup>		CIE a* <sup>3</sup>		CIE b* <sup>4</sup>		TBARS <sup>5</sup>	
	Barrow	Gilt	Barrow	Gilt	Barrow	Gilt	Barrow	Gilt
0	64.3	62.5	22.3	22.7	19.2	18.8	0.378	0.371
12	62.4	61.2	19.9	20.3	18.0	18.0	-	-
24	62.6	61.2	18.9	19.3	17.6	17.4	0.285	0.252
36	61.7	60.3	18.1	18.1	17.8	17.6	-	-
48	61.3	59.4	17.6	18.3	17.4	17.3	-	-
60	60.7	58.9	17.4	17.9	17.7	17.5	-	-
72	60.2	58.7	17.0	17.5	17.6	17.4	0.395	0.359
84	60.6	58.8	16.3	16.8	17.6	17.3	-	-
96	60.7	58.9	15.7	16.3	17.4	17.1	-	-
108	60.2	58.3	15.5	16.1	17.5	17.1	-	-
120	61.4	59.7	14.8	15.5	16.8	16.3	0.517	0.467
SE	0.661		0.163		0.236		0.0421	
P-value <sup>6</sup>	0.92		0.09		0.23		0.75	

<sup>1</sup> Two packages from each of 24 pigs per gender was sampled each hour. (n = 48)

<sup>2</sup> Lightness; 0 = black, 100 = white.

<sup>3</sup> Positive values = redness; negative values = greenness.

<sup>4</sup> Positive values = yellowness; negative values = blueness.

<sup>5</sup> Thiobarbituric acid-reactive substances, mg malonaldehyde / kg meat.

<sup>6</sup> Interactive effect of diet × gender.