RESEARCHREPORT

ANIMAL SCIENCE — Nutritional Efficiency Consortium

Title: Influence of dietary DDGS and glycerol on pork loin and bacon quality – **NPB #07-148**

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Industry Summary:

An important topic of discussion in the pork industry today is the fat quality of pork carcasses. It is well known that low quality fat (soft, oily fat) can have negative effects on the quality attributes of both fresh and processed meat products. For instance, soft fat can cause decreased shelf-life due to greater susceptibility for fat rancidity, greater occurrences of off-flavors, unattractive fat smearing in further processed products like sausage, and less apparent slice definition for sliced, packaged bacon. The primary factors currently being studied that affect pork quality are of dietary origins. With the current high demand for bio-fuels there is an abundant availability of co-products such as dried distillers grains with solubles' (DDGS). In fact, since 2001 the estimated use of DDGS in swine diets has drastically increased to about 3 million metric tons. Due to their abundance and reasonable price the use of DDGS in the swine diet can result in substantial savings in feed costs. However, DDGS contain high levels of unsaturated fats that could result in softer pork carcass fat when fed at high enough levels. In order to improve or maintain the quality of pork fat, researchers have begun to experiment with other ingredients in the swine diet. Glycerol, another bio-fuel co-product, has become a

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research topic to improve pork fat quality. Glycerol has been reported to increase the saturation of pork back fat. Therefore, the goals of this study were to determine the impact of 0 and 20% DDGS and the inclusion of glycerol at levels of 0, 2.5, and 5% in grow-finishing rations on loin and bacon quality, and determine the relationship between belly firmness and slicing yield for commercially produced bacon.

This study was conducted in a commercial swine facility with pigs being fed corn-soybean based diets. 70 days prior to slaughter, 1,160 pigs were randomly assigned to 1 of 6 dietary treatments consisting of 0% DDGS in combination with 0, 2.5, or 5% glycerol or 20% DDGS with 0, 2.5 or 5% glycerol. On day 70, two barrows from each pen were harvested at a commercial harvest facility. After chilling, loins and bellies were removed from the carcass and transported to the Kansas State University Meat Laboratory for evaluation.

Loins were evaluated for purge loss and then fabricated into pork loin chops. Loin chops were analyzed for drip loss, pH, instrumental color, visual color score, marbling score, Warner-Bratzler shear force (WBSF), fatty acid profile, cooking loss, and trained sensory evaluation.

Belly measurements were recorded for thickness, length and belly weight. Belly firmness was measured using what is called a belly bend or "flop" test. In this test a belly is centered across a bar and the length between the two ends is measured. A smaller length indicates that a belly would be softer (or that it would bend to a greater extent).

Bacon was manufactured by first injecting the raw (green) bellies to 12% of their green weight. While processing, green weight, injected weight, and pump% were recorded. After injection, bellies were cooked in a smokehouse to an endpoint temperature of 53^{o}C and subsequently stored at 2^{o}C for 24 hours. After chilling, cooked bellies were weighed and the smokehouse yield was calculated. Bellies were then transported to a commercial bacon manufacturing facility for pressing, slicing, and packaging. After processing, bacon slice yield was calculated, and samples were collected for proximate analysis (% moisture, protein, fat and ash), fatty

acid analysis, and sensory evaluation. During sensory evaluation, bacon slices were evaluated for bacon flavor intensity, brittleness, saltiness, off flavors, and cooking yield.

The addition of glycerol and DDGS to the diet did not appreciably affect any pork loin quality traits with the exception of a minor increase in off-flavor production for the 20% DDGS treatment. This was to be expected as the 20% DDGS treatment also showed an increase in the amount of unsaturation in the intramuscular fat as evidenced by higher calculated iodine values. Feeding glycerol did not affect the saturation level of any of the fatty acids that were tested. However, pigs fed 20% DDGS had higher levels of linoleic acid, eicosadienoic acid, and iodine value indicating that the fat became more unsaturated compared with pigs fed 0% DDGS.

Glycerol and DDGS in combination did not influence belly length, belly thickness, belly firmness, initial weight, green weight, pump percentage, injection weight, cooked weight, smokehouse yield, bacon yield or cooking yield. Feeding DDGS at 20% did not affect belly length, belly thickness, initial weight, or green weight but decreased belly firmness as measured by the belly bend (flop) test. Additionally, 20% DDGS tended to increase pump percentage but did not affect smokehouse yields, slice yield, or bacon cooking yields. Increasing dietary glycerol by 2.5 and 5% tended to increase belly length, but did not affect thickness, belly firmness, initial weight, green weight, injected weight, smokehouse yields, slice yields, or bacon cooking yields. Feeding DDGS at 20% in combination with glycerol or 20% DDGS and glycerol singularly did not affect the proximate composition of bacon slices. Additionally, DDGS and glycerol fed together did not affect fatty acid content. The inclusion of 20% DDGS into diets did not affect the total saturated fatty acid content but increased total monounsaturated and trans-fatty acid content as well as increased unsaturated: saturated and poly-unsaturated: saturated fatty acid ratios, as well as increased iodine values. The inclusion of 2.5 and 5% glycerol showed no effect on fatty acid content. After sensory panel evaluations it was found that DDGS and glycerol together or singularly had no effect on bacon brittleness, bacon flavor intensity, saltiness, or off-flavor development.

Additionally, our results suggest that thicker bellies are correlated with greater smoke house yields, greater slice yields, and firmer bellies. Also, bellies that had larger (firmer) flop skin down scores showed greater smokehouse yields and slice yields.

In summary, feeding DDGS and glycerol in combination or singularly at the levels tested did not practically impact loin quality traits. Feeding 20% DDGS did decrease belly firmness, although, not to a degree that would affect any processing characteristics. Furthermore, our results suggest that the addition of 20% DDGS to finishing swine diets will not be detrimental to sensory components in bacon. Feeding glycerol at 2.5 and 5% of the diet did not positively or negatively affect any fresh belly or bacon characteristic that would increase or decrease the profitability of bacon production. Finally, adding glycerol to the diet 2.5 and 5.0% did not change fatty acid composition of loin intramuscular fat or belly fat.

For more information about the project please contact Terry A. Houser Ph.D., Assistant Professor of Meat Science in the Department of Animal Sciences and Industry at Kansas State University.

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I. Scientific Abstract:

Seventy-seven barrows (PIC genetics; initial BW = 31 kg) were used to evaluate the influence of feeding dried distillers grains with solubles (DDGS) and glycerol for 70-d on pork loin and belly quality attributes. The experiment had a 2 × 3 factorial design with main effects of DDGS (0 or 20%) and glycerol (0, 2.5, or 5%) (n = 7 replications each). Loins and bellies were removed from the left side of the carcass at 24 h postmortem, vacuum packaged, and stored at 4°C. Seven 2.54-cm thick loin muscle (LM) chops were fabricated from each loin on day 10 and were utilized for analysis of percentages of drip and cooking losses, pH, instrumental color (L*a*b*), visual color score, marbling score, Warner-Bratzler shear force (WBSF), fatty acid profile, and trained sensory panels. Bellies were evaluated for initial belly weight, green weight, injected weight, belly cooked weight, pump percentage, belly smokehouse yields, slice yields, belly length, belly thickness, belly flop fat side down, belly flop fat side up, bacon cooking yields, and proximate composition. Trained sensory panelists (n = 7) evaluated LM for myofibrillar tenderness, connective tissue amount, overall tenderness, juiciness, pork flavor and off-flavor intensities. Bacon was evaluated for the sensory traits of brittleness, bacon flavor intensity, saltiness, and off-flavors. Purge, drip, and cooking losses percentages, pH, a* and b* values, visual color and marbling scores, and sensory juiciness and pork flavor intensity scores were not affected (P >

0.05) by inclusion of DDGS or glycerol in the diet for LM chops. Pigs fed 20% DDGS had less tender ($P < 0.05$) chops than LM from pigs fed 0% DDGS. LM from pigs fed 20% DDGS without added glycerol had more ($P < 0.05$) off-flavors than all other treatments. There were no DDGS x glycerol interactions, DDGS, or glycerol main effects on sensory characteristics of brittleness, bacon flavor intensity, saltiness, or off flavors. There were no DDGS x glycerol interactions *(P > 0.44)*, nor glycerol ($P > 0.08$) effects on initial belly weight, green weight, injected weight, belly cooked weight, pump percentage, belly smokehouse yields, slice yields, belly length, belly thickness, belly flop fat side down, belly flop fat side up, bacon cooking yields, or proximate composition. DDGS did not affect any measurements ($P > 0.07$) except for the belly flop fat side down method ($P < 0.04$) which showed a decrease in belly firmness. There were no DDGS x glycerol interactions ($P > 0.05$), nor glycerol main effects on fatty acid content for either the LM IMF or belly samples. LM from pigs fed 20% DDGS had more ($P < 0.05$) linoleic acid, eicosadienoic acid, and higher iodine values than LM samples from pigs fed 0% DDGS. There was less ($P < 0.05$) palmitoleic acid in LM from pigs fed 20% DDGS than those from pigs fed 0% DDGS. Inclusion of 20% DDGS decreased ($P < 0.01$) myristic acid, palmitic acid, palmitoleic acid in belly samples compared with 0% DDGS. Adding 20% DDGS increased ($P < 0.01$) stearic acid, oleic acid, vaccenic acid, linoleic acid, α-linolenic acid, eicosadienoic acid, total monounsaturated fatty acids ($P < 0.01$), total trans fatty acids, unsaturated: saturated fatty acid ratios, polyunsaturated: saturated fatty acid ratios, and iodine values in belly samples. Thicker bellies correlated with greater smoke house yields ($R > 0.54$), greater slice yields ($R > 0.52$), and firmer bellies ($R > 0.94$). Bellies that had larger (firmer) flop skin down scores were correlated with greater smokehouse yields ($R > 0.67$) and slice yields ($R > 0.60$). It is notable that the belly flop skin side up method did not significantly ($P < 0.05$) correlate with any of the data collected throughout this study. Pork producers with growing and finishing operations can make effective use of economical DDGS and glycerol from the ethanol and biodiesel industries with minimal or no reduction in pork loin or belly/bacon quality at levels tested.

Keywords: dried distillers grains with solubles, fatty acids, glycerol, off-flavor, palatability, pork quality, tenderness, bacon

II. 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. Distillers grain production is forecast to increase from 11 million tons in 2005 to 40 million tons in 2009 (Tokgoz and others 2007). This has presented new challenges to pork producers due to cost constraints of traditional feedstuffs and limited inclusion rates of co-products due to their unique chemical properties. For example DDGS have an oil content of roughly 10% which is primarily made up of highly unsaturated fatty acids. Monogastrics such as swine and poultry will assimilate subcutaneous, intermuscular and intramuscular fat with a fatty-acid profile similar to that of their diet. Therefore the result of feeding highly unsaturated fatty acids will result in softer, less oxidatively stable adipose tissue. While limited research has revealed that feeding increased levels of dried distillers grains with solubles (DDGS) to swine resulted in softer bellies (Latour and others 2007 and Whitney

and others 2006) a complete characterization of the effects of this increased unsaturation on the palatability, processing yields, and value for processors has not been reported. Furthermore, glycerol (a co-product of bio-diesel manufacturing) has been reported to increase the degree of lipid saturation and firmness of backfat in pigs fed either tallow or rapeseed oil (Mourot and others 1994).

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 and others 2006, determined that feeding 0, 10, and 20% DDGS did not affect color, firmness, marbling, shear force, and ultimate pH. It was concluded by the 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 taste panels to determine the extent of flavor changes that may have occurred. It is common knowledge that 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). Given the fact that lipid components were becoming more unsaturated as evidenced by a higher iodine value (Whitney and others 2006) it is highly likely that flavor changes did occur and merit further investigation.

One of the most popular cuts of pork and one of the largest profit centers for pork processors is bacon manufacturing. In fact, it is estimated that sales of refrigerated bacon items were $1.99 billion U.S. dollars in 2006 (Meatingplace 2007). Bacon is commercially produced by injecting curing solution into raw pork bellies with subsequent heating/smoking and slicing for retail sale. There are no data available that illustrates the effects of DDGS with and without dietary glycerol on commercial bacon manufacturing. Therefore, it is essential to determine the implications of feeding swine various levels of DDGS with and without glycerol as it relates to pork quality of loins and bellies as it relates to bacon production.

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III. Objectives:

1. Determine the impact of 0 and 20% DDGS and increasing levels of glycerol (0, 2.5, and 5.0%) in grow-finishing rations on loin and bacon quality.

2. Determine the relationship between belly firmness and slicing yield for commercially produced bacon.

3. Determine the relationship between loin and belly fatty acid composition from the Tokach study and sensory analysis.

IV. Materials and Methods:

Animals and housing

Procedures used in this experiment were approved by the Institutional Animal Care and Use Committee at Kansas State University (2453). Pigs were fed at a commercial swine facility in Southwest Minnesota. 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, had slatted floors, and each pen was equipped with a four-hole dry self feeder and one cup-style waterer. 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 (n = 23-24 pigs per pen) per treatment.

Dietary treatments and feeding

Pigs were fed corn and soybean meal based experimental diets (Table 1) in meal form across 4 phases. The treatments were arranged in a 2 × 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 allowed *ad libitum* access to feed and water throughout the experiment.

Loin evaluation

At 70-d into the study the two heaviest barrows (n = 84) were visually selected, removed, individually tattooed, and transported to a commercial swine harvest facility (JBS Swift,, 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 (≤ 0.6-cm) from the left side of each carcass. Loins (n = 77 recovered) were numbered, vacuum packaged, boxed, transported and stored at Kansas State University Meat Laboratory at 1-2°C. At 10-d postmortem, loins were evaluated for purge loss, drip loss, visual color, marbling score, and instrumental color.

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 × [(initial loin weight – packaging weight – final loin weight) / (initial loin weight – packaging weight)].

Loins were fabricated into 2.54-cm thick LM chops and were allowed to bloom 1 h prior to taking subjective and instrumental color measurements. Color measurements were taken on a cross section of the LM located at the center loin region immediately posterior to the *spinalis dorsi* muscle. Instrumental color was measured using a HunterLab Miniscan^{TM} XE Plus Spectrophotometer (Model 45/0 LAV, 2.54-cm-diameter aperture, 10° standard observer, Illuminant A; Hunter Associated Laboratories Inc.; Reston, VA) and L*

(lightness), a* (redness), b* (yellowness) value were recorded. Subjective color and marbling were evaluated using color and marbling standards developed for the National Pork Producers Council (NPPC, 1999).

Drip loss was measured utilizing a single 2.54-cm thick LM 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 h. After 24 h, 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].

During fabrication, six 2.54-cm thick LM chops were individually vacuum packaged and frozen (-40°C) for later pH, Warner-Bratzler Shear Force (WBSF), cooking loss, sensory evaluation, and fatty acid profile (FAP) analysis. LM 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).

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].

Loin sensory analysis

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, forced-air 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 6 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). 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.

Frozen LM chops used for sensory analysis were thawed at 0-2°C for approximately 12 h and cooked using the WBSF procedures. 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 (n = 7 LM chops per session maximum). There were no more than 2 sessions per day. A trained (AMSA, 1995) sensory panel (n = 7) evaluated chops on an 8-point scale for myofibrillar tenderness, connective tissue amount, overall tenderness, juiciness, pork flavor intensity, 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.

Loin and bacon fatty acid analysis

A modified gas chromatography procedure of Sukhija and Palmquist (1988) was used for fatty acid profile (FAP) analysis of intramuscular fat (IMF). A single 2.54-cm thick LM chop from each loin was trimmed of all external fat and used for FAP analysis. Given the high degree of variability within a belly, fatty

acid samples were taken from the cooked belly after slicing. The samples used for fatty acid composition were a composite sample made up of every 10^{th} slice of the belly beginning from the caudal end. Both the loin and belly samples were frozen in liquid nitrogen, pulverized using a tabletop blender (model 33BL79; Waring Products, New Hartford, CT), and analyzed for LM FAP. 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 in IMF. 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).

Fresh belly analysis

Initial belly weight (belly with skin on) was measured. Belly length was measured from flank end to blade end. Thickness was measured (skin side down) at eight locations on the belly modified from a method by Scramlin et al., (2008). Four different measurement points were taken along the ventral and dorsal edges of each belly. Firmness was measured by centering the belly skin side up and skin side down (Larsen et al. 2009) on a 42" long bell shaped stainless steel smoke stick that ran perpendicular to the length of the belly and taking measurements from skin edge to skin edge on the ventral and dorsal edges of the belly. Bellies were allowed to set on the bar one minute before measurements were taken. Before data collection bellies were held in a cooler 24 h at -1.1^{o}C. At the time of analysis belly temperatures were measured at an average temperature of -0.25^{o}C with a range of -1.3 to 0.4^{o}C.

Belly Processing

Bellies were skinned using a Townsend 900 Series Pork Skinner (Townsend Eng., Des Moines, IA., U.S.A) and injected with a multineedle pump injector (Model N30 Wolftec Inc., Werther, Germany) at 12% of

the green weight. Pickle consisted of 78.25% water, 13% salt, 4.2% sugar, 2.5% neutral pH sodium phosphate (Brifisol®450 Super; Bk Giulini Corp., Sim Valley, CA. U.S.A), 0.10% sodium nitrite, and 0.45% sodium erythorbate. All bellies were weighed before and after injection, and hung on smokehouse trucks for two h before cooking in a smokehouse (D7752 Mauer Inc., Reichenau, Germany). Pump % was calculated for all bellies using the following formula: ((pumped weight-green weight)/green weight) x100). The final endpoint temperature was 53^{o}C and upon completion of thermal cycles where immediately stored in a cooler at 2^{o}C to chill for 24 h.

After chilling, cooked bellies were weighed, and the smokehouse yield of all the bellies was calculated ((cooked weight/green weight) x100). Bellies were placed in vacuum package bags, placed in coolers and transferred to Jenning's Premium Meats (JPM) in New Franklin, Missouri for further processing. At JPM the cured and smoked slab bacon was pressed with an ANCO Model 1111 bacon press (ANCO Slicing Technologies., Chicago, IL, U.S.A), sliced with an ANCO Model 827 bacon slicer (ANCO Slicing Technologies., Chicago, IL, U.S.A) to a width of 4-mm, vacuum packaged with a Koch Ultravac Model 2100 vacuum packaging machine (Koch Equipment., Kansas City, MO, U.S.A) and then placed back into coolers and transported to the Kansas State University meat lab. At the time of slicing, belly temperatures were measured at -3.3^{o}C.

Bacon quality analysis

Bacon slice yield was calculated by weighing the bacon, removing the less valuable (# 2 or # 3 slices) then weighing the remaining #1 slices and multiplying by 100. To meet the requirements for # 1 slices, the bacon strips had to have the M. *cutaneous trunci* extending more than 50% of the width of the bacon slice and the thickness no less than 1.9 cm. Bacon qualifying for # 2 slices did not meet the thickness requirement or did not meet the proper M. *cutaneous trunci* length (Person et al., 2005). All other bacon slices not meeting the two previously mentioned requirements was classified as # 3 slices. Slices that fall in the #3 category are generally ends and pieces from cranial and caudal ends of the belly (White et al., 2008).

Bacon proximate composition

After slice yield measurements were taken, every 10th slice beginning from the caudal end were collected for proximate analysis. All bacon slices were cut into smaller pieces and a composite sample was frozen in liquid nitrogen, pulverized in a blender (Model 33Bl79, Waring Products, New Hartford, CT., U.S.A) and analyzed at the Kansas State University Analytical lab. Protein (AOAC 990.03), moisture, fat (AOAC PVM-1:2003) and ash content (AOAC 942.05) were measured.

Bacon sensory analysis

After slice yield calculation, 10 bacon slices were removed from the belly at a point one-third the length of the belly from the cranial end for sensory analysis. Bacon was placed on cooking racks in a Blodgett dual-air-flow oven set at 176^{o}C. Slices were cooked for five min on each side, and after cooking were blotted with paper towels to remove excess grease (Waylan et al., 2003). The bacon samples were cut into sub slices and the end portions were discarded in favor of more uniform bacon slices. Before sensory panels began, all panelists participated in orientation sessions designed to acclimate panelists to ranking the different categories. A minimum of eight panelists were used for each session of sensory evaluation. For each session there were seven samples provided for evaluation. One "warm up" sample was provided to allow for discussion on what would be a good response for that warm up sample. After the "warm up," sample and discussion, samples from each of the six treatments were randomly given to panelists. Panelists were individually placed in a booth with a combination of red and green light (<107.64 lumens) and were required to consume a piece of apple, a piece of cracker, and water between each bacon sample to clear their palates. The "warm up" sample was manufactured by the KSU meat lab for the panelists to discuss and "calibrate" their scores based on the group's response. After the warm up discussion, the six treatment samples were served. The panelists were asked to evaluate brittleness, bacon flavor intensity, saltiness, and off flavors. Sensory categories were reported using an eight point scale modified from the descriptive attributes found in the AMSA guidelines for Sensory, Physical and Chemical Measurements of Bacon (Olson et al., 1985). Brittleness 1 = extremely soft, 2 = very soft, 3 =

moderately soft, 4 = slightly soft, 5 = slightly crisp, 6 = moderately crisp, 7 = very crisp, and 8 = extreme crisp. Bacon flavor intensity category 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. Saltiness was ranked as 1 = extremely un-salty, 2 = very un-salty, 3 = moderately un-salty, 4 = slightly un-salty, 5 = slightly salty, 6 = moderately salty, 7 = very salty, and 8 = extremely salty. Off flavor was ranked as 1 = extremely intense, 2 = very intense, 3 = moderately intense, 4 = slightly intense, 5 = slight, and 6 = traces, 7 = practically none, and 8 = none.

Bacon cooking yield

After collecting slices for composition and sensory analysis, 10 additional bacon slices were removed from the belly at a point one-third the length of the belly from the cranial end. Of the 10 slices collected from each belly, six bacon slices were randomly selected to be cooked. Pre-cooked weights were recorded via an Explorer Pro scales model EP2102C (Ohaus Corporation Pine Brook, NJ., U.S.A) and were placed on cooking racks in a Blodgett dual-air-flow oven set at 176^{o}C. Slices were cooked for five min on each side, and after cooking were blotted with paper towels to remove excess grease, and cooking yield was calculated ((cooked weight/raw weight) x100).

Statistical analysis

The experimental design was a 2 × 3 factorial. Loin quality data were analyzed as a completely randomized block design using the general linear model procedure (PROC GLM) of SAS (SAS Institute, Inc.; Cary, NC) with pen serving as the experimental unit. Belly and bacon data was analyzed by using the PROC GLM, and PROC CORR procedures of SAS (2007). Fixed effects were DDGS treatment, glycerol treatment, and DDGS by glycerol treatment. Homogeneity of the variance was verified using the UNIVARIATE procedure of SAS. The residual vs. the predicted plot procedure was used to analyze data for outliers (greater than 2× the SD. Treatment means were calculated using the LSMEANS statement in PROC GLM. An α-level of 0.05 was used to assess significance among means. Fatty acid data were analyzed using the same design

using the mixed-model procedure (PROC MIXED) of SAS (SAS Institute, Inc.; Cary, NC) with pen serving as the experimental unit. Homogeneity of the variance and the analysis for outliers were performed as described for loin quality. Treatment means were calculated using the LSMEANS statement in PROC MIXED. An α-level of 0.05 was used to assess significance among means.

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Table 1. Diet compositions (as-fed basis)

	0 % DDGS[1]			20% DDGS[1]		
	Glycerol, %			Glycerol, %		
Ingredient, %	0%	2.5%	5%	0%	2.5%	5%
	Phase 1[3]					
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	5.0	---	2.5	5.0
DDGS	---	---	---	20.0	20.0	20.0
Choice white grease	3.0	3.0	3.0	3.0	3.0	3.0
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[2]	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-Methioine	0.01	0.02	0.02	---	---	---
Total	100	100	100	100	100	100
	Phase 2[4]					
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	5.0	---	2.5	5.0
DDGS	---	---	---	20.0	20.0	20.0
Choice white grease	3.0	3.0	3.0	3.0	3.0	3.0
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[2]	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
			Phase 3[5]			
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	5.0	---	2.5	5.0
DDGS	---	---	---	20.0	20.0	20.0
Choice white grease	3.0	3.0	3.0	3.0	3.0	3.0
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[2]	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
			Phase 4[6]			
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	5.0	---	2.5	5.0
DDGS	---	---	---	20.0	20.0	20.0
Choice white grease	3.0	3.0	3.0	3.0	3.0	3.0
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

[1]Dried Distillers Grains with Solubles

[2]Provided per 0.2 kg of diet: 227 phytase unit (FTU) of phytase

[3]Phase 1 - Fed from 31 to 54 kg

[4]Phase 2 - Fed from 54 to 77 kg

[5]Phase 3 - Fed from 77 to 100 kg

[6]Phase 4 - Fed from 100 to 124 kg

V. Results

Objective 1.

Loin Quality

No treatment differences ($P \geq 0.13$) were found for pH, purge, drip, or cook loss (Table 2). No treatment differences ($P \geq 0.13$) were found for visual color, marbling score, a* values, or b* values (Table 2). However, chops from pigs fed 5.0% glycerol had ($P < 0.05$) higher (lighter) L* values than chops from pigs fed 2.5% glycerol and chops from pigs fed 0% glycerol had intermediate L* values (Table 2). LM from pigs fed 20% DDGS had ($P < 0.05$) higher (tougher) WBSF than chops from pigs fed 0% DDGS (Table 2). There was also a trend for chops from pigs fed 2.5% glycerol to have ($P = 0.06$) higher (less tender) WBSF than chops from pigs fed either 0% or 5% glycerol. This may be due to more connective tissue as found by sensory panelists. There were DDGS main effect differences for myofibrillar tenderness, connective tissue amount, and overall tenderness (Table 2). LM from pigs fed 20% DDGS had ($P < 0.05$) lower (less tender) sensory panel scores for myofibrillar tenderness, connective tissue, and overall tenderness than chops from pigs fed 0% DDGS. In a DDGS × 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). Off-flavors descriptors from taste panelists includes rancid, stale, and oxidative.

Table 2. Main effects of DDGS[1] and glycerol on pork loin quality characteristics

	DDGS				Glycerol				
Trait	0%	20%	SE	*P* =	0%	2.5%	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]	2.0	2.0	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
Warner-Bratzler shear force, kg	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	7.5	0.06	0.04	7.4	7.6	7.6	0.08	0.11

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

[1]Dried Distillers Grains with Solubles.

[2]2 = grayish pink, 3 = reddish pink, 4 = dark reddish pink (NPPC, 1999)

[3]Greater values lighter

[4]Greater values redder

[5]Greater values yellower

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

[8]4 = slightly tough, 5 = slightly tender, 6 = moderately tender, 7= very tender, 8 = extremely tender

[9]6= traces, 7 = practically none, 8 = none

[10]4 = slightly dry, 5 = slightly juicy, 6 = moderately juicy

[11]4 = slightly bland, 5 = slightly intense, 6 = moderately intense

Table 3. Effect of DDGS[1] and glycerol on pork LM 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]1 = abundant, 2 = moderately abundant, 3 = slightly abundant, 4 = moderate, 5 = slight, 6 = traces, 7 = practically none, 8 = none

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

Belly/bacon processing characteristics

There were no DDGS x glycerol interactions or glycerol main effects ($P > 0.05$) for belly length, belly thickness, belly flop skin side down, belly flop skin side up, initial belly weight, or green weight (Table 4). There were no significant DDGS effects (Table 5) on belly length ($P > 0.22$), belly thickness ($P > 0.68$), initial belly weight ($P > 0.76$), or green weight ($P > 0.37$). Inclusion of 20% DDGS did decrease belly firmness by the belly flop skin side down measurement ($P < 0.04$), and tended to reduce belly firmness with the belly flop skin side up method ($P > 0.07$). There were no DDGS x glycerol interactions on belly pump percentage ($P > 0.05$), belly injection weight, belly cooked weight, smokehouse yield, #1 type bacon slice yield weight, #1 type bacon slice yield, or bacon cooking yields (Table 4). There were no ($P > 0.05$) DDGS x glycerol interactions, DDGS main effects or glycerol main effects for moisture, protein, fat, or ash (Table 6).

Table 4. Effects of DDGS and glycerol on belly processing characteristics

	0% DDGS			20% DDGS						
	Glycerol %			Glycerol %				*P*=		
Belly Characteristics	0	2.5	5	0	2.5	5	SE	DxG	DDGS	Gly
Belly Length, cm	68.3	69.8	70.1	67.7	69.2	69.0	0.76	0.91	0.22	0.08
Belly Thickness, cm	3.1	3.061	3.03	3.11	3.06	3.11	0.07	0.81	0.68	0.71
Flop skin down, cm	19.0	17.9	19.2	17.6	16.4	17.6	0.86	0.99	0.04	0.28
Flop skin up, cm	16.49	15.42	16.36	15.25	14.79	15.30	0.63	0.89	0.07	0.41
Initial weight, kg	8.08	7.92	7.82	7.85	7.91	8.00	0.44	0.71	0.76	0.87
Green weight, kg	6.79	6.60	6.56	6.48	6.52	6.53	0.43	0.74	0.37	0.88
Pump %	10.54	10.34	10.15	10.77	10.59	11.01	0.27	0.44	0.06	0.79
Injected weight, kg	7.51	7.28	7.23	7.18	7.21	7.25	0.48	0.71	0.48	0.86
Belly cooked weight, kg	6.81	6.61	6.58	6.51	6.56	6.56	0.46	0.77	0.48	0.90
Smokehouse yield, %	100.1	100.1	100.2	100.5	100.5	100.5	0.37	0.94	0.26	0.98
Slice Yield Weight, g	10.9	10.5	10.3	10.3	10.1	10.1	0.38	0.89	0.18	0.56
#1 Bacon Slice Yield, %	72.2	72.3	70.9	71.8	69.5	69.7	1.25	0.64	0.16	0.37
Bacon cooking yields, %	32.1	33.8	34.0	33.6	33.6	33.5	1.31	0.69	0.78	0.73

Table 5. Effects of DDGS on fresh belly characteristics

Belly Characteristics	0% DDGS	20% DDGS	SE	*P*=
Belly length, cm	69.40	68.62	0.44	0.22
Belly thickness, cm	3.07	3.09	0.04	0.68
Flop skin down, cm	18.70	17.23	0.50	0.04
Flop skin up, cm	16.09	15.12	0.37	0.07
Initial weight, kg	7.94	7.89	0.25	0.76
Green weight, kg	6.65	6.51	0.25	0.37

Table 6. Effects of DDGS and glycerol on proximate composition of bacon

	0 % DDGS			20% DDGS						
	Glycerol %			Glycerol %			*P*=			
	0	2.5	5	0	2.5	5	SE	DxG	DDGS	Glycerol
Moisture, %	39.71	41.3	41.03	43.53	41.33	43.49	1.36	0.38	0.07	0.78
Protein, %	13.72	12.81	12.84	14.15	13.14	13.31	0.51	0.99	0.34	0.13
Fat, %	43.19	43.82	44.42	40.06	43.51	41.05	1.94	0.68	0.16	0.58
Ash, %	3.53	2.08	2.09	2.33	2.17	2.14	0.58	0.40	0.42	0.32

Objective 2.

Upon further statistical analysis using the PROC CORR function of SAS, it was found that adding 20% DDGS (Table 7) related to higher #1 bacon slice yields. DDGS did not have any significant correlations with any sensory characteristics or with fatty acid composition with this study. Higher levels of glycerol had strong positive correlations (R > 0.75) with initial belly weight, green weight, injected weight, and smokehouse yield. Glycerol also did not have any strong correlations with any sensory characteristics or with fatty acid composition.

Table 7. DDGS & Glycerol correlations

Correlation	Item	R-Value[1]
DDGS	% #1 Bacon yield	0.54
Glycerol	Initial weight	0.98
Glycerol	Green weight	0.98
Glycerol	Injected weight	0.97
Glycerol	Smoke house yield	0.75

[1]All R-values are significant P < 0.05.

Initial belly weights were positively correlated with glycerol (Table 8), green weight, injected weight, and smokehouse yield. Green weight showed an increase with glycerol, initial weight, injected weight, a greater pump percentage and smokehouse yield pump percentage. This is to be expected as larger initial and

green weights would show a greater amount of yield out of the smokehouse. Larger injection weights showed a positive correlation with glycerol, initial weight, green weight, a higher pump %, greater smokehouse yields, and longer bellies. A greater pump percentage was positively correlated with higher green and injected weights, an increase in belly cooked weight and longer bellies. This is also to be expected as longer and larger bellies would allow more tissue to inject into essentially due to the greater surface area, creating a higher pump % meaning more water that is cooked off in the smokehouse thus creating greater smokehouse yields. Smokehouse yields were positively correlated with the addition of glycerol, initial weights, green weights injected weights, slice yields and firmer bellies. Higher slice yields correlated with greater smoke house yields, lower #1 bacon yields, thicker bellies and firmer bellies. A longer belly length correlated in a higher injection weight, a larger pump % but a shorter belly length was negatively correlated with # 1 bacon yields. Thicker bellies correlated with greater smoke house yields, greater slice yields, and firmer bellies. Bellies that had larger (firmer) flop skin down scores showed greater smokehouse yields, and slice yields. It is notable that the belly flop skin side up method did not significantly correlate with any of the data collected throughout this study.

Table 8. Belly processing characteristic correlations

Correlation	Item	R-Value[1]
Initial belly weight	Green weight	1.00
Initial belly weight	Injected weight	0.99
Initial belly weight	Smoke house yield	0.81
Green weight	Injected weight	0.99
Green weight	Smoke house yield	0.81
Green weight	Pump %	0.51
Injected weight	Pump %	0.58
Injected weight	Smoke house yield	0.81
Injected weight	Belly length	0.50
Pump %	Belly cooked weight	0.57

Pump %	Belly length	0.87
Smokehouse yield	Slice yield	0.71
Smokehouse yield	Flop skin down	0.67
Slice yield	% # 1 Bacon yield	-0.50
Slice yield	Belly thickness	0.52
Slice yield	Flop Skin down	0.60
Belly length	% # 1 Bacon yield	-0.50
Belly thickness	Smoke house yield	0.54
Belly thickness	Flop skin down	0.94

[1]All R-values are significant $P < 0.05$

Objective 3.

As mentioned previously in Objective #1, there was a DDGS × 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). Off-flavors descriptors from taste panelists includes rancid, stale, and oxidative.

The fatty acid profile (FAP) of LM IMF was unaffected by the addition of glycerol to the diet, however DDGS did affect the FAP. The FAP of LM IMF from pigs fed 20% DDGS indicated increased ($P < 0.05$) linoleic acid, eicosadienoic acid, and calculated iodine value compared with pigs fed 0% DDGS (Table 9). 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 ($P \leq 0.07$) for decreased margaric and vaccenic acids for pigs fed 20% DDGS compared with pigs fed 0% DDGS. Moreover, there was a trend ($P \leq 0.07$) for increased total PUFA and the ratio of PUFA to SFA.

Table 9. Main effect of DDGS[1] and glycerol on fatty acid profile of pork loin intramuscular fat

	DDGS				Glycerol				
Fatty Acid	0%	20%	SE	*P* =	0%	2.5%	5%	SE	*P* =
Palmitoleic acid (C16:1), %	3.5	3.1	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	15.6	0.58	0.04	14.5	14.9	14.7	0.72	0.91
Eicosadienoic avid (C20:2), %	0.4	0.5	0.01	< 0.01	0.5	0.4	0.4	0.02	0.96
Total SFA, %[2]	38.9	38.6	0.22	0.27	38.7	38.6	38.9	0.28	0.79
Total MUFA, %[3]	45.1	43.8	0.57	0.11	44.7	44.4	44.3	0.71	0.93
Total PUFA, %[4]	15.9	17.6	0.65	0.08	16.6	17.0	16.8	0.81	0.94
UFA:SFA[5]	1.6	1.6	0.01	0.25	1.6	1.6	1.6	0.02	0.76
PUFA: SFA[6]	0.4	0.5	0.02	0.07	0.4	0.4	0.4	0.02	0.92
Iodine value, g/100g[7]	64.3	66.0	0.57	0.04	65.0	65.6	65.0	0.71	0.81

[1]Dried Distillers Grains with Solubles

[2]Total SFA = [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]

[3]Total MUFA = [C14:1] = [C15:1] + [C16:1] + [C17:1] + [C18:1c9] + [C18:1n7] + [C18:1n11] + [C20:1] + [C24:1]

[4]Total PUFA = [C18:2n6] + [C18:3n3] + [C18:3n6] + [C20:2] + [C20:3n6] + [C20:4n6] + [C20:5n3] + [C22:5n3] + [C22:6n3]

[5][Total MUFA + Total PUFA] / Total SFA

[6]Total PUFA / Total SFA

[7]Calcuated 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)

During sensory panels there was no DDGS x glycerol interaction effects, DDGS main effects, or glycerol main effects ($P > 0.05$) on bacon brittleness, bacon flavor intensity, saltiness, and off flavor (Table 10).

Table 10. Effects of DDGS and glycerol on bacon sensory characteristics

	0% DDGS			20% DDGS						
	Glycerol %			Glycerol %					*P*=	
Sensory characteristic	0	2.5	5	0	2.5	5	SE	DxG	DDGS	Glycerol
Brittleness[1]	5.33	5.27	4.91	5.60	5.03	5.21	0.26	0.52	0.62	0.28
Bacon Flavor Intensity[2]	6.22	5.68	5.70	5.67	5.68	5.66	0.20	0.31	0.24	0.32
Saltiness[3]	5.72	5.64	5.73	5.67	5.78	5.74	0.10	0.62	0.66	0.94
Off Flavor[4]	7.80	7.72	7.77	7.42	7.64	7.57	0.16	0.65	0.10	0.90

[1]Brittleness 1 = Extremely soft, 2 = Very soft, 3 = Moderately soft, 4 = Slightly soft, 5 = Slightly crisp, 6 = Moderately crisp, 7 = Very crisp, and 8 = Extremely crisp.

[2]Bacon flavor intensity category 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

[3]Saltiness was ranked as 1 = Extremely un-salty, 2 = Very un-salty, 3 = Moderately un-salty, 4 = Slightly un-salty, 5 = Slightly salty, 6 = Moderately salty, 7 = Very salty, and 8 = Extremely salty.

[4]Off flavor was ranked as 1 = Extremely intense, 2 = Very intense, 3 = Moderately intense, 4 = Slightly intense, 5 = Slight, and 6 = Traces, 7 = Practically none, and 8 = None.

There were no DDGS x glycerol interaction effects or glycerol main effects on FAP for belly samples (Table 11). Inclusion of DDGS at 20% decreased ($P < 0.01$) myristic acid, palmitic acid ($P < 0.01$), palmitoleic acid ($P < 0.01$), did not change margaric acid ($P > 0.68$), increased stearic acid ($P < 0.01$), oleic acid ($P < 0.01$), vaccenic acid ($P < 0.01$), linoleic acid ($P < 0.01$), α-linolenic acid ($P < 0.01$), increased arachidic acid ($P > 0.06$), and eicosadienoic acid ($P < 0.01$), did not alter arachidonic acid ($P > 0.33$), other fatty acids ($P > 0.16$), or total saturated fatty acids ($P > 0.29$), increased total monounsaturated fatty acids ($P < 0.01$), did not change total polyunsaturated fatty acids ($P > 0.77$), increased total trans-fatty acids ($P < 0.01$), unsaturated: saturated fatty acid ratios ($P < 0.01$), polyunsaturated: saturated fatty acid ratios ($P < 0.01$), and iodine values ($P < 0.01$).

Table 11. Effects of DDGS and glycerol on belly fatty acid composition

	0% DDGS			20% DDGS						
	Glycerol			Glycerol					*P*=	
Item	0	2.5	5	0	2.5	5	SE	DxG	DDGS	Glycerol
Myristic acid (14:0),%	1.39	1.50	1.52	1.37	1.34	1.38	0.01	0.13	0.01	0.13
Palmitic acid (16:0), %	23.91	24.09	24.61	22.61	22.70	22.68	0.01	0.53	0.01	0.45
Palmitoleic acid (16:1),%	2.56	2.69	2.81	2.32	2.30	2.26	0.01	0.35	0.01	0.67
Margaric acid (17:0),%	0.47	0.47	0.48	0.47	0.42	0.50	0.01	0.40	0.68	0.13
Stearic acid (18:0), %	11.90	11.49	11.76	10.87	10.90	10.84	0.01	0.73	0.01	0.82
Oleic acid (18:1c9),%	39.81	39.96	39.87	37.82	38.88	38.33	0.01	0.50	0.01	0.30
Vaccenic acid (18:1n7),%	3.31	3.38	3.46	3.02	3.06	3.04	0.01	0.67	0.01	0.48
Linoleic acid (18:2n6),%	12.72	12.50	11.63	17.54	16.38	16.84	0.01	0.54	0.01	0.33
α- Linolenic acid (18:3n3),%	0.55	0.55	0.52	0.62	0.60	0.61	0.01	0.45	0.01	0.58
Arachidic acid (20:0), %	0.23	0.22	0.21	0.21	0.19	0.20	0.01	0.89	0.06	0.49
Eicosadienoic acid (20:2),%	0.67	0.65	0.61	0.80	0.78	0.82	0.01	0.13	0.01	0.62
Arachidonic acid (20:4n6),%	0.09	0.09	0.09	0.10	0.10	0.09	0.01	0.38	0.33	0.31
Other fatty acids, %	2.40	2.41	2.43	2.26	2.35	2.40	0.01	0.68	0.16	0.41
Total SFA, %[1]	38.16	38.04	38.86	35.76	35.80	35.85	0.01	0.34	0.29	0.33
Total MUFA,%[2]	46.60	46.95	47.04	44.02	45.13	44.56	0.01	0.67	0.01	0.28
Total PUFA, %[3]	13.60	13.36	12.44	18.56	17.39	17.87	0.01	0.35	0.77	0.40
Total trans fatty acids, %[4]	56.84	56.84	55.95	59.45	59.39	59.28	0.01	0.69	0.01	0.50
UFA:SFA ratio[5]	1.58	1.59	1.53	1.76	1.75	1.74	0.35	0.80	0.01	0.64
PUFA:SFA ratio[6]	0.36	0.35	0.32	0.52	0.49	0.50	0.13	0.65	0.01	0.40
Iodine value, g/100g[7]	64.21	64.13	62.65	70.52	69.42	69.71	0.02	0.63	0.01	0.45

[1]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.

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

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

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

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

[6]PUFA:SFA = Total PUFA/ Total SFA.

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

Increasing brittleness scores (crispier bacon scores) during sensory panels were correlated with greater smoke house yield, greater slice yields, greater bacon flavor intensity and a higher percentage of palmitic acid (Table 12). Saltiness (less salty) scores during sensory panels correlated to a cooking yield increase. This can be explained as loss of cooking yield could result in a more concentrated salt content. Furthermore, saltiness scores (Table 12) were linked to an increase in myristic acid, but a decrease in Total MUFAs, PUFAs, TFAs, unsaturated: saturated fatty acid ratios, and polyunsaturated: saturated fatty acid ratios. Higher off flavor scores (no off flavors) were linked to a higher percentage of myristic, palmitic, and oleic acids but negatively associated with total PUFA percentages. This should be expected as a higher PUFA content is more susceptible to lipid oxidation than saturated fatty acids (Table 12).

Table 12. Sensory characteristic correlations

Correlation	Item	R-Value[1]
Brittleness	Smoke house yield	0.57
Brittleness	Slice yield	0.52
Brittleness	Bacon flavor intensity	0.80
Brittleness	Palmitic acid	0.50
Saltiness	Bacon cooking yields	-0.81
Saltiness	Myristic acid	0.64
Saltiness	Other fatty acids	0.65
Saltiness	Total MUFA	-0.60
Saltiness	Total PUFA	-0.64
Saltiness	Total TFA	-0.66
Saltiness	UFA:SFA	-0.64
Saltiness	PUFA:SFA	-0.65

Off flavor	Myristic acid	0.70
Off flavor	Palmitic acid	0.74
Off flavor	Oleic acid	0.69
Off flavor	Total PUFA	-0.56

[1]All R-values are significant $P < 0.05$.

VI. Discussion

Feeding DDGS and glycerol did not have an effect on most pork quality traits evaluated. LM from pigs fed 2.5% glycerol were lighter colored (higher L*) than LM from pigs fed 5% glycerol. Feeding pigs 20% DDGS resulted in statistically ($P < 0.05$) 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. However, the increases in both toughness and off-flavors previously mentioned are not of practical significance in our opinion. There were increases in PUFA in LM IMF for pigs fed 20% DDGS compared with pigs fed 0% DDGS which would explain the difference in off-flavor production and could be of concern if higher levels of DDGS are used in the diet. Despite some significant differences due to feeding DDGS and glycerol, there will be minimal negative affects in practical pork production on loin quality. To reduce off-flavor development in pork from pigs fed DDGS, glycerol could be incorporated into the diet. Finally, glycerol does not change FAP in IMF. Therefore, if it is economical, 20% DDGS and 5% glycerol can be added to swine growing-finishing diets as an energy source with minimal influence on pork LM quality.

Feeding pigs 2.5 or 5% glycerol with or without DDGS in the diet did not change any belly processing characteristic, belly fatty acid composition, nor sensory panelist's perception of bacon. Additionally, prior reports have shown that including DDGS in swine diets at a level of 20% or more will decrease belly firmness due to an increasing concentration of unsaturated fatty acids. In this study the only belly characteristic that DDGS affected was the firmness of bellies that were measured fat side down. Even though there was a decrease in belly firmness with 20% DDGS, this did not affect belly yields or slicing yields compared with controls. Adding 20% DDGS to the diet did result in measurable differences in several fatty acids in the belly

samples resulting in higher iodine values indicating a more unsaturated fat. In this study it was thought that by adding glycerol into swine diets, that it would increase the fat saturation of pork bellies. Glycerol by itself, or in combination with DDGS, did not alter belly quality or fatty acid composition. It may be that a higher amount of glycerol over 5% could be added to counter act the unsaturated fatty acid concentration related to DDGS. It may also be that higher levels of DDGS need to be fed to illicit a response from feeding 2.5-5.0% glycerol.

In summary, feeding DDGS and glycerol in combination or singularly at the levels tested did not practically impact loin quality traits. Feeding 20% DDGS did decrease belly firmness, although, not to a degree that would affect any processing characteristics that were measured in this study. Furthermore, our results suggest that the addition of 20% DDGS to finishing swine diets will not be detrimental to sensory components in bacon. Feeding glycerol at 2.5 and 5% of the diet did not positively or negatively affect any fresh belly or bacon characteristic that would increase or decrease the profitability of bacon production. Finally, adding glycerol to the diet 2.5 and 5.0% did not change fatty acid composition of loin intramuscular fat or belly fat.