EFFECTS OF DRIED DISTILLERS GRAINS WITH SOLUBLES ON PORK LOIN QUALITY AND SOW FAT QUALITY

by

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Abstract

Two experiments were conducted to determine the effects of dried distillers grains with solubles (DDGS) on pork loin and fat quality. In the first experiment, 1,160 barrows (PIC) were used in a 70-d study to determine the influence of DDGS and glycerol on pork loin and fat quality attributes. Barrows were fed a corn-soybean meal based diet with the addition of selected levels of DDGS (0 or 20%) and glycerol (0, 2.5, or 5%) feed stuffs. Loins from the two heaviest pigs in each pen were removed for evaluation of pork loin and fat quality. Experiment two was a pilot study, in which eight non-pregnant sows were fed either 0 or 50% DDGS with a corn-soybean meal based diet for 92-d. In the first experiment, there were no DDGS x glycerol interactions for purge loss %, instrumental color (L*a*b*), visual color, marbling score, drip loss %, visual color, pH, Warner-Bratzler shear force (WBSF), cook loss %, myofibrillar tenderness, juiciness, pork flavor intensity, connective tissue amount, and overall tenderness. There was a DDGS x glycerol interaction ($P<0.03$) for off-flavor intensity. Pigs fed diets with 20% DDGS had higher WBSF values, lower myofibrillar tenderness, lower overall tenderness scores, lower connective tissue scores, and had more off-flavors ($P<0.05$). Loin fatty acid analysis revealed an increase in palmitoleic, linoleic, and eicosadienoic acids ($P<0.05$) and iodine value ($P<0.03$) for pigs fed 20% DDGS. In the second experiment, there were no differences ($P>0.64$) in BW or backfat change for sows fed either 0 or 50% DDGS. No differences ($P>0.23$) in lipid oxidation from lean trimmings as measured by 2-thiobarbituric acid reactive substances (TBARS) assay were reported either initially or after 5 d of retail display for sows fed either 0 or 50% DDGS. As expected, lipid oxidation increased ($P<0.003$) as measured by TBARS assay for both treatments from d 1 to 5. Jowl fatty acid analysis revealed an increase in linoleic acid ($P<0.01$), total polyunsaturated fatty acids ($P<0.01$), and the ratio of polyunsaturated fatty acids to saturated fatty acids ($P<0.03$) for sows fed 50% DDGS.

Key Words: carcass fat quality, DDGS, glycerol, pork quality, sow, tenderness

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Preface

This manuscript is written according to the style guidelines of ***Journal of Animal Science***, a scientific journal encompassing the many facets of animal science research. Chapter 1 is a brief introduction to dried distillers grains with solubles (DDGS) and their use as livestock feedstuff. Chapter 2 is a review of the literature pertaining to DDGS and their affect on growth performance and pork quality. Chapter 3 and 4 are research chapters investigating the effects of DDGS and glycerol on pork loin and fat quality and the effects of DDGS on sow carcass fat quality, respectively.

CHAPTER 1 - Introduction

The rapid expansion of the bio-fuels industry has increased the amount of grain co-products for livestock production while simultaneously decreasing the amount of traditional feedstuffs. Distillers grain production is forecast to increase from 11 million tons in 2005 to 40 million tons in 2009 (Tokgoz et al, 2007). This has presented many new challenges to pork producers due to increased costs of traditional feedstuffs and limited inclusion rates of co-products due to their unique chemical properties. For example, dried distillers grains with solubles (DDGS) have an oil content of roughly 10%, which are predominately highly unsaturated fatty acids. Monogastics, such as swine and poultry, will assimilate subcutaneous, intermuscular, and intramuscular fat with a fatty acid profile similar to their diet. Therefore, feeding highly unsaturated fatty acids should result in softer, less oxidatively stable adipose tissue, which will in turn affect consumer acceptability.

The amount and the chemical composition of dietary fat may influence many characteristics of pork fat. Glycerol (a co-product of biodiesel manufacturing) increased the degree of lipid saturation and firmness of backfat in pigs fed either tallow or rapeseed oil (Mourot et al., 1994). Whitney et al. (2006) determined that feeding increasing levels of DDGS from 0 to 30% to market hogs, there was a linear increase in unsaturated fatty acids on backfat as measured by iodine value. In addition these researchers also reported that pork quality was not impaired at levels of <20% maximum inclusion rate. It was unclear as to what the effects of increased unsaturation will have on pork loin quality as viewed by consumers. Whitney et al. (2006) determined that feeding 0, 10, and 20% DDGS did not affect color, firmness, marbling, shear force, and ultimate pH. However, these researchers did not conduct trained or consumer taste panels to determine the extent of flavor changes that would occur. Most of the flavor components produced when meat is cooked regardless of specie is derived from the lipid/phospholipid fraction (Mottram and Edwards, 1983 and Mottram, 1998). Lipid components in pigs fed DDGS were becoming more unsaturated as evidenced by a higher iodine value (Whitney et al., 2006), thus it is highly likely that flavor changes did occur. Therefore, the objective of this study was to determine the effects of feeding DDGS and glycerol on pork loin and fat quality.

Fresh pork sausage is very popular item accounting for $857 million in sales in 2006 (Meatingplace, 2007). Over 70% of the fresh pork sausage in the United States is made from hot-boned cull sows (Sutherland, Johnsonville Sausage, Watertown, WI, personal communication). Unsaturated lipids are well known to be less resistant to oxidation than saturated lipids. Lipid oxidation is the result of degradation of the lipid by oxygen and free metals, salt and light and is one of the main factors affecting meat quality and acceptability due to development of off-flavors and odors (Morrissey et al., 1998). Lipid oxidation is very important in pork sausage because sausage can be formulated to a finished fat content of up to 50% and contains salt. Therefore, changes in lipid composition of trimmings destined for sausage production come into serious question as to how they will hold up and function over extended storage. Feeding DDGS has been reported to change the saturation of the fat in market hogs. Therefore, the objective of this study was to determine the effects of feeding DDGS on sow fat quality.

References

Meatingplace. 2007. 2007 Red Meat Elite. Meatingplace 15(5):46.

Morrissey, P. A., P. J. Sheeby, K. Galvin, J. P. Kerry, and D. J. Buckley. 1998. Lipid stability in meat and meat products. Meat Sci. 49 (Supp 1):S73-S86.

Mottram, D. S. 1998. The chemistry of meat flavour. Pages 5-26 in Flavor of Meat, Meat Products and Seafoods. F. Shahidi ed. Blackie Academic and Professional, London, UK.

Mottram, D. S. and R. A. Edwards. 1983. The role of triglycerides and phospholipids in the aroma of cooked beef. J. Sci Food and Ag. 34:517-522.

Mourot, J., A. Aumaitre, A. Mounier, P. Peiniau, and A. C. Francois. 1994. Nutritional and physiological effects of dietary glycerol in the growing pig. Consequences on fatty tissues and post mortem muscular parameters. Livestock Prod. Sci. 38:237-244.

Togkgoz, A., A. Elobeid, J. Fabiosa, D. J. Hayes, B. A. Babcock, T. Yu, F. Dong, C. E. Hart, and J. C. Beghin. 2007. Emerging biofuels: Outlook of effects on U.S. grain, oilseed, and livestock markets. Page 18 in Staff Report 01-SR 101. Center for Agricultural and Rural Development, Iowa State University, Ames, IA.

Whitney M. H., G. C. Shurson, L. J. Johnston, D. M. Wulf, and B. C. Shanks. 2006. Growth performance and carcass characteristics of grower-finisher pigs fed high-quality corn distillers dried grain with solubles originating from a modern midwestern ethanol plant. J. Animal Science 84:3356-3363.

CHAPTER 2 - Literature Review

Ethanol Production

The use of corn or other cereal grain in the production of fuel, beverages, or industrial use is an expanding industry in the United States. Ethanol is produced when sugar is fermented and a major co-product produced from ethanol production is dried distillers grains with solubles (DDGS). Any feedstuffs that are high in sugar or starch can be used to produce ethanol (Renewable Fuels Association, 2007). In the United States corn, wheat, barley, cheese whey, waste beverages, sugar, and sorghum are used in ethanol production. A majority of ethanol production in the United States utilizes corn because it is the primary biological material that can be economically converted into bioethanol on an industrial scale. During the production of alcohol, starch is removed from grain and converted to alcohol and carbon dioxide (Spiehs et al., 2002). Dried distillers grains with solubles result from dry-grind ethanol processing (Ganesan et al., 2008). Each kg of corn processed results in approximately one-third kg of each of the following products: bioethanol, residual nonfermentable corn kernel components (DDGS) and carbon dioxide (Rosentrater, 2006).

Dried Distillers Grains with Solubles

Dried distillers grains with solubles are often problematic as they tend to cake and bridge during storage and transport (Ganesan et al., 2008). This can be a problem for livestock producers as they often need to store feedstuffs. There are many factors that a livestock producer must consider when storing dried distillers grains with solubles including: moisture, temperature, relative humidity, particle size, and time. Excess water is removed via centrifugation, and then these grains are combined with condensed distillers solubles, dried to ensure substantial shelf life and sold as DDGS (Rosentrater, 2006). A moisture content of approximately 12 percent is generally recommended for stability of feed products. Ethanol and DDGS should be produced from corn that does not contain mycotoxins (Shurson and Spiehs, 2005). Mycotoxins are not destroyed or inactivated during the fermentation process, thus will be present in the DDGS produced from that corn source. The concentration of mycotoxins in DDGS will be 2 to 3 times higher than the initial concentration in the grain (Shurson and Spiehs, 2005). The incidence of

documented cases of mycotoxicosis from feeding DDGS to swine is very low. Yet, corn is very susceptible to molds that can produce mycotoxins prior to harvest and during storage. The mycotoxins that are of primary concern to swine are zearalenone, vomitoxin (deoxynivalenol), T-2 toxin, fumonisin, and aflatoxins. Shurson and Spiehs (2005) stated that zearalenone and vomitoxin are the main concerns in the Midwest.

Traditionally, grain co-products such as DDGS have been treated as commodities in the market place (Shurson and Spiehs, 2005). Yet, like many co-products, there is variation in the nutritional quality of DDGS available for livestock feed. Generally, DDGS has higher concentrations of nutrients such as protein, fat, vitamins, minerals, and fiber than its parent grain (Widyaratne and Zijlstra, 2007). Dried distillers grains with solubles are highly nutritious, are energy dense, high in fat content, and nearly devoid of starch (Ganesan et al., 2008). Generally, DDGS are 86-93% dry matter, 26-34% crude protein, and 3-13% fat (Ganesan et al., 2008). The nutritional content of DDGS is dependent on the plant in which they are produced. In a study conducted by Spiehs et al. (2002), it was concluded that there was a variability in total lysine and methionine levels among sources. For this reason, diets that contain DDGS should be formulated on digestible amino acids and available phosphorus with each shipment of DDGS (Shurson and Spiehs, 2005).

Cromwell et al. (1993) conducted a study comparing physical, chemical, and nutritional characteristics of nine different sources of DDGS for chicks and pigs. Color of these DDGS ranged from very light to very dark, and the odor ranged from sweet to smoky or burnt. In addition, the nutrient content of these DDGS greatly varied. The dry matter content ranged from 87 to 93%, the crude protein ranged from 23 to 29%, the crude fat ranged from 3 to 6%, and lysine ranged from 0.59 to 0.89%. Lysine concentration tended to be higher in light-colored DDGS and lowest in the darkest-colored DDGS sources.

There is a difference in the nutritional content of DDGS depending on the grain crop from which they were produced. Widyaratne and Zijlstra (2007) conducted an experiment to determine the energy, amino acids and phosphorus digestibility and digestible nutrient content of DDGS produced from wheat and corn, to evaluate the effect of DDGS on nitrogen and phosphorus excretion patterns, and to determine whether feeding diets with DDGS results in growth-performance equal to grower-finisher pigs fed a wheat-based control diet. In this study,

Widyaratne and Zijlstra (2007) concluded that the digestible nutrient content of wheat DDGS is lower than corn DDGS.

Performance Studies

With the growing availability of DDGS in the United States and the declining amount of corn and other grain crops available for livestock feed, livestock producers are having to use co-products and other feed stuffs for livestock feed. For this reason, many universities in the Midwest have studied the use of DDGS in livestock feed. The University of Minnesota has conducted several studies to determine the maximum level of DDGS to use in various production phases of pigs before growth and performance was diminished. Studies conducted by Shurson and Spiehs (2005) showed that feeding 25-30% of high quality DDGS did not affect feed consumption for nursery and grow-finish pigs. During the growing-finishing stage, Shurson and Spiehs (2005) found that maximum of 20% DDGS can be used without decreasing performance. On the other hand, gestating sows should be fed no more than 50% DDGS and lactating sows should not be fed more than 20% DDGS (Shurson and Spiehs, 2005). However, Benz (2008) reported that feeding 20% DDGS resulted in a decrease in ADG and ADFI in growing and finishing pigs. However, abruptly switching gestating sows from a corn-soybean meal based diet to a diet containing 50% DDGS resulted in sows not consuming all of the feed they were offered (Shurson and Spiehs, 2005). Yet, after sows had adjusted to 50% DDGS, feed consumption and weight gains were equivalent to sows fed a conventional corn-soybean meal diet.

Cromwell et al. (1993) concluded that feeding chicks the darkest-colored, burnt-smelling DDGS resulted in decreased growth rate (10%), feed intake (13%), and feed conversion (6%) compared to chicks fed the lightest-colored DDGS. Therefore, the authors of this study recommend that dark-colored, burnt-smelling DDGS not be fed to chicks or pigs.

In Canada Widyaratne and Zijlstra (2007) looked at the nutritional value and digestibility of wheat DDGS. Widyaratne and Zijlstra (2007) concluded that DDGS were high in fiber content, which may have reduced nutrient digestibility and voluntary intake, and thereby growth performance.

Whitney et al. (2006) and Widmer (2007) conducted several studies that looked at the effects of feeding various levels of DDGS to grow-finish pigs. Whitney et al. (2006) found that pigs fed 20 or 30% DDGS diets had reduced average daily gain compared with pigs fed 0 or 10%

DDGS; however, average daily feed intake was not affected. Moreno et al. (2008) looked at the effects of feeding various levels of DDGS on growing-finishing pigs. Moreno et al. (2008) found that final weights decreased linearly (P=0.02) for grow-finish pigs as DDGS increased from 118 kg to 109 kg.

Glycerol

Crude glycerol is a readily available energy source from biofuel production. This may play an important role in meeting energy needs of pigs (Lammers, 2008). Lammers et al. (2008) concluded that feeding glycerol has no effect on swine growth performance. In addition, adding glycerol in the diet increases the proportion of oleic acid in the backfat at the expense of linoleic and linolenic acids, while consequently decreasing the unsaturation index of fat (Mourot et al., 1994). Mourot et al. (1994) found that chops from pigs fed glycerol had decreased water loss during cooking through the interaction between glycerol and protein during denaturation. Glycerol can induce a high osmotic pressure in muscles (Riedsel et al., 1987), which decreases the water loss. This was demonstrated by the addition of glycerol into a meat puree. Also, part of the ingested glycerol could be stored in the muscle.

Pork Quality and DDGS

In 1998, the National Pork Producers Council (NPPC) set targets for pork quality. The use of DDGS in diets can reduce belly firmness and cause soft pork fat (Shurson and Spiehs, 2005). In addition, carcass composition is altered when fat level increases in the diet, thus resulting in softer carcass fat (Benz, 2008). While it is obvious that softer bellies may impact finished bacon products, it is not as clear as to what effects increased unsaturation will have on pork loin quality as viewed by consumers. Whitney et al. (2006) determined that feeding 0, 10, and 20% DDGS did not affect color, firmness, marbling, shear force, and ultimate pH. It was concluded by these authors that DDGS could be included at up to 20% of the diet without negative impacts on quality. However, these researchers did not conduct trained or consumer sensory panels to determine the extent of flavor changes that would occur.

pH

According to the NPPC, the target pH for the loin is 5.6 to 5.8. Color and water holding capacity (WHC) are highly dependent on pH. Meat color is highly dependent upon pH, the

lower the pH the lighter the color and the higher the pH the darker the color. Accelerated pH decline and low ultimate pH are related to low water-holding capacity and unacceptable high purge loss (Huff-Lonergan and Lonergan, 2005). This is due to increased protein denaturation, thus resulting in lower protein functionality. During accelerated pH decline, there is increased heat, thus increased denaturation of protein and lower water holding capacity.

Color

What is color? Color is produced when energy in the visible range (400-700 nanometer wavelengths) is perceived by our eyes (Brewer, 1998a). The energy produced is contained in light and pigments are molecules that absorb some of the wavelengths from the light that illuminates an object. Both the pigments in the object and the light which illuminates the product determine what color the product appears. Light is scattered from an object's surface. Color is an indicator of quality to consumers and is one of the most important characteristics for them in deciding what meat items they will purchase. There is a fine line between what is acceptable color and what is unacceptable color.

The three major pigments of meat color are myoglobin, hemoglobin, and cytochrome c. Myoglobin is a globular heme protein consisting of 140-160 amino acid residues, depending upon species of animal (Renerre, 1999). The iron contained within the myoglobin molecule is responsible for the majority of fresh meat color. Ninety to ninety-five % of total iron found in the muscle cell is contained in the myoglobin molecule. The heme iron is held within the myoglobin molecule by an attachment to the proximal histidine at the 5^{th} ligand of iron. The sixth ligand of iron determines the meat pigment oxidation state. Myoglobin is 80 to 95% of meat pigment concentration, while hemoglobin is 5-20% and cytochrome c is only a very small amount.

According to the National Pork Board the ideal color for pork is 3.0 to 5.0 when utilizing a 6-point scale (NPPC Pork Quality Solutions Team, 1998). According to NPPC (1999) color scores a score of 1.0 is very pale, white and a score of 6.0 is dark purplish red. There are many factors that affect meat color including pH of meat, temperature, abnormal meat quality, postmortem age of meat, ground versus whole muscle, prior exposure to oxygen, oxygen partial pressure, oxygen consumption, and metmyoglobin reducing capacity.

Instrumental color is used as an objective measure to confirm visual observations. The two common methods for instrumental color are extraction and reflectance. Extraction instrumental color describes and estimates total pigment. However, this type of color measurement is time consuming, destructive, unrepeatable, and samples the interior of the sample, but it is good for the fact that it gives total pigment quantity, thus it is quantitative. On the other hand, reflectance instrumental color is the color we see on the surface (AMSA, 1991). Reflectance spectra utilizes an x and y-axis representing wavelength in nanometers and percent reflectance. Reflectance data can either be tristimulus or spectral. The two tristimulus systems used are CIE (Commission International d'Eclairage) or Hunter Lab and have several illuminants (i.e. A, C, D65) to obtain color data (L*, a*, b* or L, a, b). Spectral color quantifies myoglobin or gives the surface pigments (400-730 nm). Reflectance data can be acquired rapidly, is non-destructive, surface measurement, repeatable, and color descriptive, thus diagnostic. Diffuse light is associated with an object's color, while spectral reflectance is associated with an object's gloss. Generally, diffusely reflected light is measured for meat color. Measurement of changes in meat color are most commonly achieved by the use of CIE L*a*b* values. L* values are useful in determining change in lightness with a value of 0 equal to black and 100 equal to white. An indication of redness is a positive a* value, whereas a negative a* value is greenness. A positive b* value indicates yellowness, while a negative b* value represents blueness. In addition to the L*a*b* values, reflectance spectra may be used to indicate color changes (Mancini and Hunt, 2005).

Water Holding Capacity (WHC)

Water holding capacity (WHC) is defined as the ability of meat to retain water during processing (Huff-Lonergan and Lonergan, 2005). Water holding capacity is very important as many sensory traits including juiciness, flavor, tenderness, and mouthfeel are dependent on the amount of water being retained in a product. The majority of the approximately 75% water in muscle is held tightly within the structure of the muscle and muscle cells (Huff-Lonergan and Lonergan, 2005). Water in meat products can be bound, immobilized, or free. Bound water is when charged hydrophilic groups on the muscle proteins attract water, forming a tightly bound layer (Aberle et al., 2001). Immobilized water has less orderly molecular orientation toward the charged group. Free water is held only by capillary forces, and their orientation is independent

of the charged group. Free water is not held very tightly as it is only held by weak forces and membranes. According to Huff-Lonergan and Lonergan (2005), early postmortem events including rate and extent of pH decline, proteolysis, and protein oxidation all influence the ability of meat to retain moisture. The meat industry is most concerned with free water as it can affect profit margins. Low pH meat is close to the isoelectric point, thus is the least likely to retain water. The isoelectric point of protein is the pH at which there are as many positive charges as negative charges on the protein. According to the NPPC Pork Quality Solution Team (1998) drip loss should not exceed 2.5%. Offer and Knight (1988) concluded that product weight losses due to purge averages 1-3% in fresh meats, while Melody et al. (2004) stated the purge loss can be as high as 10% in PSE products (i.e., loin, ham).

Palatability

Palatability is described as the satisfaction derived from eating (Jeremiah, 1998). For this reason many research experiments/studies use either trained or consumer sensory panels to evaluate the eating quality of pork. Eating quality of pork is a very important component of improving pork's competiveness with other meat (Miller, 1998). Trained sensory panels provide a measurable response to how much of an attribute or the level or intensity of a specific attribute (Miller, 1998). Conversely, according to Miller (1998), consumer panels provide information on the preference or acceptance of the eating qualities of pork. Trained panelists often evaluate such characteristics as myofibrillar tenderness, connective tissue amount, overall tenderness, juiciness, pork flavor intensity, and off-flavor intensity. Myofibrillar tenderness is the ease in which the muscle fiber fragments during mastication. Connective tissue amount is the structural component of the muscle surrounding the muscle fiber that will not break down during mastication. Miller (1998) described the connective tissue component as the first initial chews and the bubble-gum-like substance remaining after chewing and immediately prior to swallowing. Overall tenderness combined effect of myofibrillar tenderness and connective tissue amount. The amount of perceived moisture that is released from a product during mastication is known as juiciness. Pork flavor intensity is the pork meat flavor. Off-flavor is flavors that are not generally associated with pork meat flavor. These flavors are often describes as rancid, oxidative, bitter, acid, sour, metallic, and livery.

Marbling

According to Jeremiah (1998), marbling is the fat intermingled with the lean within a muscle, or visible intramuscular fat. Consumers generally prefer minimal visual fat (marbling), however, sensory panelists favor increased intramuscular fat (Jeremiah, 1998). The ideal intramuscular fat (marbling) is 2 to 4% (NPPC Pork Quality Solution Team, 1998). Increasing intramuscular fat from <1.5 to >3.5% increases flavor intensity and juiciness (Brewer, 1998a). However, intramuscular fat has inconsistent effects on tenderness.

Tenderness

Tenderness is the ease with which a product is penetrated, fractured, and broken down during mastication (Jeremiah, 1998). However, tenderness in pork is generally not a big concern as pork is generally enhanced. The National Pork Producers Council Pork Quality Solution Team has reported that the target tenderness (WBSF) for pork is less than 3.2 kg at 7 days postmortem (1998). The amount of connective tissue and the degree of cross-linkage of the connective tissue are factors that affect tenderness. Connective tissue is a minor component of meat, which comprises approximately 1-4% of dry weight in most muscle types (Taylor, 2004). Connective tissue contributes the most to the texture of raw meat, while myofibers make the largest contribution to the texture of cooked meat. As temperature increases, the contribution of connective tissue to the texture of meat decreases.

Yet, tenderness can be a concern when postmortem environments are not ideal. For example, when pork is exposed to severe chilling or blast freezing temperatures cold shortening can occur, thus producing less tender pork.

Lipid Oxidation and Off-flavor Development

Oxidation is the process of taking electrons away from a molecule, which gives that molecule a more positive charge. Oxidation of fatty acids is given the term lipid oxidation or oxidative rancidity. Lipid oxidation is one of the main factors affecting quality and acceptability of meat products (Morrissey et al., 1998). Acceptability is dependent upon the extent in which oxidative rancidity has occurred (Gray, 1978). There are many things that are catalysts for oxidation. Electron transfer, hydrogen abstraction, and exchange of free electrons cause oxidation in meat systems (McMillan, 1996). Inherent muscle properties that may affect oxidative properties include unsaturated fatty acids, amino acids in proteins, heme groups in

pigments, and conjugated double bonds in vitamins. Factors that affect oxidative processes in muscle foods include inherent muscle properties, storage and processing to cause pigment or lipid degradation, metal ions, pH, enzymes, salts, heating, freezing, light exposure, and exposure to air or oxygen (McMillan, 1996).

Luckily, all muscle foods have inherent antioxidant properties, which can be classified as lipid, cytosolic, and enzymic antioxidant systems (Gray, 1978). The functionality of these three systems is dependent on animal species, muscle type, and diet. Lipid oxidation occurs as a result of oxidation of unsaturated fatty acids by free radicals and results in warmed-over flavor (WOF). Scavenging of free radicals and chelating free metal ions are primarily in lipid and cytosolic antioxidant systems. The lipid and cytosolic antioxidant activity are dependent upon diet and anatomical location as a result of muscle fiber type.

There are three steps in the development of lipid oxidation; initiation, propagation, and termination (Morrissey et al., 1998). The first step is initiation which requires oxygen. Initiation occurs when a hydrogen atom (H) is eliminated from an unsaturated fatty acid (RH) by bonding with oxygen (O_2) or other catalysts. Propagation is the second step which results from the formation of a fatty acyl radical (R•) which reacts with oxygen, forming a peroxy radical (ROO•). During the propagation step a chain reaction is set off, further oxidizing remaining unsaturated fatty acids when more radicals are produced. The final step is termination. Propagation is completed in the termination step, oxygen becomes unavailable to bind with the fatty acyl radical.

Most of the flavor components produced when meat is cooked, regardless of specie, is derived from the lipid/phospholipid fraction (Mottram and Edwards, 1983 and Mottram, 1998). Lipids contribute to the flavor of raw meat and meat products through hydrolysis of triglycerides and phospholipids and by oxidation of fatty acids (Skibsted et al., 1998).

Major products of lipid oxidation include aldehydes, ketones, and acids. Phospholipids can oxidize and create off-flavors. Endogenous factors affecting lipid oxidation include species, age of animal, muscle type, diet, and enzyme activity. Exogenous factors affecting lipid oxidation are packaging type, processing methods, and added ingredients. Lipid oxidation can lead to discoloration, drip loss, off-odor, and off-flavor development, and the production of toxic compounds (Morrissey et al., 1998; Gray et al., 1978). Softer fat is more susceptible to oxidative damage (Morrissey et al., 1998) and cause additional difficulties for retailers that are moving

toward centralized butchery and modified atmosphere packaging. Both of these lead to meats being exposed to higher levels of oxygen for a longer period time prior to retail (Morrissey et al., 1998).

Lipid oxidation in meat systems is most commonly measured using the 2-thiobarbituric acid reactive substances (TBARS) assay. TBARS values over 1.0 mg/kg are considered rancid (Tarladgis, 1960). Thiobarbituric acid methods for the determination of malonaldehyde in rancid foods are less precise than peroxide determination on rancid fats (Tarladgis, 1960). The oxidation of phospholipids and protein bond lipids are undoubtedly responsible for types of odor and flavor deterioration in meat.

The most common off-flavor associated with dried distillers grains with solubles is WOF. Other names for WOF are stale, cardboard-like, and rancid. The following meats are listed in order from the fastest rate of off-flavor development to the slowest rate of off-flavor development; fish, poultry, pork, beef, and lamb (Brewer, 1998b). Given the fact that lipid components were becoming more unsaturated as evidenced by a higher iodine value (Whitney et al., 2006) it is likely that flavor changes did occur. The rate of off-flavor development can be attributed to the polyunsaturated fatty acid content on the muscle food. The rate of the oxidation reaction is dependent on heat, light, and enzymes. Heating meat encourages the rate of oxidation to increase (Brewer, 1998b).

There are several different kinds of antioxidant properties including metal chelating, radical scavenging, and ascorbate- and tocopherol-regenerating ability in model systems (Packer et al., 1995). However, the use of Vitamin E in feed supplementation can decrease the rate and extensiveness of oxidation. Vitamin E is a natural antioxidant and radically locates in the cell membrane where oxidation is most likely to be a problem (Brewer, 1998b). The use of antioxidants protects polyunsaturated fatty acids from oxidation by sacrificing themselves to the oxidation process (Jadhav et al., 1996). In addition, the use of natural and synthetic antioxidants can be used in enhanced products. The use of these antioxidants can help prevent off-flavor development.

Fatty Acids

There are several classes of lipids including fatty acids, triglycerides, and phospholipids. Fatty acids are a major constituent of triglycerides. Triglycerides consist of a glycerol backbone

with three fatty acids attached. Phospholipids are esters containing fatty acids and phosphoric acid. They are found in cell membranes and allow the membrane to be pliable and hydrophobic. Feeding polyunsaturated fatty acid (PUFA) rich lipids protected from biohydrogenation improves the ratio of PUFA to saturated fatty acids (SFA). Wood et al. (2003) concluded that diet has a major effect of fatty acid percentages in longissimus, but the effect of total lipid was greater. In muscle, linoleic acid (C18:2n-6) is deposited more in phospholipid than neutral lipid.

An iodine value measures the level of unsaturation of fats and therefore can be utilized as a measure of carcass fat firmness (Eggert et al., 2001). Iodine will bind to unsaturated or double bonds in fatty acids. Therefore, a greater amount of iodine will bind to a sample that has a greater proportion of unsaturated fatty acids (AOCS, 1998).

Barton-Gade (1987) and Madsen et al. (1992) stated that an acceptable iodine value is 70g/100g, but Boyd et al. (1997) said an iodine value of 75g/100g was acceptable. Several packing plants in the U.S. have set their maximum iodine value at 73g/100g. Yet, there is little data available on the influence of feeding duration of dietary fat on fatty acid composition. Increasing levels of unsaturated fat had a greater impact on fat iodine value than choice white grease (CWG), even when dietary iodine values were similar (Benz, 2008). Benz (2008) reported that feeding 15% DDGS increased backfat iodine value. Furthermore, Whitney et al. (2006) found that belly fat IV increased 1.7g/100g for every 10% DDGS in growing/finishing diets.

References

Aberle, E. D., J. C. Forrest, D. E. Gerrard, and E. W. Mills. 2001. Properties of Fresh Meat. Pages 109 - 116 in Principles of Meat Science 4th Ed. Kendall/Hunt Publishing Co., Dubuque, IA.

AMSA. 1991. Guidelines for Meat Color Evaluation. American Meat Sci Assoc., Savoy, IL.

AOCS. 1998. Official Methods and Recommended Practices of the AOCS Method Cd 1c-85. 5th ed. Am Oil Chem. Soc., Champaign, IL.

Barton-Gade, P. A. 1987. Some experience on measuring the quality of pork fat. Pages 47-52 in Meat Research Institute, Special Rep. No. 2. J. D. Wood ed. In: Proc. CEC workshop on fat in lean pigs. Brussels.

Benz, J .M. 2008. Influence of dietary ingredients on pork fat quality. MS Thesis. Kansas State Univ., Manhattan.

Boyd, R. D., M. E. Johnston, K. Scheller, A. A. Sosnicki, and E. R. Wilson. 1997. Relationship between dietary fatty acid profile and body fat composition in growing pigs. PIC Technical Memo 153. PIC, Franklin, KY.

Brewer, M. S. 1998a. Consumer attitudes towards color and marbling of fresh pork. In National Pork Board Pork Quality Facts. National Pork Board, Des Moines, IA.

Brewer, M. S. 1998b. What is "warmed over flavor?". In National Pork Board Pork Quality Facts. National Pork Board, Des Moines, IA.

Cromwell, G. L., K. L. Herkeloinan, and T. S. Stahly. 1993. Physical, chemical, and nutritional characteristics of distillers dried grains with solubles for chicks and pigs. J. Anim. Sci. 71:679-686.

Eggert, J. M., M. A. Belury, A. Kempa-Steczko, S. E. Mills, and A. P. Schinckel. 2001. Effects of conjugated linoleic acid on the belly firmness and fatty acid composition of genetically lean pigs. J. Anim. Sci. 79:2866-2872.

Ganesan V., K. Muthukumarappan, and K. A. Rosentrater. 2008. Sorption isotherm characteristics of distillers dried grains with Solubles (DDGS). Transactions of the ASABE. 51(1):169-176.

Gray, J. I. 1978. Measurement of lipid oxidation: a review. J. of Amer. Oil Chem. Soc. 55:539-546.

Huff-Lonergan, E. and S. M. Lonergan. 2005. Mechanisms of water-holding capacity of meat: The role of postmortem biochemical and structural changes. Meat Sci. 71:194-204.

Jadhav, S. J., S. S. Nimbalkar, A. D. Kulkarni, and D. L. Madhavi. 1996. Lipid oxidation in biological and food systems. In Food Antioxidants: Technological, Toxicological, and Health Perspectives. Marcel Dekker, Inc. New York.

Jeremiah, L. E. 1998. Marbling and Tenderness. In National Pork Board Pork Quality Facts.

Lammers P. J., B. J. Kerr, T. E. Weber, W. A. Dozier, III, M. T. Kidd, K. Bregendahl, and M. S. Honeyman. 2008. Digestible and metabolizable energy of crude glycerol for growing pigs. J. Anim. Sci. 86:602-608.

Madsen, A., K. Jakobsen, H. P. Mortensen. 1992. Influence of dietary-fat on carcass fat quality in pigs – a review. ACTA Ag. Scandinavica section A –Anim Sci. 42(4):220-225.

Mancini, R. A. and M. C. Hunt. 2005. Review: Current research in meat color. Meat Sci 71:100-121.

McMillan, K. W. 1996. Initiation of oxidative processes in muscle foods. Pages 53-63 in 49th Annual Reciprocal Meat Conference: 1996 June 9-12; Provo UT. American Meat Science Association, Chicago, IL.

Melody, J. L., S. M. Lonergan, L. J. Rowe. T. W. Huiatt, M. S. Mayes, and E. Huff-Lonergan. 2004. Early postmortem biochemical factors influence tenderness and water-holding capacity of three porcine muscles. J. Anim. Sci. 82:1195-1205.

Miller, R. 1998. Sensory Evaluation of Pork. In National Pork Board Pork Quality Facts. National Pork Board, Des Moines, IA.

Moreno, R., P. S. Miller, T. E. Burkey, S. J. Jones, S. L. Cuppett, T. P. Carr, T. F. Jones, and R. M. Diedrichsen. 2008. The effects of corn distillers dried grain with solubles (DDGS) on carcass characteristics and pork quality. Pages 8-11 in Nebraska Swine Day Report. M. Oetjen ed. University of Nebraska, Lincoln, NE.

Morrissey, P. A., P. J. Sheeby, K. Galvin, J. P. Kerry, and D. J. Buckley. 1998. Lipid stability in meat and meat products. Meat Science 49 (Supp 1):S73-S86.

Mottram, D. S. 1998. The chemistry of meat flavour. Pages 5-26 in Flavor of Meat, Meat Products and Seafoods. 2nd ed. F. Shahidi ed. Blackie Academic and Professional, London, UK

Mottram, D. S. and R. A. Edwards. 1983. The role of triglycerides and phospholipids in the aroma of cooked beef. Journal of Science of Food and Agriculture 34:517-522.

Mourat, J., A. Aumaitre, A. Mounier, P. Peiniau, and A. C. Francois. 1994. Nutritional and physiological effects of dietary glycerol in the growing pig. Consequences on fatty tissues and post mortem muscular parameters. Livestock Production Science 38:237-244.

NPPC Pork Quality Solutions Team. 1998. Pork Quality Targets. In National Pork Board Pork Quality Facts. National Pork Board, Des Moines, IA.

Offer G. and P. Knight. 1988. The structural basis of water-holding capacity in meat. Part 1: general principles and water uptake in meat processing. Pages 61-171 in Developments in meat science. R. Lawrie ed. Elsevier Applied Science, New York.

Packer, L. E., H. Witt, and H. J. Tritschler. 1995. Alpha-lipoic acid as a biological antioxidant. Free Rad. Biol. Med. 19(2):227-250.

Riedsel, M. L., D. Y. Allen, G. T. Peake, and K. Al-Quattan. 1987. Hyperhydration with glycerol solution. J. Appl. Physiol. 63:2262-2268.

Renerre, M. 1999. Biochemical basis of fresh meat colour. Pages 344-353 in 45th ICoMST.

Renewable Fuels Association. 2007. Building New Horizons: Ethanol Industry Outlook 2007. Washington DC. http://www.ethanolrfa.org/objects/pdf/outlook/RFA_Outlook_2007.pdf. Accessed September 1, 2008.

Rosentrater, K. A. 2006. Some physical properties of distillers dried grains with solubles (DDGS). Applied Engineering in Ag. 22(4):589-595.

Skibsted, L. H., A. Mikkelsen, and G. Bertelsen. 1998. Lipid-derived off-flavors in meat. Pages 217-256 in Flavor of Meat, Meat Products and Seafoods. F. Shahidi ed. Blackie Academic and Professional, London, UK.

Spiehs, M. J., M. H. Whitney, and G. C. Shurson. 2002. Nutrient database for distiller's dried grains with solubles produced from new ethanol plants in Minnesota and South Dakota. J. Anim. Sci. 80:2639-2645.

Shurson, J. and M. J. Spiehs. 2005. Feeding recommendations and example diets containing Minnesota-South Dakota produced DDGS for swine. http://www.ddgs.umn.edu/feeding-swine/exampleswinediets-revised.pdf. Accessed August 1, 2008.

Tarladgis, B. G., B. M. Watts, M. T. Younathan, and L. Dugan Jr. 1960. A distillation method for quantitative determination of malonaldehyde in rancid foods. J. Amer. Oil Chem. Soc. 37:44-48.

Taylor, R. G. 2004. Connective tissue structure, function and influence on meat quality, Pages 306-313 in Encyclopedia of Meat Sciences. W. K. Jensen, C. Devine, and M. E. Dikeman eds. Elsevier Ltd., Oxford, UK.

Whitney M. H., G. C. Shurson, L. J. Johnston, D. M. Wulf, and B. C. Shanks. 2006. Growth performance and carcass characteristics of grower-finisher pigs fed high-quality corn distillers dried grain with solubles originating from a modern Midwestern ethanol plant. J. Anim. Sci. 84:3356-3363.

Widmer, M. R. 2007. Energy and nutrient digestibility of high protein distillers dried grains and corn germ by growing pigs and effects on pig performance, carcass quality, and pork palatability. MS Thesis. South Dakota State Univ., Brookings.

Widyaratne G. P. and R. T. Zijlstra. 2007. Nutritional value of wheat and corn distiller's dried grain with solubles: Digestibility and digestible contents of energy, amino acids and phosphorus, nutrient excretion and growth performance of grower-finisher pigs. Can. J. Anim. 87:103-114.

Wood, J. D., R. I. Richardson, G. R. Nute, A.V. Fisher, M. M. Campo, E. Kasapidou, P. R. Sheard, and M. Enser. 2003. Effects of fatty acids on meat quality: a review. Meat Sci. 66:21-32.

CHAPTER 3 - Effects of feeding dried distillers grains with solubles and glycerol on pork loin quality

Abstract

A total of 77 barrows (PIC, initially 31kg) were used to determine the influence of feeding dried distillers grains with solubles (DDGS) and glycerol for 70-d on pork loin quality attributes. The pigs were blocked by weight and randomly assigned to six dietary treatments with seven replications per treatment. Pigs were fed corn-soybean meal based diets with the addition of DDGS or glycerol feed stock. The experimental design was arranged in a 2 x 3 factorial with main effects of feeding DDGS (0 or 20%) and glycerol (0, 2.5, or 5%). Pork loins from the left side of the carcass were removed, vacuumed packaged, and were utilized for analysis 10-d postmortem. There were no DDGS x glycerol interactions, nor main effect differences for purge loss %, instrumental color (L*a*b*), visual color, marbling score, drip loss %, visual color, pH, cook loss %, juiciness, and pork flavor intensity. In a DDGS x glycerol interaction ($P < 0.05$) for off-flavor intensity, pigs fed 20% DDGS without addition of glycerol had more off-flavors than any other treatment. Pigs fed diets with added DDGS had higher WBSF values, lower myofibrillar tenderness, lower overall tenderness scores, and lower connective tissue scores ($P < 0.05$) compared with pigs fed diets with no DDGS. The loin fatty acids for pigs fed 20% DDGS had increased ($P < 0.05$) linoleic acid, eicosadienoic acid, and calculated iodine value compared with loin fatty acids from pigs fed 0% DDGS. There was a decrease ($P < 0.05$) in palmitoleic acid for pigs fed 20% DDGS compared with pigs fed 0% DDGS. In conclusion, chops from pigs fed 2.5% glycerol had lighter chops than chops from pigs fed 5% glycerol. Feeding pigs 20% DDGS resulted in less tender chops with more off-flavors. Yet, the inclusion of glycerol in the diet decreased the intensity of off-flavors in pork chops. Finally, there was an increase in polyunsaturated fatty acids and calculated iodine value in loin intramuscular fat for pigs fed 20% DDGS compared with loin intramuscular fat from pigs fed 0% DDGS.

Keywords: DDGS, glycerol, off-flavor, pork quality, tenderness

1. Introduction

The rapid expansion of the bio-fuels industry has increased the amount of available grain co-products for livestock production while simultaneously decreasing the amount of traditional feedstuffs. This has presented a new challenge for pork producers due to increased costs of traditional feedstuffs. Dried distillers grains with solubles (DDGS) have an oil content of roughly 10%, which is primarily made up of highly unsaturated fatty acids. Monogastics, such as swine and poultry, will assimilate subcutaneous, intermuscular, and intramuscular fat with a fatty acid profile similar to their diet. Therefore, the result of feeding highly unsaturated fatty acids may result in softer, less oxidatively stable adipose tissue, which will in turn affect consumer acceptability. Additionally, glycerol, a co-product of biodiesel manufacturing, has potential as a feedstuff in animal diets, given price and availability. Glycerol is another source of energy and has the same energy as corn.

To date, there has been some research conducted on growth and performance of pigs fed DDGS and glycerol. Yet, research addressing the effects of DDGS and glycerol on palatability parameters of pork loin quality is not currently available. Therefore, the objective of this research was to determine the effects of feeding 20% DDGS and two levels (2.5% and 5%) of glycerol on economically important pork loin quality traits.

2. Materials and Methods

2.1 Pig Management

The experiment was conducted in a commercial swine facility in Southwest Minnesota. The facility had a slatted floor and each pen was equipped with a four-hole dry self feeder and one cup waterer. The facility was a double curtain-sided, deep-pit barn that operated on mechanical ventilation during the summer and on automatic ventilation during the winter. A total of 1,160 barrows (PIC L 337 x 1050, initial BW 31 kg) were fed in a 97-d study. The pigs were blocked by initial weight and randomly assigned to one of six treatments with seven replicate pens per treatment. There were 23 to 24 pigs per pen. Procedures used in this experiment were approved by the Kansas State University Animal Care and Use Committee (2453).

2.2 Diets and Feeding

Pigs were fed corn-soybean meal based experimental diets (Tables A.1, A.2, A.3, and A.4) in meal form across 4 phases. The treatments were arranged in a 2 x 3 factorial with main effects of DDGS (0 or 20%) and glycerol (0, 2.5, or 5%) as fed. Multiple lots of glycerol from the same soybean biodiesel production facility (Minnesota Soybean Processors, Brewster, MN) were used in the trial. All experimental diets were balanced to maintain a constant standardized ideal digestible (SID) lysine:ME ratio within each phase. For both DDGS and glycerol, the NRC (1998) ME value of corn (3,412 kcal/kg) was used in diet formulation. Pigs were fed *ad libitum.*

2.3 Loin Evaluation

At 70-d into the study the two heaviest barrows (total 77 pigs) were visually selected, removed, individually tattooed, and shipped to a commercial swine harvest facility (JBS Swift Processing plant, Worthington, MN) for slaughter. Following slaughter, deep chill (-34°C for 90 minutes), and chilling, a pork loin, boneless, center-cut loin (NAMP #412B) was removed with minimal fat from the left side of each carcass. Loins were numbered, vacuum packaged, and boxed. Loins were transported and stored at Kansas State University Meat Laboratory at 1-2°C. At 10-d postmortem, the loin was evaluated for purge loss, drip loss, visual color, marbling score, and instrumental color.

Purge loss

Purge loss was measured by first weighing the loin in the packaging material. The loin was then removed from the packaging, blotted dry, and then the loin and dried packaging were reweighed. Percentage purge loss was calculated as 100 x (initial loin weight – packaging weight – final loin weight) / (initial loin weight – packaging weight).

Color and Marbling

Loins were fabricated into 2.54-cm chops and were allowed to bloom for at least one hour prior to taking subjective and instrumental color measurements. Color measurements were taken on a cross section of the *longissimus dorsi* muscle located at the center loin region immediately posterior to the end of the *spinalis dorsi* muscle. Instrumental color was measured using a Hunter Lab Miniscan^{TM} XE Plus Spectrophotometer (Model 45/0 LAV, 2.54-cm-diameter aperture, 10° standard observer, Illuminate A; Hunter Associated Laboratories Inc.;

Reston, VA). Color was reported as L* (lightness), a* (redness), b* (yellowness) values. Subjective color and marbling were evaluated using color and marbling standards developed for the National Pork Producers Council (NPPC, 1999).

Drip loss

Drip loss was measured utilizing a single 2.54 cm center-cut chop from each loin. Each chop was weighed and placed into a Ziploc plastic bag immediately following fabrication. This chop was then placed into refrigerated storage (0-3°C) for 24 hours. After 24 hours, chops were removed from the plastic bag, blotted dry with paper towels, and re-weighed to determine the amount of purge loss accumulation for the proceeding 24 h period. Percentage drip loss was calculated as 100 x (initial chop weight – final chop weight) / initial chop weight.

pH analysis

During fabrication, six 2.54-cm chops were individually vacuum packaged and frozen (-40°C) for pH, Warner-Bratzler Shear Force, cooking loss, sensory evaluation, and fatty acid profile analysis. Chops used to determine pH analysis were also used for WBSF. The pH was measured utilizing an Accumet Basic pH Meter (Fisher Scientific, Waltham, MA) with Pinnacle Series Gel Spear Point electrode (Nova Analytics Corporation, Woburn, MA).

Cooking loss

Chops used to determine cooking loss were also used for WBSF. Chops were weighed prior to cooking and after a 30 min cooling period following cooking. Percentage cooking loss was calculated as 100 x (initial chop weight – cooked chop weight) / initial chop weight.

2.4 Palatability

Warner-Bratzler Shear Force (WBSF)

Chops frozen for WBSF evaluation were thawed for approximately 12 hours at 0-2°C and cooked to 40°C, turned, and cooked to a final internal temperature of 70°C in a dual flow, convection gas oven (Blodgett, model DFC-102 CH3; G.S. Blodgett Co.; Burlington, VT) preheated to 163°C. Chop temperatures were monitored with copper-constantan thermocouples (Omega® Engineering; Stamford, CT) inserted into the approximate geometric center of each chop and attached to a Doric temperature recorder (model 205; Vas Engineering; San Francisco,

CA). The chops were chilled overnight at 0-2°C before six round cores (1.27-cm diameter) were obtained from each chop parallel to the long axis of the muscle fibers using a 1.27-cm corer (G-R Manufacturing Co., Manhattan, KS) attached to electric drill (Craftsman 3/8" Electric Drill, Sears, Hoffman Estates, IL). Each core was sheared once perpendicular to the direction of the muscle fibers using a Warner-Bratzler V-shaped blunt blade (G-R Manufacturing Co., Manhattan, KS) attached to an Instron Universal Testing Machine (model 4201, Instron Corp., Canton, MA) with a 50-kg compression load cell and a crosshead speed of 250 mm/min. Peak shear force values were recorded in kg and the values from the cores were averaged for statistical analysis.

Sensory Evaluation

Frozen chops were thawed at 0-2°C for approximately 12 hours and cooked using the same procedures used for WBSF chops. Cooked chops were cut into 2.54-cm x 1.27-cm x 1.27-cm samples. Samples were kept warm in enamel double-boiler pans with warm water in the bottom portion. Each panelist received two cubes from each sample in random order. Each session included a warm-up sample and samples from all treatments. Panelists were provided with unsalted saltine crackers and filtered distilled water (The Brita Products Company, Oakland, CA) to cleanse their pallets between samples. A trained (AMSA, 1995) sensory panel (n=8) evaluated chops on an 8-point scale for myofibrillar tenderness, juiciness, pork flavor intensity, connective tissue amount, overall tenderness, and off-flavor intensity. The scale used for myofibrillar and overall tenderness was 1 = extremely tough, 2 = very tough, 3 = moderately tough, 4 = slightly tough, 5 = slightly tender, 6 = moderately tender, 7 = very tender, and 8 = extremely tender. For juiciness, the scale used was 1 = extremely dry, 2 = very dry, 3 = moderately dry, 4 = slightly dry, 5 = slightly juicy, 6 = moderately juicy, 7 = very juicy, and 8 = extremely juicy. The scale used for pork flavor was 1 = extremely bland, 2 = very bland, 3 = moderately bland, 4 = slightly bland, 5 = slightly intense, 6 = moderately intense, 7 = very intense, and 8 = extremely intense. For connective tissue and off flavor intensity, the scale used was 1 = abundant, 2 = moderately abundant, 3 = slightly abundant, 4 = moderate, 5 = slight, 6 = traces, 7 = practically none, and 8 = none. Panelists described off-flavors, if present, using a provided list of potential descriptors and their own descriptors not present on the list. Panelists' scores were averaged for statistical analysis.

2.5 Fatty acid analysis

A modified gas chromatography procedure of Sukhija and Palmquist (1988) was used for fatty acid analysis. A single 2.54-cm chop from the loin was trimmed of all external fat and used for fatty acid profile analysis. The samples were frozen in liquid nitrogen, pulverized using a tabletop blender (model 33BL79; Waring Products, New Hartford, CT), and analyzed at Kansas State University Analytical Lab for determination of the fatty acid profile of the loin. Loin (50μg) samples were combined with 2 mL of methanolic-HCl and 3 mL of internal standard (2 mg/mL of methyl Heptadecanoic acid (C17:0) in benzene) and heated in a water bath for 120 min at 70°C for transmethylation. After cooling, the addition of 2 mL of benzene and 3 mL of K_2CO_3 allowed the methyl esters to be extracted and transferred to a vial for subsequent quantification of the methylated fatty acids by gas chromatography for fatty acid analysis. Fatty acids from each of the fat samples were expressed as a percentage of the total fatty acids. Iodine value (IV) was calculated by using the fatty acid profile of each sampling according to the following equation (AOCS, 1998):

C16:1 (0.95) + C18:1 (0.86) + C18:2 (1.732) + C18:3 (2.616) + C20:1 (0.785) + C22:1 (0.723).

2.6 Statistical Analysis

The experimental design was a 2 x 3 factorial. Data were analyzed as a completely randomized design using the general linear model procedure (PROC GLM) of SAS (SAS Institute, Inc.; Cary, NC) with pen serving as the experimental unit. Fixed effects were DDGS treatment, glycerol treatment, and DDGS by glycerol treatment. Fatty acid data were analyzed using the same design using the mixed-model procedure (PROC MIXED) of SAS (SAS Institute, Inc.; Cary, NC). Least squares means for each measurement of interest were obtained.

3. Results and Discussion

3.1 Growth Performance

Duttlinger (in progress) reported the growth performance data. Increasing dietary glycerol did not affect ($P > 0.14$) any growth performance traits (Appendix Table B.1). The addition of 20% DDGS to the diet increased ($P < 0.02$) average daily feed intake and lower ($P <$

0.01) gain to feed ratio than pigs not fed DDGS; however, feeding 20% DDGS did not affect ($P > 0.73$) average daily gain. Increasing levels of glycerol did not have an effect on growth.

3.2 Carcass Evaluation

Carcass Characteristics

Duttlinger (in progress) reported carcass characteristics including yield, carcass weight, carcass weight variation, backfat depth, loin depth, fat-free lean index, and lean percentages (Appendix Table B.2). Dietary glycerol level did not affect ($P > 0.17$) carcass weight, dressing percentage, backfat depth, loin depth, fat-free lean index, or lean percentage. In addition, adding 20% DDGS to the diet did not affect ($P > 0.18$) any carcass characteristics.

3.3 Loin Evaluation

pH

No treatment differences ($P > 0.13$) were found for pH (Table 3.1). The pH means were within an acceptable pH range with no values indicating PSE or DFD pork. These results agree with those found by Whitney et al. (2006) and Widmer (2007), who both found no difference in pH.

Color and Marbling

No treatment differences ($P >0.13$) were found for visual color, marbling score, a* values, or b* values (Table 3.1). However, chops from pigs fed 5.0% glycerol had ($P < 0.05$) higher (lighter) L* values than chops from pigs fed 2.5% glycerol (Table 3.1). Whitney et al. (2006) found no significant difference between 0% and 20% DDGS for L* values (using Illuminant D65) and visual color and marbling score. In addition, Moreno et al. (2008) also found no differences in L* values.

Purge Loss

At 10-d postmortem, no treatment differences ($P > 0.57$) were found for purge loss (Table 3.1), which contradict the results from Whitney et al. (2006), who found 11-d purge loss was greater for loins from pigs fed 20% DDGS compared with loins from pigs fed 0% DDGS.

Drip Loss

No treatment differences ($P > 0.26$) were found for drip loss (Table 3.1). Whitney et al. (2006) also concluded that feeding 0% and 20% DDGS did not affect drip loss.

Cook Loss

Cook loss was not different ($P > 0.23$) for all treatments (Table 3.1). Whitney et al. (2006) also concluded no difference in cook loss.

3.4 Palatability

Warner-Bratzler Shear Force

Chops from pigs fed 20% DDGS had ($P < 0.05$) higher (tougher) WBSF than chops from pigs fed 0% DDGS (Table 3.1). However, this contradicts other DDGS research that did not find an increase in shear force values (Whitney et al., 2006 and Moreno et al., 2008). There was also a trend for chops from pigs fed 2.5% glycerol to have ($P = 0.06$) higher (tougher) WBSF than chops from pigs fed either 0% or 5% glycerol. This may be due to more apparent connective tissue found by sensory panelists.

Sensory Evaluation

There was a DDGS main effect difference for myofibrillar tenderness, connective tissue amount, and overall tenderness (Table 3.1). Chops from pigs fed 20% DDGS had ($P < 0.05$) lower (tougher) sensory panel scores for myofibrillar tenderness, connective tissue, and overall tenderness than chops from pigs fed 0% DDGS. These results contradict the findings of Widmer (2007), who found no difference in chop tenderness. In a DDGS x glycerol interaction ($P = 0.04$) chops from pigs fed 20% DDGS and no glycerol had more off-flavor than all other treatment combinations (Table 3.2). Off-flavors descriptors from taste panelists includes rancid, stale, and oxidative. These descriptors are commonly associated with oxidative rancidity. This would be expected as pork chops from 20% DDGS have a higher percentage of polyunsaturated fats when compared to 0% DDGS (Table 3.1). In a study conducted by Moreno et al. (2008), a consumer taste panel concluded that aftertaste off-flavors were more prevalent as dietary DDGS increased.

Fatty Acid Analysis

The loin fatty acids for pigs fed 20% DDGS had increased ($P < 0.05$) linoleic acid, eicosadienoic acid, and calculated iodine value compared with pigs fed 0% DDGS (Table 3.1). There was a decrease ($P < 0.05$) in palmitoleic acid for pigs fed 20% DDGS compared with pigs fed 0% DDGS. There was a trend ($P < 0.07$) for decreased margaric and vaccenic acids for pigs fed 20% DDGS compared with pigs fed 0% DDGS. Moreover, there was a trend ($P < 0.07$) for increased total PUFA and the ratio of PUFA to SFA.

In comparison, Duttlinger (in progress) reported jowl fat, belly fat, and backfat fatty acids (Appendix Tables B.5, B.6, and B.7). Pigs fed 20% DDGS had increased ($P < 0.01$) linoleic acid, total PUFA, ratio of unsaturated fatty acids to saturated fatty acids (UFA:SFA) in jowl fat, belly fat, and backfat compared with pigs fed diets with no DDGS. Yet, increasing glycerol tended to decrease (linear, $P < 0.08$) linoleic acid, total PUFA, (linear, $P < 0.10$) PUFA:SFA, and (linear, $P < 0.11$) IV in backfat, with no change to jowl and belly IV ($P > 0.24$).

It is interesting that more statistical differences were found in jowl fat, belly fat, and backfat than loin fat. This could be due to the fact that intramuscular fat is the last to be deposited in the body, thus probably the last one affected by diet changes (Wood et al., 2003).

Summary

Chops from pigs fed 2.5% glycerol were lighter (higher L*) than chops from pigs fed 5% glycerol. Feeding pigs 20% DDGS resulted in less tender chops with more off-flavors. Yet, the inclusion of glycerol in the diet decreased the intensity of off-flavors in pork chops to levels similar to chops from pigs not fed DDGS. Therefore, the inclusion of glycerol in the diet should reduce the negative impact of feeding DDGS on chop off-flavor.

Conclusions

Feeding DDGS and glycerol had no negative impacts on most pork quality traits evaluated. There may be an increase in polyunsaturated fatty acids in loin intramuscular fat for pigs fed 20% DDGS compared with pigs fed 0% DDGS. Chops from pigs fed DDGS tend to be tougher than pigs not fed DDGS. Furthermore, despite some significant differences due to feeding DDGS and glycerol, there will be minimal negative affects in practical pork production on loin quality. To help reduce off-flavor development in pigs fed DDGS, glycerol should be

incorporated into the diet. Finally, glycerol does not change fatty acid profile in intramuscular fat.

Table 3.1 Main effect of DDGS[1] and glycerol on pork loin quality characteristics

	DDGS				Glycerol				
Trait	0%	20%	SE	*P* =	0%	2.50%	5%	SE	*P* =
pH	5.7	5.7	< 0.01	0.13	5.7	5.7	5.7	< 0.01	0.78
NPPC color score[2]	3.3	3.2	0.11	0.29	3.1	3.5	3.2	0.14	0.13
Instrumental color									
L*[3]	61.0	61.4	0.52	0.56	61.5[ab]	60.0[b]	62.1[a]	0.63	0.05
a*[4]	20.5	20.4	0.23	0.61	20.3	20.2	20.8	0.28	0.29
b*[5]	17.6	17.7	0.27	0.75	17.7	17.4	18.0	0.33	0.37
NPPC marbling score[6]	2	2	0.15	0.82	2.2	1.8	1.9	0.18	0.25
Purge loss, %	1.7	1.6	0.13	0.84	1.7	1.7	1.6	0.16	0.87
Drip loss, %	2.6	3.0	0.27	0.26	2.7	3.0	2.6	0.32	0.78
Cooking loss, %	25.7	26.1	0.48	0.52	25.7	25.3	26.7	0.58	0.23
WBSF, kg[7]	3.2[b]	3.5[a]	0.11	0.04	3.2	3.6	3.1	0.14	0.06
Sensory traits									
Myofibrillar tenderness[8]	5.9[a]	5.7[b]	0.09	0.03	5.8	5.8	5.8	0.11	0.85
Connective tissue amount[9]	7.5[a]	7.4[b]	0.05	0.03	7.5	7.4	7.5	0.07	0.56
Overall tenderness[8]	6.3[a]	6.0[b]	0.08	0.02	6.1	6.1	6.2	0.10	0.84
Juiciness[10]	5.3	5.2	0.06	0.21	5.2	5.2	5.2	0.07	0.86
Pork flavor intensity[11]	5.5	5.4	0.04	0.35	5.5	5.5	5.5	0.05	0.92
Off-flavor intensity[9]	7.6[a]	7.5[b]	0.06	0.04	7.4	7.6	7.6	0.08	0.11
Fatty Acids									
Palmitoleic acid (C16:1), %	3.5[a]	3.1[b]	0.10	< 0.01	3.3	3.3	3.4	0.12	0.88
Margaric acid (C17:0), %	0.6	0.5	0.04	0.07	0.6	0.5	0.5	0.05	0.54
Vaccenic acid (C18:1n7), %	4.4	4.0	0.14	0.06	4.3	4.1	4.2	0.17	0.58
Linoleic acid (C18:2n6), %	13.9[b]	15.6[a]	0.58	0.04	14.5	14.9	14.7	0.72	0.91

Eicosadienoic acid (C20:2), %	0.4[b]	0.5[a]	0.01	< 0.01	0.5	0.4	0.4	0.02	0.96
Total SFA, %[12]	38.9	38.6	0.22	0.27	38.7	38.6	38.9	0.28	0.79
Total MUFA, %[13]	45.1	43.8	0.57	0.11	44.7	44.4	44.3	0.71	0.93
Total PUFA, %[14]	15.9	17.6	0.65	0.08	16.6	17.0	16.8	0.81	0.94
UFA:SFA[15]	1.6	1.6	0.01	0.25	1.6	1.6	1.6	0.02	0.76
PUFA:SFA[16]	0.4	0.5	0.02	0.07	0.4	0.4	0.4	0.02	0.92
Iodine value, g/100g[17]	64.3[b]	66.0[a]	0.57	0.04	65.0	65.6	65.0	0.71	0.81

[1]Dried Distillers Grains with Solubles.

[2]1 = pale pinkish gray to white, 2 = grayish pink, 3 = reddish pink, 4 = dark reddish pink, 5 = purplish red, 6 = dark purplish red (NPPC, 1999).

[3]0 = black, 100 = white

[4] positive = reddness, negative = greenness.

[5]postitive = yellowness, negative = blueness.

[6]Visual scale, which approximates the percentage of intramuscular fat content (NPPC, 1999).

[7]Warner-Bratzler Shear Force.

[8]1 = extremely tough, 2 = very tough, 3 = moderately tough, 4 = slightly tough, 5 = slightly tender, 6 = moderately tender, 7 = very tender, 8 = extremely tender.

[9]1 = abundant, 2 = moderately abundant, 3 = slightly abundant, 4 = moderate, 5 = slight, 6 = traces, 7 = practically none, 8 = none.

[10]1 = extremely dry, 2 = very dry, 3 = moderately dry, 4 = slightly dry, 5 = slightly juicy, 6 = moderately juicy, 7 = very juicy, 8 = extremely juicy.

[11]1 = extremely bland, 2 = very bland, 3 = moderately bland, 4 = slightly bland, 5 = slightly intense, 6 = moderately intense, 7 = very intense, 8 = extremely intense.

[12]Total saturated fatty acids = [C6:0] + [C8:0] + [C10:0] + [C11:0] + [C12:0] + [C14:0] + [C15:0] + [C16:0] + [C17:0] + [C18:0] + [C20:0] + [C21:0] + [C22:0] + [C24:0].

[13]Total monounsaturated fatty acids = [C14:1] + [C15:1] + [C16:1] + [C17:1] + [C18:1c9] + [C18:1n7] + [C18:1n11] + [C20:1] + [C24:1].

[14]Total polyunsaturated fatty acids = [C18:2n6] + [C18:3n3] + [C18:3n6] + [C20:2] + [C20:3n6] + [C20:4n6] + [C20:5n3] + [C22:5n3] + [C22:6n3].

[15]Unsaturated fatty acids : saturated fatty acids ratio = [Total MUFA + Total PUFA] / Total SFA.

[16]Polyunsaturated fatty acids : saturated fatty acids ratio = Total PUFA / Total SFA.

[17]Calculated Iodine Value = [C16:1] × 0.95 + [C18:1] × 0.86 + [C18:2] × 1.732 +[C18:3] × 2.616 + [C20:1] × 0.785+[C22:1] × 0.723 (AOCS, 1998)

[ab]Means within same treatment and trait without a common superscript differ ($P < 0.05$).

Table 3.2 Effect of DDGS[1] and glycerol on off-flavor intensity[2]

	0% DDGS			20% DDGS						
	Glycerol, %			Glycerol, %				P<		
Item	0	2.5	5	0	2.5	5	SE	DxG	DDGS	Glycerol
Off-Flavor Intensity	7.7[a]	7.6[a]	7.7[a]	7.2[b]	7.7[a]	7.5[a]	0.11	0.04	0.11	0.03

[1]Dried Distillers Grains with Solubles.

[2]Off flavor intensity scale: 1 = abundant, 2 = moderately abundant, 3 = slightly abundant, 4 = moderate, 5 = slight, 6 = traces, 7 = practically none, and 8 = none.

[ab]Within a row, means without a common superscript differ (P<0.05).

References

AMSA. 1995. Research guidelines for cookery, sensory evaluation, and instrumental tenderness measurements of fresh meat. American Meat Sci Assoc., Chicago, IL.

AOCS. 1998. Official Methods and Recommended Practices of the AOCS Method Cd 1c-85. 5th ed. Am Oil Chem. Soc., Champaign, IL.

Moreno, R., P. S. Miller, T. E. Burkey, S. J. Jones, S. L. Cuppett, T. P. Carr, T. F. Jones, and R. M. Diedrichsen. 2008. The effects of corn distillers dried grain with solubles (DDGS) on carcass characteristics and pork quality. Pages 8-11 in Nebraska Swine Day Report. M. Oetjen ed. University of Nebraska, Lincoln, NE.

NPPC. 1999. Pork Quality Standards. National Pork Producers Council, Des Moines, IA.

Sukhija, P. S. and D. L. Palmquist. 1988. A rapid method for determination of total fatty acid content and composition of feedstuffs and feces. J. Ag. Food Chem. 36:1202-1206.

Widmer, M. R. 2007. Energy and nutrient digestibility of high protein distillers dried grains and corn germ by growing pigs and effects on pig performance, carcass quality, and pork palatability. MS Thesis. South Dakota State Univ., Brookings.

Whitney M. H., G. C. Shurson, L. J. Johnston, D. M. Wulf, and B. C. Shanks. 2006. Growth performance and carcass characteristics of grower-finisher pigs fed high-quality corn distillers dried grain with solubles originating from a modern Midwestern ethanol plant. Journal of Animal Science 84:3356-3363.

Wood, J. D., R. I. Richardson, G. R. Nute, A.V. Fisher, M. M. Campo, E. Kasapidou, P. R. Sheard, and M. Enser. 2003. Effects of fatty acids on meat quality: a review. Meat Sci. 66:21-32.

CHAPTER 4 - Effects of dried distillers grains with solubles on sow carcass fat quality

Abstract

An experiment was conducted to determine the effects of feeding non-pregnant sows a diet containing 50% dried distillers grains with solubles (DDGS) on carcass fat oxidation and composition. A total of 8 open sows were allotted to one of 2 diets by parity (average 2.3) and BW (initially 215 kg). One diet was a corn-soybean meal-based gestation diet, while the other diet was a corn-soybean meal-based diet that contained 50% DDGS. All sows were fed 2.27 kg of feed per day in a single feeding for 92-d. All sows were harvested on d 92 at the KSU Meat Laboratory, chilled for 48 h, fabricated into lean trimmings, ground, packaged in oxygen permeable overwrap and placed into a simulated retail display. Overall (d 0 to 92), there were no differences (P>0.64) in BW (-1.5 vs 1.25 kg) or backfat (0.75 vs 0) change for sows fed either 0 or 50% DDGS. No differences (P>0.23) in lipid oxidation from lean trimmings as measured by 2-thiobarbituric acid reactive substances (TBARS) assay were reported either initially (0.128 vs 0.171 mg/kg) or after 5 d (0.249 vs 0.283 mg/kg) of retail display for sows fed either 0 or 50% DDGS. As expected, lipid oxidation increased (P<0.003) as measured by TBARS for both treatments from d 1 to 5. Jowl fatty acid analysis revealed an increase in linoleic acid (P<0.01; 12.66 vs 15.58%), total polyunsaturated fatty acids (P<0.01; 14.94 vs 18.12%), and the ratio of polyunsaturated fatty acids to saturated fatty acids (P<0.03; 0.47 vs 0.58%) for sows fed 50% DDGS. Also, there was a trend for increased jowl iodine value (P<0.08; 69.33 vs 72.38) for sows fed 50% DDGS. In summary, feeding 50% DDGS to open sows for 92-d did not significantly affect BW, backfat, and lipid oxidation, but increased the concentration of linoleic acid and total polyunsaturated fatty acids and tended to increase jowl iodine value. However, the magnitude of unsaturation change to jowl fat for sows fed DDGS on a limit fed basis was not as great as previously observed in finishing pigs fed DDGS *ad libitum*.

Key words: carcass fat quality, DDGS, fatty acid profile, sow, TBARS

1. Introduction

With the increase in bio-fuel production, the availability of feed coproducts like dried distillers grains with solubles (DDGS) from ethanol manufacturing, has greatly increased. Dried distillers grains with solubles is the product that remains after the ethanol is removed from the fermented corn mash. Fat in DDGS is approximately 3 times higher than corn (3.9 vs 10.7%). Because of the high level of unsaturated fatty acids present in DDGS, carcass fat has been shown to decrease in firmness and percentage of saturated fatty acids when finishing pigs have been fed DDGS. When using iodine value as the fat firmness measurement, for every 10% DDGS fed to finishing pigs the iodine value increases approximately 2 g/100g. This increase has been documented in grow-finish pigs fed *ad libitum* in which body fat levels increase during the finishing period. However, available research has not evaluated if the same results will occur in limit fed sows that have less change in body fat accumulation than finishing pigs. Most cull sows in the U.S. are harvested and processed into fresh sausage products. As a result, the stability of the fat from cull sow trimmings is very important to retail shelf life and consumer acceptance of fresh sausage products. Therefore the objective of this study was to determine in a pilot project the effects of feeding open sows a diet containing 50% DDGS on carcass fat quality and stability.

2. Materials and Methods

2.1 Sow Management

Procedures used in this experiment were approved by the Kansas State University Animal Care and Use Committee. The experiment was conducted at the Kansas State University Swine Teaching and Research Farm. A total of 8 non-pregnant sows allotted in a randomized design to 1 of 2 diets by parity and body weight (BW). Each sow was maintained in a gestation stall for 92-d with *ad libitum* access to water via a nipple waterer.

The control diet was a standard corn-soybean meal-based gestation diet and the experimental diet was a corn-soybean meal-based diet that contained 50% DDGS (Table 4.1). All sows were fed once daily 2.27 kg of feed.

The sows weight and back fat thickness were taken 2.54 to 5.08 cm from the midline over the last rib (P2) on d 0 and 92.

Table 4.1 Sow cull diet composition (as-fed basis)[1]

Ingredient, %	Control	DDGS[2]
Corn	80.92	37.11
Soybean meal (46.5% CP)	14.93	9.26
DDGS	--	50
Monocalcium phosphate (21% P)	1.7	0.55
Limestone	1.2	1.83
Salt	0.5	0.5
Vitamin premix	0.25	0.25
Trace mineral premix	0.15	0.15
Sow add pack	0.25	0.25
Phytase 600[3]	0.1	0.1
TOTAL	100	100
Calculated analysis		
Standardized ileal digestible lysine ,%	0.57	0.57
CP, %	13.8	21.1
Crude fat, %	3.4	6.9
ME, kcal/lb	1,484	1,493
Ca, %	0.85	0.85
P, %	0.69	0.64
Available P, %[4]	0.52	0.52

[1]Diets fed once daily for 92 d with all sows receiving 2.27 kg per d.

[2] Dried distillers grains with solubles.

[3]Provided per lb of diet: 227 phytase unit (FTU) of phytase.

[4]Includes expected P release of 0.12% from added phytase.

2.2 Carcass Processing

On d 92 of the feeding period, sows were transported to and harvested at the Kansas State University Meats Laboratory. Following slaughter all carcasses were chilled for 48 h at 0 to 2°C, fabricated into lean trimmings, ground and packaged in 0.5 kg portions in 20.32 cm x 14.61 cm x 1.74 cm foam trays, overwrapped with an oxygen permeable PVC film (MAPAC M film, 23, 250 cc/m2/24h, 72 gauge, Resinite Packaging Films Border, Inc., North Andover, MA), and placed into simulated retail display cases. The jowl was also removed for fatty acid analysis.

Display Conditions

Ground lean trimming were displayed for 5 d at 2°C in open-top display cases (Unit model DMF8, Tyler Refrigeration Corp., Niles, MI) under continuous fluorescent lighting (2153 lux, 3000 K, and CRI=85, Bulb model F32T8/ADV830/Alto, Philips, Bloomfield, NJ) to simulate retail display. Display case temperatures were monitored using temperature loggers (RD-TEMP-XT; Omega Engineering, Inc., Stamford, CT).

Lipid Oxidation

Lipid oxidation was measured using the 2-thiobarbituric acid reactive substances (TBARS) assay which measures mg of malonaldehyde and other lipid degradation products per kg of sample. Lipid oxidation was measured on d 1 (the day of grinding) and after 5 d of retail display. At the time of grinding, a portion of the ground lean trimmings were cut and frozen at -80°C to be used for initial TBARS values. On the last day of retail display, ground lean trimmings were removed from packages and frozen at -80°C to determine post display TBARS values. The initial and post display samples were frozen in liquid nitrogen and then pulverized using a tabletop blender (model 33BL79; Waring Products, New Hartford, CT). Ten grams of sample were blended for 30 sec with 10 ml of water and 15 ml of perchloric acid (Tarladgis et al., 1960). After blending, samples were filtered through filter paper (Cat. No. 1002, 125mm dia; Whatman International Ltd., Maidstone, England), 5 ml of thiobarbituric acid solution was added to the 5 ml of filtrate, and samples were allowed to react for 18 h. Absorbance was measured on a Spectrophic 21 spectrophotometer (Bausch & Lomb, Rochester, NY). Control solutions of known concentrations of malonaldehyde were plotted to calculate TBARS concentrations. Results were reported as mg malonaldehyde per 1 kg of fresh muscle tissue.

Fatty Acid Profile

A modified gas chromatography procedure of Sukhija and Palmquist (1988) was used for fatty acid analysis. At the time of fabrication the jowl was removed from each carcass for fatty acid analysis. The samples were frozen in liquid nitrogen, pulverized using a tabletop blender (model 33BL79; Waring Products, New Hartford, CT), and analyzed at Kansas State Univeristy Analytical Laboratory to determine the fatty acid profile of jowl fat. Fat (50µg) was combined with 2 mL of methanolic-HCl and 3 mL of internal standard (2 mg/mL of methyl Heptadecanoic acid (C17:0) in benzene) and was heated in a water bath for 120 min at 70°C for transmethylation. After cooling, the addition of 2 mL of benzene and 3 mL of K_2CO_3 allowed

the methyl esters to be extracted and transferred to a vial for subsequent quantification of the methylated fatty acids by gas chromatography for fatty acid analysis. Fatty acids from each of the fat samples were expressed as a percentage of the total fatty acids. Iodine value was calculated by using the fatty acid profile of each sampling according to the following equation (AOCS, 1998):

C16:1 (0.95) + C18:1 (0.86) + C18:2 (1.732) + C18:3 (2.616) + C20:1 (0.785) + C22:1 (0.723).

2.4 Statistical Analysis

Data were analyzed by Analysis of Variance using the MIXED procedure of SAS (SAS Inst, Inc., Cary, NC). Sow served as the experimental unit. Fixed effect was DDGS. Least squares means for each measurement of interest were obtained. Pairwise comparisons of treatment least squares means were made with significant differences at an α level of ($P<0.05$).

3. Results and Discussion

3.1 Performance

There were no differences in sow body weight or P2 backfat existed at the start or end of the experiment for sows fed the two dietary treatments (Table 4.2; $P>0.62$). This contradicts the study conducted by Legan et al. (2007), who found cull sows fed DDGS had lower ($P<0.05$) BW than sows fed ground corn. However, these cull sows were fed 100% DDGS, where the sows in our study were fed 50% DDGS. This could have been due to the decrease in feed consumption between the treatment groups. On the other hand, Legan et al. (2207) also found no significant differences in backfat depth.

Table 4.2 Body weight and backfat of sows[1]

Body weight, lb				
Initial	212.7	218.5	34.6	0.80
Final	212.0	219.1	21.3	0.62
Change	-0.7	0.5	18.9	0.92
P2 backfat, mm[2]				
Initial	12.5	13.3	1.7	0.76
Final	13.3	13.3	0.8	0.99
Change	0.8	0	1.1	0.64

[1]A total of 8 non-pregnant sows (4 / treatment) fed for 92 d.

[2] P2 backfat is measured approximately 2.54 to 5.08 cm from the midline over the last rib.

3.2 Ground Pork Evaluation

Lipid Oxidation

There were no differences in TBARS values due to treatment (Table 4.3; P>0.23) which indicated that the amount of lipid oxidation was not significantly higher in the 50% DDGS fed sows compared with control. In addition, the rate of lipid oxidation was similar between the two treatment groups over the 5 d display period. As expected, TBARS values increased (P<0.003) regardless of treatment from d 1 to d 5. It is well known that lipid oxidation increases with increased storage time.

Table 4.3 Lipid oxidation values of ground pork from cull sow trim[1]

	Control	50% DDGS	P-value
TBARS, mg/kg			
d 1	0.13	0.171	0.335
d 5	0.25	0.283	0.452
P-value	0.0163	0.0249	
SE = 0.0307			

[1]A total of 8 non-pregnant sows (4 / treatment).

[2]Day effect, $P < 0.003$.

Fatty Acid Profile

Sows fed 50% DDGS for 92-d had (P<0.01) jowl samples with higher percentages of linoleic and eicosadienoic acids and total polyunsaturated fatty acids (PUFA), and a higher

(P<0.03) ratio of PUFA to saturated fatty acids (SFA) than control sows (Table 4.4). These changes may be explained as a result of the increased crude fat level of the diet for sows fed DDGS. Because the oil content of DDGS is high in unsaturated fatty acids, this appears to have resulted in fat composition changes for sows fed DDGS. There was a trend for an increase in total monosaturated fatty acids and iodine value (P<0.08) for sows fed 50% DDGS compared with control sows. In the study conducted by Legan et al. (2007), fatty acid profiles were not conducted on jowl fat, but rather bratwurst made from the cull sows. The bratwurst like the jowl fat in this study found no differences of palmitic and oleic acids and calculated IV between treatments. In contradiction with our study, Legan et al. (2007) found no differences in linoleic acid, but found a difference in arachidonic acid. In addition, Legan found a difference in the calculated saturated to unsaturated ratio, but our study did not find this difference. In growing-finishing pigs, Benz (2008) found increased percentages of linoleic, polyunsaturated fatty acids, and calculated iodine value in pigs fed increasing levels of DDGS. The magnitude of change in IV for sows fed DDGS on a limit fed basis was not as great as previously observed in finishing pigs fed DDGS on an *ad libitum* fed basis. In fact, there was a change of approximately 3.1g/100g increase with a 50% inclusion, while finishing pigs typically have an increase of approximately 2g/100g for every 10% DDGS in the diet fed *ad libitum*.

Table 4.4 Effect of DDGS on sow jowl fat quality[1]

Item	Control	50% DDGS	SE	P-value
Myristic acid (14:0), %	1.41	1.36	0.03	0.32
Palmitic acid (16:0), %	21.08	20.54	0.33	0.3
Palmitoleic acid (16:1), %	3.01	2.79	0.09	0.12
Margaric acid (17:0), %	0.28	0.33	0.03	0.26
Stearic acid (18:0), %	8.62	8.27	0.51	0.64
Oleic acid (18:1c9), %	43.9	41.93	0.81	0.13
Vaccenic acid (18:1n7), %	4.16	3.92	0.09	0.12
Linoleic acid (18:2n6), %	12.66	15.58	0.53	0.01
α-linolenic acid (18:3n3), %	0.56	0.58	0.05	0.81
Arachidic acid (20:0), %	0.33	0.37	0.03	0.42
Eicosadienoic acid (20:2), %	0.93	1.12	0.03	0.01
Arachidonic acid (20:4n6),	0.13	0.13	0.01	0.51
Other fatty acids, %	15.6	18.66	0.59	0.01
Total SFA, %[2]	32.03	31.2	0.84	0.51
Total MUFA, %[3]	53.03	50.69	0.8	0.08
Total PUFA, %[4]	14.94	18.12	0.65	0.01
Total *trans* fatty acids, %[5]	0.37	0.49	0.1	0.44
UFA:SFA ratio[6]	2.13	2.21	0.08	0.49
PUFA:SFA ratio[7]	0.47	0.58	0.03	0.03
Iodine value, g/100g[8]	69.33	72.38	1.03	0.08

[1]Total of 8 sows with 4 sows per treatment

[2] Total saturated fatty acids = {[C8:0] + [C10:0] + [C12:0] + [C14:0] + [C16:0] + [C17:0] + [C18:0] + [C20:0] + [C22:0] + [C24:0]}, where the brackets indicate

[3]Total monounsaturated fatty acids = {[C14:1] + [C16:1] + [C18:1c9] + [C18:1n7] + [C20:1] + [C24:1]}, where the brackets indicate concentration.

[4]Total polyunsaturated fatty acids = {[C18:2n6] + [C18:3n3] + [C18:3n6] + [C20:2] + [C20:4n6]}, where the brackets indicate concentration.

[5]Total *trans* fatty acids = {[C18:1t] + [C18:2t] + [C18:3t]}, where the brackets

[6]UFA:SFA ratio = [Total MUFA + Total PUFA] / Total SFA.

[7]PUFA:SFA ratio = Total PUFA / Total SFA.

[8]Calculated as IV = [C16:1] × 0.95 + [C18:1] × 0.86 + [C18:2] × 1.732 + [C18:3] × 2.616 + [C20:1] × 0.785+[C22:1] × 0.723, where the brackets indicate concentration (AOCS, 1998).

Summary

Feeding 50% DDGS in a single feeding has no significant effect on BW or P2 backfat. However, feeding 50% DDGS to open sows increased the concentration of linoleic acid and total polyunsaturated fatty acids and tended to increase jowl IV value compared to control sows.

References

AOCS. 1998. Official Methods and Recommended Practices of the AOCS Method Cd 1c-85. 5th ed. Am Oil Chem. Soc., Champaign, IL.

Benz, J . M. 2008. Influence of dietary ingredients on pork fat quality. MS Thesis. Kansas State Univ., Manhattan.

Legan, E. M., H. M. White, A. P. Schinckel, PAS, A. M. Gaines, and M. A. Latour. 2007. Evaluating growth and carcass changes in cull gilts fed distillers dried grains with solubles. The Professional Animal Scientist 23:612-615.

Sukhija, P. S. and D. L. Palmquist. 1988. A rapid method for determination of total fatty acid content and composition of feedstuffs and feces. J. Ag. Food Chem. 36:1202-1206.

Tarladgis, B. G., B. M. Watts, M. T. Younathan, and L. Dugan Jr. 1960. A distillation method for quantitative determination of malonaldehyde in rancid foods. J. Amer. Oil Chem. Soc. 37:44-48.

Appendix A - Feed Rations for Chapter 3

Table A.1 Phase 1 diet composition (as-fed basis)[1] (Duttlinger, in process)

	DDGS, %[2]					
	0			20		
Ingredient, %	0% glycerol	2.50% glycerol	5% glycerol	0% glycerol	2.50% glycerol	5% glycerol
Corn	68.18	65.47	62.77	55.16	52.46	49.75
Soybean meal (46.5% CP)	26.63	26.83	27.03	19.69	19.89	20.09
Glycerol	---	2.5	5	---	2.5	5
DDGS	---	---	---	20	20	20
Choice white grease	3	3	3	3	3	3
Monocalcium P, (21% P)	0.63	0.63	0.63	0.18	0.18	0.18
Limestone	0.85	0.85	0.85	1.13	1.13	1.13
Salt	0.35	0.35	0.35	0.35	0.35	0.35
Vitamin premix	0.08	0.08	0.08	0.08	0.08	0.08
Trace mineral premix	0.1	0.1	0.1	0.1	0.1	0.1
Optiphos 2000[3]	0.03	0.03	0.03	0.03	0.03	0.03
L-Lysine HCl	0.15	0.15	0.15	0.3	0.3	0.3
DL-Methionine	0.01	0.02	0.02	---	---	---
Total	100	100	100	100	100	100
Calculated analysis						
SID[4] amino acids, %						
Lysine	0.98	0.98	0.98	0.98	0.98	0.98
Methionine:lysine	28	28	29	30	30	29
Met & Cys:lysine	57	57	57	61	61	60
Threonine:lysine	60	60	60	61	61	60
Tryptophan:lysine	19	19	19	18	18	18
SID Lysine:calorie ratio, g/Mcal ME	2.82	2.82	2.82	2.81	2.81	2.81
ME, kcal/lb	1,578	1,578	1,578	1,582	1,582	1,582
Total lysine, %	1.1	1.1	1.1	1.13	1.13	1.13
CP, %	18.33	18.2	18.06	19.57	19.44	19.3
Ca, %	0.55	0.55	0.55	0.55	0.55	0.55
P, %	0.51	0.5	0.49	0.47	0.46	0.46
Available P, %[5]	0.28	0.28	0.28	0.28	0.28	0.28

[1]Fed from 68 to 120 lb.

[2]Dried distillers grains with solubles.

[3]Provided per pound of diet: 227 phytase unit (FTU) of phytase.

[4]Standardized ileal digestible .

[5]Includes expected P release of .07% from added phytase.

Table A.2 Phase 2 diet composition (as-fed basis)[1] (Duttlinger, in process)

	DDGS, %[2]					
	0			20		
Ingredient, %	0% glycerol	2.50% glycerol	5% glycerol	0% glycerol	2.50% glycerol	5% glycerol
Corn	74.27	71.57	68.87	61.2	58.5	55.8
Soybean meal (46.5% CP)	20.66	20.86	21.06	13.72	13.92	14.12
Glycerol	---	2.5	5	---	2.5	5
DDGS	---	---	---	20	20	20
Choice white grease	3	3	3	3	3	3
Monocalcium P, (21% P)	0.55	0.55	0.55	0.13	0.13	0.13
Limestone	0.85	0.85	0.85	1.13	1.13	1.13
Salt	0.35	0.35	0.35	0.35	0.35	0.35
Vitamin premix	0.06	0.06	0.06	0.06	0.06	0.06
Trace mineral premix	0.08	0.08	0.08	0.08	0.08	0.08
Optiphos 2000[3]	0.03	0.03	0.03	0.03	0.03	0.03
L-Lysine HCl	0.15	0.15	0.15	0.3	0.3	0.3
Total	100	100	100	100	100	100
Calculated analysis						
SID[4] amino acids, %						
Lysine	0.83	0.83	0.83	0.83	0.83	0.83
Methionine:lysine	29	29	28	32	32	32
Met & Cys:lysine	60	59	58	66	65	64
Threonine:lysine	61	61	61	62	62	61
Tryptophan:lysine	19	19	19	17	17	17
SID Lysine:calorie ratio, g/Mcal ME	2.38	2.38	2.38	2.38	2.38	2.38
ME, kcal/lb	1,580	1,580	1,580	1,585	1,585	1,585
Total lysine, %	0.93	0.93	0.93	0.97	0.96	0.96
CP, %	16.06	15.93	15.79	17.31	17.17	17.04
Ca, %	0.52	0.52	0.52	0.52	0.52	0.52
P, %	0.47	0.46	0.45	0.43	0.43	0.42
Available P, %[5]	0.25	0.24	0.24	0.25	0.25	0.25

[1]Fed from 120 to 170 lb.

[2]Dried distillers grains with solubles.

[3]Provided per pound of diet: 227 phytase unit (FTU) of phytase.

[4]Standardized ileal digestible.

[5]Includes expected P release of .07% from added phytase.

Table A.3 Phase 3 diet composition (as-fed basis)[1] (Duttlinger, in process)

	DDGS, %[2]					
	0			20		
Ingredient, %	0% glycerol	2.50% glycerol	5% glycerol	0% glycerol	2.50% glycerol	5% glycerol
Corn	78.67	75.97	73.27	64.12	61.42	58.72
Soybean meal (46.5% CP)	16.28	16.48	16.68	10.9	11.1	11.3
Glycerol	---	2.5	5	---	2.5	5
DDGS	---	---	---	20	20	20
Choice white grease	3	3	3	3	3	3
Monocalcium P, (21% P)	0.55	0.55	0.55	0.1	0.1	0.1
Limestone	0.85	0.85	0.85	1.13	1.13	1.13
Salt	0.35	0.35	0.35	0.35	0.35	0.35
Vitamin premix	0.05	0.05	0.05	0.05	0.05	0.05
Trace mineral premix	0.07	0.07	0.07	0.07	0.07	0.07
Optiphos 2000[3]	0.03	0.03	0.03	0.03	0.03	0.03
L-Lysine HCl	0.15	0.15	0.15	0.25	0.25	0.25
Total	100	100	100	100	100	100
Calculated analysis						
SID[4] amino acids, %						
Lysine	0.72	0.72	0.72	0.72	0.72	0.72
Methionine:lysine	31	30	30	35	35	35
Met & Cys:lysine	63	62	61	72	71	71
Threonine:lysine	62	62	62	66	66	65
Tryptophan:lysine	19	19	19	17	17	17
SID Lysine:calorie ratio, g/Mcal ME	2.06	2.06	2.06	2.06	2.06	2.06
ME, kcal/lb	1,582	1,582	1,582	1,586	1,586	1,586
Total lysine, %	0.81	0.81	0.81	0.85	0.85	0.85
CP, %	14.4	14.27	14.13	16.2	16.06	15.93
Ca, %	0.5	0.5	0.5	0.51	0.51	0.51
P, %	0.45	0.44	0.44	0.42	0.41	0.41
Available P, %[5]	0.23	0.23	0.23	0.23	0.23	0.23

[1]Fed from 170 to 220 lb.

[2]Dried distillers grains with solubles.

[3]Provided per pound of diet: 227 phytase unit (FTU) of phytase.

[4]Standardized ileal digestible.

[5]Includes expected P release of .07% from added phytase.

Table A.4 Phase 4 diet composition (as-fed basis)[1] (Duttlinger, in process)

	DDGS, %[2]					
	0			20		
Ingredient, %	0% glycerol	2.50% glycerol	5% glycerol	0% glycerol	2.50% glycerol	5% glycerol
Corn	80.64	77.93	75.23	66.09	63.39	60.69
Soybean meal (46.5% CP)	14.29	14.5	14.7	8.91	9.11	9.31
Glycerol	---	2.5	5	---	2.5	5
DDGS	---	---	---	20	20	20
Choice white grease	3	3	3	3	3	3
Monocalcium P, (21% P)	0.6	0.6	0.6	0.15	0.15	0.15
Limestone	0.85	0.85	0.85	1.13	1.13	1.13
Salt	0.35	0.35	0.35	0.35	0.35	0.35
Vitamin premix	0.04	0.04	0.04	0.04	0.04	0.04
Trace mineral premix	0.05	0.05	0.05	0.05	0.05	0.05
Optiphos 2000[3]	0.03	0.03	0.03	0.03	0.03	0.03
L-Lysine HCl	0.15	0.15	0.15	0.25	0.25	0.25
Total	100	100	100	100	100	100
Calculated analysis						
SID[4] amino acids, %						
Lysine	0.64	0.64	0.64	0.64	0.64	0.64
Methionine:lysine	31	31	31	37	36	36
Met & Cys:lysine	65	64	63	75	74	73
Threonine:lysine	63	62	62	67	67	66
Tryptophan:lysine	19	19	18	17	17	17
SID Lysine:calorie ratio, g/Mcal ME	1.92	1.92	1.92	1.92	1.92	1.92
ME, kcal/lb	1,582	1,582	1,582	1,586	1,586	1,586
Total lysine, %	0.76	0.76	0.76	0.79	0.79	0.79
CP, %	13.65	13.51	13.37	15.44	15.31	15.17
Ca, %	0.51	0.51	0.51	0.51	0.51	0.51
P, %	0.45	0.44	0.44	0.42	0.41	0.41
Available P, %[5]	0.22	0.22	0.22	0.22	0.22	0.22

[1]Fed from 220 to 273 lb.

[2]Dried distillers grains with solubles.

[3]Provided per pound of diet: 227 phytase unit (FTU) of phytase.

[4]Standardized ileal digestible.

[5]Includes expected P release of .07% from added phytase.

Appendix B - All Interaction Means for Chapter 3

Table B.1 Effect of DDGS[1] and glycerol on grow-finish pig performance[2](Duttlinger, in process)

	DDGS:	0%			20%				*P* -value		
Item	Glycerol:	0%	2.50%	5%	0%	2.50%	5%	SE	DxG	DDGS	Glycerol
D 0 to 97											
Initial wt, kg		30.8	30.9	31.3	31.0	31.2	30.9	1.12	0.95	0.98	0.98
ADG, kg		0.97	0.96	0.96	0.97	0.96	0.96	0.01	0.99	0.73	0.44
ADFI, kg		2.43	2.39	2.40	2.45	2.46	2.51	0.03	0.29	0.02	0.59
G/F		0.40	0.40	0.40	0.40	0.39	0.38	0.00	0.13	0.01	0.33
Final wt, kg		124.1	123.4	123.3	124.2	124.2	123.4	1.45	0.96	0.76	0.87

[1]Dried Distillers Grains with Solubles.

[2]A total of 1,160 pigs, initially 31.0 kg, were used in a 97 d experiment.

Table B.2 Effect of DDGS[1] and glycerol on grow-finish pig carcass characteristics for pigs marketed on d 97[2,3] (Duttlinger, in process)

	DDGS:	0%			20%				*P* -value		
Item	Glycerol:	0%	2.50%	5%	0%	2.50%	5%	SE	DxG	DDGS	Glycerol
Carcass wt, kg		93.1	92.9	92.1	91.4	91.9	92.7	1.08	0.63	0.45	0.99
Carcass wt CV, %		9.0	9.4	9.2	8.8	8.1	8.9	0.67	0.67	0.35	0.94
Yield, %		75.1	75.5	75.7	74.5	75.9	75.7	0.47	0.56	0.93	0.17
Backfat, mm		19.9	19.7	19.8	19.3	19.0	19.6	0.48	0.87	0.18	0.81
Loin depth, mm		62.9	62.8	60.7	60.9	61.2	62.0	0.79	0.12	0.27	0.77
FFLI, %[4]		49.2	49.1	49.1	49.3	49.4	49.3	0.24	0.93	0.32	0.96
Lean, %		54.3	54.3	54.2	54.4	54.6	54.4	0.33	0.95	0.43	0.86

[1]Dried Distillers Grains with Solubles.

[2]A total of 1,160 pigs, initially 68.4 lb., were used in a 97-d experiment with 27 to 28 pigs per pen and 7 replications per treatment.

[3]A total of 1,035 pigs were marketed with 23 to 26 pigs per pen.

[4]Fat-free lean index.

Table B.3 Effect of DDGS and glycerol on pork loin quality characteristics

	DDGS:	0%			20%			*P* -value		
Item	Glycerol:	0%	2.50%	5%	0%	2.50%	5%	SE	DxG	DDGS	Glycerol
Purge Loss, %		1.76	1.75	1.45	1.55	1.61	1.69	0.24	0.57	0.84	0.89
Instrumental Color											
L*[2]		61.03	59.96	61.96	61.91	59.95	62.34	0.91	0.87	0.56	0.05
a*[3]		20.51	20.11	20.97	20.16	20.31	20.64	0.41	0.72	0.61	0.29
b*[4]		17.85	17.1	17.94	17.57	17.61	18.07	0.48	0.69	0.75	0.37
Visual Color[5]		3.2	3.5	3.3	3	3.4	3.1	0.2	0.96	0.29	0.13
Marbling Score[6]		2.2	1.6	2	2.3	2	1.8	0.27	0.5	0.82	0.25
Drip Loss, %		2.47	2.89	2.35	2.99	3.02	2.95	0.44	0.86	0.26	0.78
pH		5.7	5.7	5.7	5.7	5.7	5.7	0.003	0.95	0.13	0.78
WBSF, kg		3.14	3.24	3.07	3.29	3.92	3.21	0.2	0.27	0.04	0.06
Cooking Loss, %		25.55	25.72	25.72	25.82	24.82	27.62	0.85	0.24	0.52	0.23

[1] Dried distillers grains with solubles.

[2] 0 = black, 100 = white.

[3] Increasing redness.

[4] Increasing yellowness.

[5] 1 = pale pinkish gray to white, 2 = grayish pink, 3 = reddish pink, 4 = dark reddish pink, 5 = purplish red, 6 = dark purplish red (NPPC, 1999).

[6] Visual scale, which approximates the percentage of intramuscular fat content (NPPC, 1999).

Table B.4 Effect of DDGS[1] and glycerol on trained sensory panel scores for pork loin chops

	DDGS:	0%			20%			P-value		
Item	Glycerol:	0%	2.50%	5%	0%	2.50%	5%	SE	DxG	DDGS	Glycerol
Myofibrillar Tenderness[2]		5.9	5.9	6	5.7	5.6	5.7	0.16	0.92	0.03	0.85
Juiciness[3]		5.3	5.2	5.2	5.1	5.2	5.2	0.11	0.31	0.21	0.86
Pork Flavor Intensity[4]		5.5	5.5	5.5	5.4	5.4	5.5	0.08	0.57	0.35	0.92
Connective Tissue Amount[5]		7.5	7.6	7.6	7.5	7.2	7.4	0.1	0.25	0.03	0.56
Overall Tenderness[2]		6.2	6.3	6.3	6	6	6	0.14	0.82	0.02	0.84
Off-Flavor Intensity[5]		7.7	7.6	7.7	7.2	7.7	7.5	0.11	0.03	0.04	0.11

1 Dried distillers grains with solubles.

[2] Myofibrillar and overall tenderness scale: 1 = extremely tough, 2 = very tough, 3 = moderately tough, 4 = slightly tough, 5 = slightly tender, 6 = moderately tender, 7 = very tender, and 8 = extremely tender.

[3] Juiciness scale: 1 = extremely dry, 2 = very dry, 3 = moderately dry, 4 = slightly dry, 5 = slightly juicy, 6 = moderately juicy, 7 = very juice, and 8 = extremely juicy.

[4] Pork Flavor scale: 1 = extremely bland, 2 = very bland, 3 = moderately bland, 4 = slightly bland, 5 = slightly intense, 6 = moderately intense, 7 = very intense, and 8 = extremely intense.

[5] Connective tissue and off flavor intensity scale: 1 = abundant, 2 = moderately abundant, 3 = slightly abundant, 4 = moderate, 5 = slight, 6 = traces, 7 = practically none, and 8 = none.

Table B.5 Effect of DDGS[1] and glycerol on grow-finish pig jowl fat quality[2,3] (Duttlinger, in process)

	0% DDGS			20% DDGS						
	Glycerol, %			Glycerol, %				*P*- value		
Item	0	2.5	5	0	2.5	5	SE	D×G	DDGS	Glycerol
Myristic acid (14:0), %	1.32	1.48	1.46	1.31	1.3	1.35	0.04	0.1	0.005	0.06
Palmitic acid (16:0), %	21.4	22.1	22.14	20.78	20.91	20.89	0.29	0.51	0.0002	0.27
Palmitoleic acid (16:1), %	2.75	3.02	2.97	2.48	2.44	2.46	0.12	0.4	0.0001	0.61
Margaric acid (17:0), %	0.53	0.49	0.56	0.53	0.5	0.53	0.03	0.73	0.63	0.14
Stearic acid (18:0), %	9.3	8.95	9.22	8.93	9.09	8.75	0.26	0.47	0.29	0.88
Oleic acid (18:1c9), %	41.28	42.17	41.21	39.5	40.19	39.99	0.45	0.63	0.0001	0.29
Vaccenic acid (18:1n7), %	3.29	3.6	3.45	2.99	3.03	3.02	0.08	0.28	0.0001	0.13
Linoleic acid (18:2n6), %	14.48	13.04	13.61	18.63	17.04	17.7	0.68	0.99	0.0001	0.11
α-linolenic acid (18:3n3), %	0.71	0.65	0.69	0.73	0.73	0.72	0.73	0.48	0.11	0.64
γ-linolenic acid (18:3n6), %	0.47	0.3	0.36	0.23	0.4	0.33	0.47	0.57	0.68	0.99
Arachidic acid (20:0), %	0.35	0.31	0.36	0.26	0.33	0.29	0.06	0.6	0.35	0.92
Eicosadienoic acid (20:2), %	0.85	0.76	0.79	0.95	0.97	0.97	0.03	0.23	0.0001	0.57
Arachidonic acid (20:4n6), %	0.12	0.12	0.1	0.12	0.12	0.12	0.009	0.22	0.42	0.55
Other fatty acids, %	1.57	1.48	1.52	1.2	1.46	1.37	0.2	0.66	0.28	0.92
Total SFA, %[4]	33.39	33.79	34.22	32.22	32.58	32.25	0.47	0.64	0.0007	0.61
Total MUFA, %[5]	49.15	50.69	49.46	46.55	47.4	47.24	0.5	0.56	0.0001	0.08
Total PUFA, %[6]	17.46	15.52	16.32	21.23	20.02	20.51	0.72	0.88	0.0001	0.11
Total *trans* fatty acids, %[7]	0.61	0.55	0.6	0.41	0.58	0.52	0.13	0.69	0.45	0.9
UFA:SFA ratio[8]	2	1.96	1.93	2.11	2.08	2.11	0.04	0.7	0.0007	0.66
PUFA:SFA ratio[9]	0.53	0.46	0.48	0.66	0.62	0.64	0.03	0.91	0.0001	0.19
Iodine value, g/100 g[10]	70.5	68.6	68.9	74.1	73.3	74	0.88	0.69	0.01	0.33

[1]Dried distillers grain with solubles.

[2]A total of 1,160 pigs (initially 68.4 lb.) were used in a 97-d experiment with 27 to 28 pigs per pen and 7 replications per treatment.

[3]A total of 84 pigs were used for fat sample collection with 2 pigs per pen and 7 replications per treatment.

[4]Total saturated fatty acids = {[C8:0] + [C10:0] + [C12:0] + [C14:0] + [C16:0] + [C17:0] + [C18:0] + [C20:0] + [C22:0] + [C24:0]}, where the brackets indicate concentration.

[5]Total monounsaturated fatty acids = {[C14:1] + [C16:1] + [C18:1c9] + [C18:1n7] + [C20:1] + [C24:1]}, where the brackets indicate concentration.

[6]Total polyunsaturated fatty acids = {[C18:2n6] + [C18:3n3] + [C18:3n6] + [C20:2] + [C20:4n6]}, where the brackets indicate concentration.

[7]Total *trans* fatty acids = {[C18:1t] + [C18:2t] + [C18:3t]}, where the brackets indicate concentration.

[8]UFA:SFA ratio = [Total MUFA + Total PUFA] / Total SFA.

[9]PUFA:SFA ratio = Total PUFA / Total SFA.

[10]Calculated as IV=[C16:1] × 0.95 + [C18:1] × 0.86 + [C18:2] × 1.732 +[C18:3] × 2.616 + [C20:1] × 0.785+[C22:1] × 0.723, where the brackets indicate concentration (AOCS, 1998).

Table B.6 Effect of DDGS[1] and glycerol on grow-finish pig belly fat quality[2,3]

	0% DDGS			20% DDGS						
	Glycerol, %			Glycerol, %				*P* -value		
Item	0	2.5	5	0	2.5	5	SE	D×G	DDGS	Glycerol
Myristic acid (14:0), %	1.32	1.39	1.43	1.26	1.24	1.27	0.04	0.26	0.0002	0.22
Palmitic acid (16:0), %	23.2	23.12	23.62	21.6	21.95	21.57	0.33	0.42	0.0001	0.84
Palmitoleic acid (16:1), %	2.16	2.26	2.37	2.01	1.95	1.93	0.08	0.19	0.0001	0.75
Margaric acid (17:0), %	0.54	0.53	0.57	0.54	0.49	0.55	0.02	0.76	0.3	0.11
Stearic acid (18:0), %	11.81	11.3	11.55	10.32	10.9	10.49	0.35	0.31	0.002	0.98
Oleic acid (18:1c9), %	39.09	39.49	39.21	37.16	38.41	37.84	0.36	0.35	0.0001	0.4
Vaccenic acid (18:1n7), %	2.72	2.83	2.85	2.53	2.51	2.51	0.04	0.32	0.0001	0.59
Linoleic acid (18:2n6), %	14.51	14.08	13.52	19.88	17.86	18.82	0.66	0.42	0.0001	0.16
α-linolenic acid (18:3n3), %	0.65	0.66	0.65	0.72	0.68	0.71	0.03	0.53	0.04	0.9
γ-linolenic acid (18:3n6), %	0.25	0.33	0.29	0.22	0.25	0.29	0.12	0.94	0.67	0.87
Arachidic acid (20:0), %	0.34	0.35	0.36	0.29	0.33	0.32	0.04	0.91	0.25	0.75
Eicosadienoic acid (20:2), %	0.78	0.77	0.75	0.94	0.9	0.98	0.03	0.15	0.0001	0.54
Arachidonic acid (20:4n6), %	0.1	0.12	0.11	0.11	0.1	0.11	0.007	0.2	0.51	0.99
Other fatty acids, %	1.12	1.32	1.28	1.11	1.13	1.21	0.12	0.76	0.37	0.56
Total SFA, %[4]	37.61	37.12	38	34.42	35.3	34.59	0.6	0.38	0.0001	0.9
Total MUFA, %[5]	45.6	46.32	46.12	43.18	44.43	43.91	0.39	0.55	0.0001	0.35
Total PUFA, %[6]	16.79	16.56	15.87	22.4	20.27	21.5	0.72	0.33	0.0001	0.25
Total *trans* fatty acids, %[7]	0.43	0.55	0.52	0.42	0.48	0.51	0.1	0.96	0.72	0.57
UFA:SFA ratio[8]	1.67	1.7	1.63	1.91	1.84	1.9	0.05	0.41	0.0001	0.89
PUFA:SFA ratio[9]	0.45	0.45	0.42	0.65	0.58	0.63	0.03	0.35	0.0001	0.37
Iodine value, g/100 g[10]	66.7	66.8	65.5	73.6	71.5	72.9	1.07	0.4	0.01	0.6

[1]Dried distillers grain with solubles.

[2]A total of 1,160 pigs (initially 68.4 lb.) were used in a 97-d experiment with 27 to 28 pigs per pen and 7 replications per treatment.

[3]A total of 84 pigs were used for fat sample collection with 2 pigs per pen and 7 replications per treatment.

[4]Total saturated fatty acids = {[C8:0] + [C10:0] + [C12:0] + [C14:0] + [C16:0] + [C17:0] + [C18:0] + [C20:0] + [C22:0] + [C24:0]}, where the brackets indicate concentration.

[5]Total monounsaturated fatty acids = {[C14:1] + [C16:1] + [C18:1c9] + [C18:1n7] + [C20:1] + [C24:1]}, where the brackets indicate concentration.

[6]Total polyunsaturated fatty acids = {[C18:2n6] + [C18:3n3] + [C18:3n6] + [C20:2] + [C20:4n6]}, where the brackets indicate

[7]Total *trans* fatty acids = {[C18:1t] + [C18:2t] + [C18:3t]}, where the brackets indicate concentration.

[8]UFA:SFA ratio = [Total MUFA + Total PUFA] / Total SFA.

[9]PUFA:SFA ratio = Total PUFA / Total SFA.

[10]Calculated as IV=[C16:1] × 0.95 + [C18:1] × 0.86 + [C18:2] × 1.732 +[C18:3] × 2.616 + [C20:1] × 0.785+[C22:1] × 0.723, where the brackets indicate concentration (AOCS, 1998).

Table B.7 Effect of DDGS[1] and glycerol on grow-finish pig backfat[2,3] (Duttlinger, in process)

	0% DDGS			20% DDGS						
	Glycerol, %			Glycerol, %				*P* -value		
Item	0	2.5	5	0	2.5	5	SE	D×G	DDGS	Glycerol
Myristic acid (14:0), %	1.36	1.44	1.46	1.31	1.27	1.34	0.04	0.3	0.0006	0.19
Palmitic acid (16:0), %	23.62	23.78	24.54	22.12	22.38	22.4	0.34	0.51	0.0001	0.22
Palmitoleic acid (16:1), %	2.24	2.28	2.36	1.92	1.95	1.95	0.09	0.81	0.0001	0.69
Margaric acid (17:0), %	0.54	0.54	0.57	0.54	0.5	0.54	0.03	0.76	0.34	0.44
Stearic acid (18:0), %	11.97	11.7	12.25	10.86	11.11	10.93	0.38	0.63	0.003	0.87
Oleic acid (18:1c9), %	38.55	39.01	38.89	36.62	37.99	37.23	0.35	0.43	0.0001	0.07
Vaccenic acid (18:1n7), %	2.69	2.78	2.76	2.41	2.46	2.46	0.05	0.95	0.0001	0.41
Linoleic acid (18:2n6), %	14.59	14.1	12.98	19.99	18.03	18.8	0.76	0.44	0.0001	0.16
α-linolenic acid (18:3n3), %	0.65	0.64	0.59	0.7	0.66	0.68	0.03	0.45	0.02	0.37
γ-linolenic acid (18:3n6), %	0.19	0.16	0.17	0.13	0.14	0.16	0.03	0.64	0.29	0.9
Arachidic acid (20:0), %	0.33	0.29	0.31	0.24	0.25	0.25	0.02	0.64	0.003	0.76
Eicosadienoic acid (20:2), %	0.74	0.73	0.68	0.88	0.86	0.89	0.02	0.18	0.0001	0.51
Arachidonic acid (20:4n6),	0.1	0.09	0.09	0.11	0.11	0.09	0.008	0.4	0.21	0.32
Other fatty acids, %	1.13	1.18	1.03	0.96	1.06	1.01	0.06	0.45	0.05	0.25
Total SFA, %[4]	38.24	38.17	39.55	35.44	35.89	35.84	0.66	0.56	0.0001	0.42
Total MUFA, %[5]	44.98	45.6	45.52	42.33	43.85	43.1	0.41	0.53	0.0001	0.05
Total PUFA, %[6]	16.78	16.22	14.93	22.23	20.26	21.06	0.82	0.44	0.0001	0.16
Total *trans* fatty acids, %[7]	0.38	0.4	0.33	0.3	0.37	0.34	0.04	0.52	0.31	0.42
UFA:SFA ratio[8]	1.62	1.62	1.53	1.83	1.8	1.8	0.05	0.63	0.0001	0.46
PUFA:SFA ratio[9]	0.44	0.43	0.38	0.63	0.57	0.59	0.03	0.52	0.0001	0.23
Iodine value, g/100 g[10]	66.1	65.7	63.5	73.1	71	71.8	1.22	0.48	0.01	0.27

[1]Dried distillers grain with solubles.

[2]A total of 1,160 pigs (initially 68.4 lb.) were used in a 97-d experiment with 27 to 28 pigs per pen and 7 replications per treatment.

[3]A total of 84 pigs were used for fat sample collection with 2 pigs per pen and 7 replications per treatment.

[4]Total saturated fatty acids = {[C8:0] + [C10:0] + [C12:0] + [C14:0] + [C16:0] + [C17:0] + [C18:0] + [C20:0] + [C22:0] + [C24:0]}, where the brackets indicate concentration.

[5]Total monounsaturated fatty acids = {[C14:1] + [C16:1] + [C18:1c9] + [C18:1n7] + [C20:1] + [C24:1]}, where the brackets indicate concentration.

[6]Total polyunsaturated fatty acids = {[C18:2n6] + [C18:3n3] + [C18:3n6] + [C20:2] + [C20:4n6]}, where the brackets indicate concentration.

[7]Total *trans* fatty acids = {[C18:1t] + [C18:2t] + [C18:3t]}, where the brackets indicate concentration.

[8]UFA:SFA ratio = [Total MUFA + Total PUFA] / Total SFA.

[9]PUFA:SFA ratio = Total PUFA / Total SFA.

[10]Calculated as IV= [C16:1] × 0.95 + [C18:1] × 0.86 + [C18:2] × 1.732 +[C18:3] × 2.616 + [C20:1] × 0.785+[C22:1] × 0.723, where the brackets indicate concentration (AOCS, 1998).

Table B.8 Effect of DDGS[1] and glycerol on grow-finish loin intramuscular fat quality

	0% DDGS			20% DDGS						
	Glycerol, %			Glycerol, %				*P*- value		
Item	0	2.5	5	0	2.5	5	SE	D x G	DDGS	Glycerol
Myristic acid (14:0), %	1.21	1.25	1.33	1.31	1.27	1.33	0.06	0.72	0.36	0.39
Palmitic acid (16:0), %	22.95	23.16	23.15	22.82	22.96	23.04	0.36	0.99	0.6	0.81
Palmitoleic acid (16:1), %	3.58	3.46	3.52	3.01	3.11	3.21	0.17	0.7	0.005	0.88
Margaric acid (17:0), %	0.71	0.59	0.57	0.52	0.51	0.51	0.08	0.61	0.07	0.54
Stearic acid (18:0), %	12.86	12.94	12.96	13.04	12.65	12.76	0.24	0.58	0.6	0.79
Oleic acid (18:1n9t), %	0.27	0.25	0.24	0.37	0.28	0.28	0.05	0.77	0.14	0.33
Oleic acid (18:1n9c), %	36.02	35.65	35.47	34.79	35.41	34.93	0.90	0.84	0.36	0.93
Vaccenic acid (18:1n7), %	4.43	4.08	4.58	4.16	4.02	3.79	0.24	0.31	0.06	0.58
Linoleic acid (18:2n6), %	13.50	14.30	13.80	15.55	15.59	15.58	1.02	0.92	0.04	0.91
α-linolenic acid (18:3n3), %	0.29	0.31	0.31	0.30	0.31	0.30	0.02	0.61	0.97	0.52
Arachidic acid (20:0), %	0.72	0.71	0.69	0.69	0.72	0.69	0.03	0.79	0.85	0.76
Eicosadienoic acid (20:2), %	0.41	0.41	0.40	0.49	0.48	0.49	0.03	0.91	0.0004	0.96
Arachidonic acid (20:4n6), %	0.14	0.15	0.14	0.19	0.13	0.11	0.03	0.31	0.9	0.47
Total SFA, %[2]	38.81	38.94	39.07	38.69	38.35	38.75	0.39	0.82	0.27	0.79
Total MUFA, %[3]	45.60	44.66	45.06	43.72	44.07	43.60	1.00	0.79	0.11	0.93
Total PUFA, %[4]	15.58	16.40	15.87	17.62	17.59	17.66	1.16	0.92	0.07	0.94
Total *trans* fatty acids, %[5]	0.51	0.47	0.47	0.60	0.51	0.50	0.06	0.85	0.29	0.42
UFA:SFA ratio[6]	1.58	1.57	1.56	1.59	1.61	1.58	0.03	0.8	0.25	0.76
PUFA:SFA ratio[7]	0.40	0.42	0.41	0.46	0.46	0.46	0.03	0.96	0.07	0.92
Iodine value, g/100g[8]	64.07	64.71	64.22	65.87	66.40	65.87	1.02	1.0	0.04	0.81

[1]Dried distillers grain with solubles.

[2]Total saturated fatty acids = {[C6:0] + [C8:0] + [C10:0] + [C11:0] + [C12:0] + [C14:0] + [C15:0] + [C16:0] + [C17:0] + [C18:0] + [C20:0] + [C21:0] + [C22:0] + [C24:0]}, where the brackets indicate concentration.

[3]Total monounsaturated fatty acids = {[C14:1] + [C15:1] + [C16:1] + [C17:1] + [C18:1c9] + [C18:1n7] + [C18:1n11] + [C20:1] + [C24:1]}, where the brackets indicate concentration.

[4]Total polyunsaturated fatty acids = {[C18:2n6] + [C18:3n3] + [C18:3n6] + [C20:2] + [C20:3n6] + [C20:4n6] + [C20:5n3] + [C22:5n3] + [C22:6n3]}, where the brackets indicate concentration.

[5]Total *trans* fatty acids = {[C18:1t] + [C18:2t] + [C18:3t]}, where the brackets indicate concentration.

[6]UFA:SFA ratio = [Total MUFA + Total PUFA] / Total SFA.

[7]PUFA:SFA ratio = Total PUFA / Total SFA.

[8]Calculated as IV=[C16:1] × 0.95 + [C18:1] × 0.86 + [C18:2] × 1.732 +[C18:3] × 2.616 + [C20:1] × 0.785+[C22:1] × 0.723, where the brackets indicate concentration (AOCS, 1998).

Appendix C - Sensory Panel Evaluation for Chapter 3

Kansas State University - Sensory Panel Evaluation							
Study: Gipe/Houser Spring 2008							
Name:				Date:		Time:	
SAMPLE	MYOFIBRILLAR TENDERNESS	JUICINESS	PORK FLAVOR INTENSITY	CONNECTIVE TISSUE AMOUNT	OVERALL TENDERNESS	OFF-FLAVOR INTENSITY	OFF-FLAVOR DESCRIPTOR
WU							
A							
B							
C							
D							
E							
F							
	8. Extremely tender 7. Very tender 6. Moderately tender 5. Slightly tender 4. Slightly tough 3. Moderately tough 2. Very tough 1. Extremely tough	8. Extremely juicy 7. Very juicy 6. Moderately juicy 5. Slightly juicy 4. Slighty dry 3. Moderately dry 2. Very dry 1. Extremely dry	8. Extremely intense 7. Very intense 6. Moderately intense 5. Slightly intense 4. Slightly bland 3. Moderately bland 2. Very bland 1. Extremley Bland	8. None 7. Practically none 6. Traces 5. Slight 4. Moderate 3. Slightly abundant 2. Moderately abundant 1. Abundant	8. Extremely tender 7. Very tender 6. Moderately tender 5. Slightly tender 4. Slightly tough 3. Moderately tough 2. Very tough 1. Extremely tough	8. None 7. Practically none 6. Traces 5. Slight 4. Moderate 3. Slightly abundant 2. Moderately abundant 1. Abundant	