INFLUENCE OF DIETARY DRIED DISTILLERS GRAINS AND GLYCEROL ON BACON QUALITY

by

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Abstract

The objectives of this study were to determine the impact of 0 and 20% dried distillers grains with soluble (DDGS) and increasing levels of glycerol (0, 2.5 and 5%) in grow-finishing rations on bacon quality and to determine the relationship between belly firmness and slicing yield for commercially produced bacon. A total of 84 barrows (PIC, initially 31.03 kg) were fed corn-soybean meal-based diets organized in a 2 x 3 factorial with primary effects of DDGS (0 or 20%) and glycerol (0, 2.5, or 5%) as fed. Belly length was measured from flank end to blade end. Belly thickness was measured at eight locations evenly spaced around the perimeter of the belly. Belly firmness was measured by centering bellies perpendicularly (skin side up and skin side down) over a stainless steel smokestick and measuring the flex between the edges on the ventral and dorsal edges of the belly. Bellies were injected at 12% of the skinned belly weight resulting in a final concentration of 1.74% salt, 0.5% sugar, 0.3% sodium phosphate, 120 ppm sodium nitrite, and 500 ppm sodium erythorbate in the bellies. Bellies were cooked to an internal temperature of 53^{o}C, chilled, pressed and sliced for evaluation. Belly slice yield was calculated by determining the yield of #1 type bacon slices. Proximate analysis and fatty acid analysis were evaluated by taking every 10th bacon slice beginning from the caudal end to make a composite sample for each belly. Iodine value was calculated using the resulting fatty acid content results. Twenty bacon slices were removed from the belly one-third the length of the belly from the cranial end for sensory analysis and cooking yields. Sensory characteristics were evaluated on an 8-point scale for brittleness, bacon flavor intensity, saltiness and off-flavor. There were no significant DDGS x glycerol interactions on any parameters measured ($P > 0.08$). Inclusion of 20% DDGS in pig diets decreased belly firmness ($P < 0.04$) as measured by the belly flop fat side down method. Twenty percent DDGS decreased the percentage of myristic acid, palmitic acid, palmitoleic acid, stearic acid, oleic acid, vaccenic acid, total saturated fatty acids, and total monounsaturated fatty acids ($P < 0.01$). In contrast, 20% DDGS increased the percentage of linoleic acid, α-linolenic acid, eicosadienoic acid, total polyunsaturated fatty acids and decreased unsaturated: saturated fatty acid ratios, polyunsaturated: saturated fatty acid ratios, and iodine values ($P < 0.01$). Statistical correlation analysis of belly processing characteristics showed that by increasing belly weight there will be an increase in smokehouse yields (R = 0.81), increasing smokehouse yields will increase slice yield (R = 0.71), increasing belly thickness results in firmer bellies (R = 0.94) and increasing belly firmness will increase slice yields (R = 0.60). Fatty acid content did not correlate with any belly processing characteristic ($R < 0.50$). Iodine values were highly correlated with Total MUFA (R = 0.83) Total PUFA (R = 0.79), Total TFA (R = 0.75), and UFA: SFA ratio, and PUFA: SFA ratios (R = 0.83). The inclusion of 0, 2.5 and 5% glycerol in swine diets did not affect any measured parameters in this study. In conclusion, feeding DDGS at a level of 20% decreased belly firmness and changed the fatty acid profile; however, it did not affect belly processing or sensory characteristics. Glycerol fed at 2.5 or 5.0% did not affect belly quality, fatty acid profile, or sensory characteristics of bacon.

Key words: bacon, belly quality, dried distillers grains, glycerol, pork

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This thesis is dedicated to Andy and Sarah Teesdale. Without Andy and Sarah's support, I would have abandoned my path a long time ago.

CHAPTER 1 - INTRODUCTION

The high demand for biofuel has led to increased availability of feed co-products from ethanol manufacturing. Dried distillers grains with solubles (DDGS) is an example of a co-product manufactured during the production of biofuels. Dried distillers grains with soluble remain after ethanol is removed from fermented corn mash and contains high levels of nutrients when compared to corn (Saunders and Rosentrater 2009). Furthermore, DDGS contain high levels of unsaturated fatty acids which have been shown to cause finishing pigs fed DDGS to have a lower percentage of saturated fat resulting in softer bellies (Shackelford et al., 1990). This is especially important as bellies have become one of the most valuable pork products domestically. Soft bellies are believed to cause poor slicing yields for meat processors, while consumers will see problems with separation and cohesiveness of bacon products, as well as reduced shelf life for products (Apple et al., 2007).

In order to make firmer bellies, researchers have begun investigating the effect other dietary ingredients, such as glycerol; have on belly firmness when supplemented into finisher pig rations. Glycerol in its crude form is produced as a by-product of the biodiesel process via transesterification of fat (Schieck et al., 2009). Prior research has shown that feeding glycerol to pigs can alter levels of fat saturation in pork carcasses (Duttlinger et al, 2008; Mourot et al., 1994). Therefore, combining glycerol with DDGS in swine diets could improve belly firmness. Thus, the objective of this study was to investigate the effect of dietary glycerol and DDGS on length and thickness of fresh bellies, belly firmness, smokehouse and slice yields, bacon cooking yields, sensory characteristics of bacon, and fatty acid content in belly fat.

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CHAPTER 2 - REVIEW OF LITERATURE

History of Bacon

"Etymologically, the word bacon means meat from the back of an animal," (Ayto 1993). The word bacon originates from the Germanic base of "bak," which coincidently is also the source of the English word back. Bakkon, in the Germanic language migrated to the Frankish "bako" before being borrowed by the French to be used in the form as we know it today, "bacon." Eventually the English language acquired bacon sometime in the twelfth century. The word bacon was originally used as a substitute name for the term "flitch," which described a side of cured pig meat. In sixteenth-century England, bacon gained new names in "rasher" and "streaky" (Ayto 1993). In this era however, bacon was a term applied to cured meat in general as well as fresh pork. It was not until the seventeenth century that using bacon as a substitute for fresh pork died out. Another name for bacon in the early centuries was collop, which also referred to a rasher of salt bacon before becoming the term for sliced meat (Davidson 2006).

Bacon has been featured quite prominently throughout the history of man. Historically it has been recognized that the first wild boars where domesticated in Egypt 10,000 B.C. and in Europe about 7,000 B.C. (Alcock 2006). During those times, pigs were generally regarded as the most useful type of livestock because it was possible to consume most of the animal. Pigs could produce two litters a year, each litter consisting of many piglets, and were easy to keep because they would eat almost anything. These traits made it easy for explorers to travel with pigs as Hernando de Soto brought with him the first pigs to North America when he landed near what is now known as Tampa Bay, Florida (Pruess 2006). Eventually, pigs escaped from the settlers and the natives started eating pigs. The natives liked pork so much they eventually started attacking de Soto to steal pigs. The economic ease of raising pigs in comparison to other species of livestock has continued throughout history within multiple societies and countries. In fact, smoked bacon was a prominent food source on the Mayflower during the trip to the new world in 1620 (Alcock 2006).

Salt plays a critical role in building bacon popularity due to its use in preserving meat. Empires were made on salt; to an extent that in the Roman Empire salt made up a part of a man's wages (Alcock 2006). Salt was naturally used to preserve pork bellies, thus leading to bacon as we know it today as the salt impurities such as sodium nitrate would cause curing chemical reactions. Though it is unclear where the concept of salting meat originated, it is believed that ancient Sumerian civilizations dating to the fourth and third millenniums B.C. were likely the source of curing (Pegg et al., 2006). Included in literature as early as 1542, bacon was described by the English monk and physician Andrew Boorde as healthy for carters and plowmen, and that collopes and eggs made for a wholesome meal (Trager 1995).

Bacon not only is a good food source but can be used as a spice to add flavor to bland dishes. This was especially apparent as authors such as James Trager described the use of bacon in flavoring meals for royalty in the middle ages. During the late 1800's in the U.S., southerners ate mostly bacon and corn bread with the rare fruit and vegetable (Pruess 2006). This was partially due to the emancipation of slaves under the 13th amendment who started poor and lived predominately on bacon along with any food stuff they could hunt and gather. In fact, bacon became a coveted food source for pioneers exploring the west as well as for soldiers on both sides of the civil war (Pruess 2006). Bacon was also a staple in British diets, during the First World War when food rationing programs where implemented. While fresh meat was rationed by price, bacon was separated into its own category and rationed separately from other meat products. Bacon rations were quickly raised from eight to 16 ounces per week after the war began. During the Second World War, bacon showed its continued popularity as it was the first meat product to be rationed. The Danes even bred a new breed of pig, the landrace to meet British demands for bacon (Trager 1995). According to Alan Davidson, the "possession of a couple of flitches of bacon did more for domestic harmony than fifty thousand Methodist sermons and religious tracts. The sight of them upon the rack tends more to keep a man from stealing than whole volumes of penal statutes."

Even in the U.S., there is no denying the popularity of bacon; in fact the Imperial Packaging Co. changed its name to the Beech-Nut Packing Corp. to reflect the popularity of their bacon which was smoked using beech nuts. The owner of this company, Walter Lipe, even named his daughter (Roseanne Bacon Lipe) after his products. Bacon was so popular that it was at the forefront of innovation as pre-sliced bacon was introduced by Oscar Mayer in 1924. Not only was Oscar Mayer one of the first to produce convenience foods, but also began experimenting with packaging as they shingled bacon slices, wrapped them in cellophane and placed them in a cardboard frame, which is an idea that Oscar Mayer still holds the patent for (Lauer 2009).

Despite centuries of popularity, criticism of bacon came in 1977 when it was discovered that carcinogenic compounds known as nitrosamines could be formed in bacon. Nitrosamines are formed when nitrites combined with amines under high heat conditions (Trager 1995). This however, has not readily damaged the popularity of bacon as it is still a popular food product to this day, as bacon is often mentioned in popular media. Bacon has been used in comedy bits by comedians such as Conan O'Brien and mentioned repeatedly in the hit cartoon series the "Simpsons," and the popular television series "The Office." Bacon was mentioned by several poets and even included into Craig Morgan's hit country song "Little Bit of Life." Doing an online search of bacon yields many fan pages and blogs dedicated to recipes. Multiple books such as “Bacon, a Love Story: A Salty Survey of Everybody’s Favorite,” are available that are solely dedicated to bacon. All in all, one would be hard pressed to find another single food type that exceeds bacon in the amount of media exhibition that it receives.

Curing Process

There are two main ingredients for curing: salt and sodium nitrite (NO_2). To go hand in hand with the Egyptians being the first to domesticate pigs, they were also recognized as one of the first civilizations to use salting and drying as methods to preserve meat (Pearson 1984). The salt application was vastly different than what is used today because salt was added in high concentrations to reduce water activity, thereby inhibiting bacterial growth and extending the shelf life and suitability of the product (Aberle et al., 2001). Today, it is commonly recognized that salt is generally not included at levels over 2.5% (Cassens 1994). Currently, federal regulations state that sodium nitrite should be limited to120 ppm ingoing into bacon products (CFR 1984).

By accident, it was found that salt impurities such as sodium nitrate could cause a pink cured color and a distinctive cured flavor in muscle tissue. Sodium nitrate is converted to sodium nitrite which is responsible for the cured color. The pigment responsible for the cured pink color is nitrosylmyoglobin and when heated forms nitrosylhemochromogen. Nitrosylhemochromogen is formed via the occupation of the sixth ligand of the heme iron complex by nitric oxide (Aberle et al., 2001). Nitric oxide is formed from the sodium nitrite in the curing mixture. Though there are many chemical pathways for the production of nitric oxide, there are only three mechanisms that will be mentioned (Table 2.1). One of these pathways relates to the conversion of nitrous acid (HNO_2) to nitric oxide (NO), nitric acid (HNO_3) and water (H_20). The second chemical pathway is the reduction of sodium nitrite (NO_2) by native reductants found in meat tissue. The last chemical reaction is the abatement of nitrite (NO_2) by adding reduction promoters like ascorbate and /or erythorbate (Sebranek and Fox 1985).

Table 2.1 Generation of Nitric Oxide

(Sebranek & Fox 1985)

1. $HNO_2 \longrightarrow HNO_3 + NO + H_2O$
2. NO_2^- + Endogenous reductants $\longrightarrow$ NO
3. NO_2^- + Ascorbate or Erythorbate $\longrightarrow$ NO

The majority of nitric oxide production produced in cured meat products occurs in pathways where native reductants and added reductive agents are present, because in order to produce nitrous acid, a strong acid environment is required. The concentration of nitrosylmyoglobin is directly related to the intensity of the cured color. Addition of sodium nitrite beyond what is needed to cause the curing reaction will not increase cured color intensity of bacon or other cured meat products (Pegg and Shahidi 2000). Nitrosylhemochromogen is a heat stable pigment and will not change color with additional cooking. However, nitrosylhemochromogen is able to fade in the presence of excess oxygen and light (Pegg and Shahidi 2000). Fading due to light is a process that begins with nitric oxide dissociating from heme groups, which is catalyzed by photo oxidation. Following this, nitric oxide and the heme groups are oxidized by oxygen. A brownish-gray color is then formed on the exterior of cured products and is referred to as hemichrome (Aberle et al., 2001).

Sodium nitrite is the most important factor for flavor development in bacon as it is responsible for the unique flavor. Therefore, it is recognized that all that is required to make an acceptable bacon product is sodium nitrite and sodium chloride (Pegg and Shahidi 2000). Pegg and Shahidi (2000) acknowledge that the role of nitrite in cured meat flavor and the chemical changes involved are complex and not well understood. It has been shown that there is a linear relationship between taste panel scores of bacon flavor to the logarithm of the nitrite concentrations in curing brines (MacDougal et al, 1975). It is understood that a minimum of 50 ppm of nitrite are required to develop a satisfactory cured-meat flavor (Sebranek 2009). Pegg and Shahidi (2006) also state that other flavor factors like salt, sugar, and smoke also play roles in creating acceptable flavors. Equally important to flavor is the flavor stability as lipid oxidation will cause off flavors. The main factor for flavor stability is the antioxidant capability of nitrite. The iron in the heme is immobilized which inhibits catalytic activity thus prohibiting lipid oxidation potential. Nitric oxide also serves as a free radical acceptor that stops free radical chain reactions that produce oxidation (Aberle et al., 2001).

Bacon Processing Methods and Ingredients

Dry Curing

The first and oldest process for meat curing is dry curing, which traditionally is used with bacon or ham products. With this process, a mixture of salt, sodium nitrate or sodium nitrite, and other spices are uniformly applied to the exposed cut surface of the meat. After the spice application, the meat is stored in a cool room for curing. The curing mixture will be solubilized by the moisture contained in the muscle tissue, allowing the slow penetration into the meat at a rate of 2.5 cm/week (Pegg and Shahidi 2006). This method requires several salt applications, making this a long, labor intensive process. Another drawback with this method is that thicker pieces of meat will take longer in the production cycle, therefore taking up more production space. After curing, the leftover cure on the surface is rinsed off and the salt is allowed to equilibrate via diffusion (Pegg and Shahidi 2006). Currently, this process is generally used only for country cured hams, bacon products and European style cured ham products.

Brine Curing

Another process for curing is called brine curing. In this method, the curing ingredients and seasonings that are water soluble are mixed with water to make the brine solution. Not all brines are created equal as the strength of the pickle is determined by the levels of salt added. This is measured in degrees via a salometer at a particular temperature (usually 40^{o}F/4.4^{o}C). The presence of other ingredients such as sugars, phosphates, nitrite and sodium erythorbate can also affect the salometer reading. In general, brine strength will range from 60^{o} to 70^{o} with 70^{o} being the most common brine saturation (Pegg and Shahidi 2006). Within the brine curing process, there are several different application processes bacon manufactures can use. The raw bellies can simply be placed in a container that is filled with the brine, which is called a cover pickle. With a cover pickle the ingredients will infiltrate the muscle fibers much quicker than a dry curing process. A big disadvantage with this method is the capacity for microbial growth and spoilage. Despite the presence of salt and product refrigeration, microbial growth will still occur as there is a high water activity in the pickling environment. Another major disadvantage to this process is that it is a slow process taking several days for the bacon to fully cure and takes up a lot of space as the turnover rate of these products is low (Pegg and Shahidi 2006).

Needle Injection

Another way to apply the brine solution to bacon products is by needle injection. The first method developed to inject curing solutions into meat via a single needle was discovered late in the 19^{th} century. This vastly decreased the curing time of bacon but was later perfected by the invention of a multi-needle injection system. Multiple needle injection systems allowed for faster bacon processing. In this system conveyor belts carry bellies under a cache of balanced equally spaced needles, while injecting curing solution into many channels throughout the belly. Injection systems typically use a 70^{o} (70% saturation) brine strength. In addition to faster processing time multiple needle injection systems offer several other advantages such as: improved product yields and reduced production costs (Pegg and Shahidi 2006). Tiger striping, the possibility of metal shards and larger initial cost mark the disadvantages of needle injection processing.

Belly Tumbling

An additional processing method that is used in bacon processing is tumbling. While not a required step in bacon processing, tumbling provides several advantages to the process. Tumbling is a process whereby mechanical action acts on muscle fibers. The force on the muscle fibers makes cellular membranes more porous allowing for faster brine assimilation. In the current day and age, most tumbling units are equipped with the ability to pull a vacuum. By pulling a vacuum, the muscle fibers are pulled apart thereby allowing more efficient brine absorption into the muscle fibers (Pegg and Shahidi 2006). This process allows for increased brine pickup as well as greater protein extraction. Also, pulling a vacuum can fix color problems by providing more uniform color as the cure is more evenly dispersed in the muscle tissue (Aberle et al., 2001). A small disadvantage is the increased production time needed for tumbling processes.

Modern Commercial Bacon Processing

The code of federal regulations states that the standard of identity for bacon is that the weight of cured pork bellies ready for slicing and labeling as bacon shall not exceed the weight of the fresh uncured pork bellies (CFR 1984). For modern day processing the Food Standards and Labeling Policy Book describes how bacon can be labeled. In general, the term “bacon” describes the cured belly of a pig carcass. Bacon products intended for further cooking that are intended to be labeled “roasted,” or “partially cooked,” are required to be cooked to 64^{o}C.

However, there are many types of bacon products. For example, canned pasteurized bacon is a shelf stable item that has to have a 7% or greater brine concentration. Pre-fried canned bacon must have a Moisture/Salt-protein (M/SP = Moisture/ (Salt x Protein)) index of 0.4 or more, with a Brine ratio (Brine ratio = Moisture/Salt) of 9.0 or less, a brine concentration of 10% or more (Brine concentration = Salt/(Moisture+ Salt), and a maximum yield of 40%. Cooked bacon cannot yield more than 40% (60% shrink). Pre-cooked bacon is allowed to use Butylated hyroxyanisole (BHA) and Butylated hydroxytolunene (BHT) at 0.01% individually or 0.02% in combination. A Bacon-like product is a category that requires these products to meet the same cooking requirements for bacon products.

Currently, most commercial bacon operations brine-cure bellies via injection. After injection, bellies are affixed to a bacon comb and hung in a smokehouse. Bellies are then stored in a cooler while nitrite reactions take place forming the characteristic cured color. Curing times can vary and there is no definite amount of time that bacon must be held to allow curing reactions to occur. However, if the bellies are not held long enough, bleached out cured coloring will occur in the bacon. In general, there are no set smokehouse schedules for cooking/smoking of bacon as different processors will use different cooking cycles. However, it is common for processors to use multi temperature/stage cooking with the goal of an internal temperature of 52.2^{o} to 55.5^{o}C or single temperature program targeting 54.4^{o} to 60^{o}C (Pearson and Tauber 1984**).** A smoking stage can also be included in all or part of the cooking schedule depending on processor designs or desires. While cooking bacon, relative humidity should be kept within a range of 25-40%. After cooking, bellies are stored in tempering coolers with the goal of reducing internal temperature to -3.3 to -2.2^{o}C. After the tempering stage, bellies are pressed and sliced. By reducing the internal temperature to -3.3 to -2.2^{o}C, bellies will retain their shape when pressed. Pressing the bellies allows greater uniformity and higher slicing yields. Bellies will be sliced by high-speed slicers and the resulting pieces will be mechanically shingled for ease of packaging. Slices are commonly cut at three different thicknesses: Thick (3.17 mm), regular (1.59) and thin (0.79 mm). Thin slices are also known as hotel or restaurant sliced. After slicing, bacon is usually packaged in some type of vacuum package to extend shelf life (Pearson and Tauber 1984).

Processing Ingredients

As mentioned earlier, salt and sodium nitrites are essential ingredients for bacon production, but there are other ingredients commonly used in combination with salt and nitrites. Sugar is used in curing recipes to compensate for harsh flavors that come from the high salt concentrations. Even though salt levels have decreased, thereby lowering the importance of sugar as a flavoring ingredient, sugar has other helpful functions. Depending on the type of sugar, sugar can affect the color of bacon. Due to the heating process, sugar can cause browning via maillard browning reactions. Browning can also occur if there is a large amount of reducing sugar as burning during cooking can occur. Sugar can also serve as an energy source for microbes that would reduce nitrates to nitrites (Cassens 1994).

Cure accelerators are also common ingredients used in curing formulations. Ascorbic acid, sodium erythorbate and citric acid are examples of cure accelerators. These compounds accelerate the curing process by inducing nitrous acid to form NO resulting in a more uniform cure color. These compounds can induce nitrous acid to form nitric oxide. Any leftover cure accelerators after curing reactions will have antioxidant effects (Cassens 1994). The FSIS Directive Processing Inspectors calculations handbook states that any cure accelerator (generally sodium ascorbate and sodium erythorbate) can only be included at a level of 550 ppm into bacon products (USDA 1996).

Phosphates are common ingredients in bacon production and are limited by the USDA to 0.5% for residuals in finished products (Pearson and Tauber 1984). Phosphates come in different forms such as sodium tripolyphosphates and sodium polyphosphates. Phosphates work as a water binding ingredient as it raises the meat pH allowing for increased water binding and increased yields. Despite its advantages, sodium phosphates in general have some drawbacks as they have a low solubility in water and if used in excess can cause metallic/soapy flavors. Phosphates could also have preservative effects by retarding oxidative rancidity development (Cassens 1994). Phosphates work as antioxidants by chelating metal ions preventing the initiation of oxidation.

Smoking can also be viewed as an ingredient in bacon production. The smoking process provides chemicals that can help preserve bacon. Smoke is highly complex and can contain over 300 different compounds (Pearson and Tauber 1984). Acids, phenols, carbonyls, alcohols and polycyclic hydrocarbons are all compounds that are found in smoke vapor. Smoke composition can vary depending on the wood source, temperature of combustion, and the amount of oxygen available during combustion. The phenol compounds contained in the smoke vapor provide bacteriostatic effects, serve as an antioxidant, and help to provide the smoky flavor. The carbonyls will also provide smoke flavor and help give an attractive mahogany brown color (Cassens 1994). Acids will coagulate the surface proteins making a physical barrier or “skin” to bacteria as well as making a more acidic environment that will challenge the growth of bacteria (Pearson and Tauber 1984). Microbial counts on the surface of bacon would be lowered in part from the heat that could accompany the smoking process and in part due to the bacteriostatic effects of components from the phenols and acids in the smoke (Cassens 1994). Maillard browning reactions occur on the surface of bacon making attractive mahogany brown colors. Carbonyls present in the smoke react with free amino groups of the meat proteins to form Maillard products. To get desired color, it is important to balance smoke density, air velocity and humidity during smoking cycles. To maximize the Maillard browning reaction, it is important to control the humidity on the surface of the bacon. Too much moisture will cause color to run making unattractive splotches or dark muddy colors (color defects) on belly surfaces. Smoke is negatively charged allowing it to stick to the positively charged water molecules. If there are large spots of moisture on the surface, the smoke will adhere causing darker unattractive splotches. Maximum color development will occur with a surface moisture content of 12-15% (Pearson and Tauber 1984).

Bacon Quality

There are no quality grades separating bacon into different price categories. Processors in the past, would grade bacon usually by weight of each individual green belly. These grades would typically manifest in different brand names and prices (Pearson and Tauber 1984). In the mid 1970's researches such as Jabaay et al. (1975) and Smith et al. (1975) explored factors affecting the desirability of bacon to consumers. It was found that even though there were no quality grades for bacon, consumers still discriminated against some bacon products based on individual visual evaluation criteria. Due to these consumer demands, the U.S.D.A changed federal regulations requiring processors to package bacon in transparent packaging (USDA 1972). In these transparent packages, the bacon should be displayed in such a way that the consumer can see 70% of a representative slice of bacon (Smith et al., 1975). These consumer demands began investigations into what consumers deemed quality bacon. Jabaay et al. (1975)

reported that as bacon became fatter consumer panelists preference scores decreased with uncooked bacon. Furthermore, Jabaay et al. (1975) reported that the desirability of bacon slices changed depending on the anatomical source of the bacon from the belly. This was due to the difference in muscle to fat ratios from cranial, medial and caudal regions. As Jabaay et al. (1975) reported, consumers desired leaner bacon; this gave rise to a bacon classification system based on slice dimensions and lean characteristics. The bacon ranking system described by Person et al. (2005) is divided into three classifications: type #1, #2, and #3 slices. Type #1 bacon slices will have the M. cutaneous trunci extending greater than 50% the length of bacon slice and its profile be no less than 1.9 cm in thickness. Type #2 bacon slices would have a profile thickness no less than 1.9 cm or would have the M. cutaneous trunci not extending greater than 50% of the length of the bacon slice. Type #3 bacon slices are slices that do not meet any of the previously mentioned characteristics. Pieces falling into the type #3 category generally come from the shoulder or ham ends and are generally described as "ends and pieces" (Person et al., 2005). Outside of this grading system, there has been an increasing amount of research on belly firmness as a means to evaluate bacon quality. Soft bellies result in poor slicing yields, unattractive products and will cause separation and shelf life problems in processed bacon products (Apple et al., 2007).

Fat Composition

In bacon production there are concerns with lipid composition as poor lipid composition (unsaturated fatty acid content) will result in soft bellies contributing to poor sliceability, decreased belly yields and poor shelf stability of packaged bacon (Larsen et al., 2009). Good fat quality is described as firm and white while poor fat quality is identified as soft, oily, wet, grey and/or floppy (Hugo and Roodt 2007; Wood 1984). The chemical composition of belly fat is the driving factor behind fat quality. In pork fat there are three basic types of fat based on saturation levels. The first being saturated fatty acids (SFAS), followed by monounsaturated fatty acids (MUFAS), and polyunsaturated fatty acids (PUFAS) (Hugo and Roodt 2007). The structure of fat will determine the processing characteristics as the saturation of fat determines the melting point of the fat. Each fatty acid will contain strings of carbon atoms (2-24+) with a carboxyl functional group on the end. Fats that are highly saturated will have a higher melting point than fats that are highly unsaturated. As the fatty acid becomes more unsaturated, more hydrogen is displaced due to carbon-carbon double bonds. Table 2.2 lists fatty acids found in pork fat. During bacon production, the length of processing and temperature of the room could affect belly quality as lower melting points would see bellies becoming very soft. This would cause shattering or tearing when the bellies are sliced, and would be more susceptible to lipid oxidation as the unsaturated carbon chains would be more susceptible to oxygen interaction.

Table 2.2 List of Common Fatty Acids in Pork Fat

Fatty Acid	Common Name	Type	Approximate Occurrence
C14:0	Myristic	Saturated	1-4%
C16:0	Palmitic	Saturated	20-30%
C16:1	Palmitoleic	Monounsaturated	2-6%
C18:0	Stearic	Saturated	5-12%
C18:1	Oleic	Monounsaturated	35-45%
C18:2	Linoleic	Polyunsaturated	8-25%
C18:3	Linolenic	Polyunsaturated	0.20-1.5%

Currently, the most popular way to quantify the level of unsaturated fats in the pork industry, is to obtain the iodine value (IV) of the fat. The principle of this test is that iodine will bind to the double bonds within the fat. If there are more double bonds, more iodine will be bonded to the fatty acid. Saturated fat (firmer fat) will have a lower IV compared to softer fat because there are fewer double bonds to absorb the iodine. Iodine values in pork fat will typically be between 60 and 100 (Hansen 2001). U.S. pork processors, such as Smithfield, have set the IV threshold at 78 while the Danish pork industry has set their threshold ≤ 70 (Boyd et al., 1997; Hansen 2001). IV is commonly derived by analyzing fatty acids via gas chromatography and the IV calculated using the following equation (AOAC 1997): IV = (C16:1*0.95)+(C18:1*0.86)+(C18:2*1.73)+(C18:3*2.62)+(C20:1*0.79). There are numerous factors affecting fat composition including diet, level of fatness, age, body weight, gender, breed, and fat location.

Adipose Tissue Development

Fat develops from the storage of lipids in adipocytes. Fat is composed mostly of adipocytes, which are composed of adipoblasts that fill up with lipids to form adipocytes. Mammals have two types of adipose tissue: brown and white adipose tissue. Brown adipose tissue is present in mammalian newborns and provides heat to critical organs to maintain body functions and is usually used up in the first several days of life. Brown adipose tissue will not be discussed as newborn pigs do not possess this type of fat (Mersmann and Smith 2004). White adipose tissue (WAT) is an energy depot that provides energy in lieu of food but also serves to insulate the animal in cold environments and protects internal organs. In some regards, WAT acts as an endocrine organ as it produces many chemicals such as leptin, which diminishes feed consumption (Gregoire 2001). WAT can also serve to regulate immunity via inflammatory reactions (Gregoire 2001). Growth of fat is caused by the growth of adipocytes via hypertrophy and hyperplasia. When adipocytes are immature, water takes up 95% of the volume of the adipocyte. However, maturing cells will displace water with lipid storage.

Adipocytes originate from multipotent mesenchymal cells which come from the embryonic mesoderm (Mersmann and Smith 2004). The mesenchymal cells will differentiate into either fibroblasts or adipoblasts. Adipoblasts are precursors to adipocytes as adipoblasts will fill with lipid, forming a small fat cell that with the proper adipogenic signals will grow into a mature adipocyte. Structurally, adipoblasts are < 20 µM in diameter but mature adipocytes can get as large as 300 µM. However, if no adipogenic signal is received, then there will be spontaneous delipidation forming an adipoblast once again (Mersmann and Smith 2004**)**. Adipocytes are not capable of dividing; therefore the only way to increase adipose tissue is by hyperplasia of preadipocytes. With the required transcription factor stimulus, CCAAT- enhancer binding protein alpha (C/EBPα) and peroxisome proliferator-activated receptor gamma (PPARγ), differentiation will occur (Rangwala and Lazar 2000). Increasing concentrations of C/EBPα and PPARγ will cause transcription and translation of adipocytes genes to produce lipoprotein lipase and adipocytes fatty acid-binding protein (aP2) (Trayhurn and Beattie 2001). These compounds are needed to change the lipids from the blood plasma into triacylglycerol also known as the most common storage lipid (Mersmann and Smith 2004**)**. Triacylglycerol droplets will collect together to form large lipid droplets. Ultimately, a single large lipid is formed which fills the majority of the adipocytes volume. As triacylglycerol is accreted, the size of the adipocytes gets bigger due to the large lipid collected, which then pushes cytoplasmic components and the cell nucleus to the periphery of the cell. Hypertrophy of differentiated cells is the major source of increase in adipose tissue in mammals (Mersmann and Smith 2004**)**.

Anabolic and Catabolic Lipid Metabolism

The metabolic process of fatty acid synthesis is commonly referred to as de novo fatty acid synthesis. In swine, glucose is the key ingredient for fatty acid synthesis. Glucose is transformed into pyruvate via the glycolytic metabolic pathway which then enters the mitochondria (Mersmann and Smith 2004). In the mitochondria, pyruvate is ultimately metabolized into citrate via the TCA cycle. Citrate is transported out of the mitochondria into the cytosol where it combines with acetate originating from the pig's large intestine to reform into acetyl-CoA. The cytosolic acetyl-CoA is then carboxylated by acetyl-CoA carboxylase into malonyl-CoA that is subsequently decarboxylated to form fatty acids which then form triacylglycerol that it collected in the adipocytes. Lipolysis is the system which degrades adipocyte triacylglyerol (Gerrard and Grant 2003). Lipase sequentially breaks two fatty acid chains from the triacylglycerol. Lipolysis will result in three fatty acids and one glycerol compound. The free fatty acids can either be re-esterfied to form lipids, oxidized, or transported by plasma to be used as a building block by other tissue.

The adipocyte is a dynamic structure that continually changes via anabolic and catabolic metabolism. The anabolic pathway is used for fat synthesis when food is available while the catabolic pathway is the mechanism used when food is unavailable (Mersmann and Smith 2004). As previously mentioned, leptin is a peptide released by the adipocyte to stop food intake as excess energy is not needed. Insulin and adrenergic hormones are responsible for regulating adipocyte metabolism. Insulin stimulates fatty acid and triacylglycerol synthesis while at the same time inhibiting lipolysis. Adrenergic hormones stimulate lipolysis and inhibit the anabolic pathway. When the pig eats, insulin will rise while adrenergic hormones decrease allowing the anabolic pathway to function. When the pig is starved, adrenergic hormones rise and insulin declines allowing lipolysis to occur to supply energy to the animal (Mersmann and Smith 2004).

Anatomical Development of Adipose Tissue

The first fat depot created in a pig would be the visceral fat that is formed around the body organs. Visceral fat is found throughout the body as its purpose is to protect and insulate organs. Mesentric, caul, perirenal, leaf, kidney, pelvic and heart fat are all areas of fat falling in the visceral fat category. Mesentric fat surrounds the intestine; caul fat is housed over the stomach and neighboring organs, perirenal fat surrounds the kidneys, and leaf fat is found between the thoracic cavity and the ribs (Gerrard and Grant 2003). Subcutaneous fat is the second fat depot to form during growth in pigs. Subcutaneous fat will eventually account for 70% of the adipose tissue in the pig. The subcutaneous layer forms three layers at different stages in animal growth. The outer layer is the first to develop and functions as insulation for the animal. The middle layer is the second subcutaneous fat layer to form, and is usually the thickest and most metabolically active layer. The inner layer which is the last subcutaneous fat layer to develop is very thin and is very hard to detect (Gerrard and Grant 2003). The third fat depot is intermuscular fat commonly referred to as seam fat. The fourth depot to form is the intramuscular fat also known as marbling. This depot constitutes the lowest amount of the total carcass fat. This depot of fat is deposited between muscle bundles and specifically attaches to the perimysium (Gerrard and Grant 2003).

Factors Affecting Fat Composition

Age and Anatomical Location

Age plays a role in the composition of adipose tissue. Younger animals will show differences compositionally in fat when compared to older animals. Adipose tissue is highly variable and can contain anywhere between 76 and 94% lipid, 1-4% protein and 5-20% water (Gerrard and Grant 2003). In younger animals, fat composition will consist of higher water and protein levels and lower lipid content when compared to older animals. This is due to the fat cell growing in size as the animal gets older. This is due to a decreasing need for metabolic energy spent on growth. The ability of adipose tissue to operate lipid metabolism is related to the number and size of adipocytes within the adipose tissue (Gerrard and Grant 2003). The factors that alter lipid metabolism act by regulating enzymes across many adipocytes, therefore different anatomical regions could have different enzyme activity.

Anatomical location has an effect on adipose tissue composition. Fat depots will develop at different rates and times during animal growth, and as a result will always vary in composition. Each area of adipose tissue will have a different unsaturated:saturated fatty acid ratio. Even among the subcutaneous layer, there are different levels of saturation amongst the multiple layers in this fat depot (Gerrard and Grant 2003).

Genetic Influences on Fat Composition

Genetic selection can influence fat quality of pigs (Villegas et al., 1973; Scot et. al., 1981; Wariss et al., 1990; Cameron and Enser 1991; Lo Fiego et. al, 2005). According to Cameron and Enser, there can be high heritability with certain types of fatty acids during metabolism (Table 2.3) in lipids thus affecting fat quality. Most saturated fatty acids found in pork fat (myristic and palmitic) with the exception of stearic acid, have a lower heritability compared to monounsaturated fatty acids (palmitoleic and oleic) and when compared to polyunsaturated fatty acids like Linolenic acid. Due to different heritability of fatty acids, breed types will deposit different fatty acids thus showing differences in fat composition. Pigs with different genetics will have different abilities to synthesize and mobilize fatty acids that will result in fat depots with either more or less saturated fats.

Table 2.3 Heritability of Fatty Acids

(Cameron and Enser 1991)

Fatty Acid	Common Name	Heritability (h^2)
C14:0	Myristic	0.33
C16:0	Palmitic	0.24
C16:1	Palmitoleic	0.50
C18:0	Stearic	0.73
C18:1	Oleic	0.28
C18:2	Linoleic	0.24
C18:3	Linolenic	0.62

Over the years genetic lines have changed as it was once common for genetic lines in the 1950s and 1960s to accumulate subcutaneous fat over five cm at market weight while our genetic lines today will deposit nowhere near that much fat. Leaner genotype pigs will have less adipocyte hypertrophy therefore making fewer new adipocytes. Leaner breeds will be more likely to deposit less saturated fat as they have a higher heritability for the deposition of unsaturated fats. Villegas et al. (1973) reported that Hampshire pigs contained higher levels of unsaturated fat and less saturated fatty acids when compared to Duroc pigs, while Yorkshire and crossbred pigs (Duroc x Yorkshire x Hampshire) contained intermediate levels of unsaturated fatty acids between Duroc and Hampshire breeds.

Hormone Effects on Fat Composition

It is commonly known that fat composition differs between males, females, and castrates. In general, the entities most responsible for sex differences are hormones, more specifically estrogen and testosterone. Estrogen promotes fat deposited in the lipid layers while testosterone prevents lipid deposition. The greater amount of fat in females is attributed to an increased size of adipocytes but with fewer adipocytes per tissue unit. Females are also understood to contain more lipid content in the fat depots when breed, weight and anatomical locations are maintained consistently when compared to boars (Gerrard and Grant 2003). This is due to testosterone inhibiting fat deposition. Barrows will possess higher proportions of saturated fatty acids while having lower mono- and poly-unsaturated fatty acids (Nurnberg et al., 1998). Comparatively, boars will have higher concentrations of PUFA than females, which will contain higher concentrations of PUFA than barrows (Nurnberg et al., 1998).

Absorption of Dietary Fatty Acids

Diet plays a major role in the adipose tissue accretion and lipid metabolism. High fat diets will inhibit fatty acid synthesis in non-ruminants; essentially shutting down de novo fat synthesis (Mayes, 1996). Furthermore, the fatty acid profile of the diet will change the triglyceride composition that is stored in adipocytes. During low energy intake, the rate of lipolysis increases, freeing fatty acids to be oxidized (Gerrard and Grant 2003). The opposite is true during high energy intake periods as unneeded energy is stored as triglycerides. The effects of these dietary changes vary depending on the stage of animal growth. Dietary protein:energy ratios are significant considerations as diets with amino acid deficiencies/imbalances will see lipogenesis rates increase. Increased lipogenesis occurs as lean tissue accretion will not be encouraged with unbalanced diets (Gerrard and Grant 2003).

Pigs will deposit fatty acids relatively unchanged from dietary sources (Babatunde et al., 1968). As this is the case, it is very important to consider the fatty acid chain length as well as the saturation level in the diet. The type of fat, whether saturated, unsaturated, monounsaturated or polyunsaturated, will be deposited if consumed in the pigs diet. If one type of fat is increased in the diet the same type of fat will be deposited in fat depots. Pigs cannot create polyunsaturated fatty acids naturally and will only gain these types of fats through dietary means the same way essential amino acids are obtained. Several researchers have reported high levels of Linoleic and Linolenic acids to be contained in fat tissue when fed high percentages of these compounds (Koch et al., 1968; Irie and Sakimoto 1992). It was concluded that because pigs do not synthesize linoleic acid, these fatty acids had to be obtained from the dietary fat.

Sources of Dietary Fat

There can be many different sources of fat included in swine diets, such as animal fats, vegetable oils, restaurant grease, feed-grade tallow, white or yellow grease, and hydrolyzed animal-vegetable fat (Engel et al., 2001; Rentfrow et al., 2002; Apple et. al., 2007). Canola oil and soybean oil are examples of these vegetable oils. The fatty acids contained in these oils are highly integrated into carcass fat depots as pigs can more efficiently utilize the unsaturated fat in these sources than they can saturated fat sources. Animal fats are straight-chained and generally will be a blend of saturated and unsaturated fatty acids. In comparison with vegetable oils, animal fats will be higher in unsaturated and monounsaturated fatty acids, while vegetable oils will have higher levels of polyunsaturated fatty acids.

Effect of Dietary Fat on Belly Quality

In the 1996 Pork Chain Quality Audit it was reported that 2% of pork carcasses surveyed had soft/oily bellies (Cannon et al., 1996). Cannon et al. (1996) attributed the cause of soft bellies to incorporation of a higher percentage of fats in the swine diets. It is commonly recognized that feeding unsaturated fat sources in swine diets will decrease belly firmness resulting in undesirable bacon production (Miller et al., 1993). Since soft bellies contain more unsaturated fats, these bellies will be more susceptible to oxidative rancidity (Moerck and Ball 1973). Today soft bellies are still a concern due to changing feed sources.

Conjugated Linoleic Acid

Overview of Conjugated Linoleic Acid

The American Heart Association recognizes that diets that have higher unsaturated to saturated fat ratios are healthier. It is recognized that PUFAs lower cholesterol and will protect against coronary heart disease and atherosclerosis (Gatlin et al., 2002). In response to these consumer demands, pork producers started producing leaner pigs by feeding diets with unsaturated fat sources. As a result, belly production suffered as there was increasing soft bellies. Conjugated linoleic acid (CLA) became an ingredient to diets that could help make firmer bellies. Conjugated linoleic acid is composed of a group of positional and geometric isomers of linoleic acid that have conjugated double bonds located at positions 7,9-, 8,10-, 9,11-, 10,12- or 11,13- on the carbon chain (Thiel-Cooper et al., 2001; Dunshea et al., 2005). Conjugated linoleic acid was first isolated from grilled ground beef and became known as a cancer inhibitor with antioxidant abilities (Chin et al., 1994). Conjugated linoleic acid is mostly found in foods derived from ruminant animals (Chin et al., 1992). Dietary CLA supplementation in swine diets is a mix of the previously mentioned isomers with the major isomers being the cis/trans-9,11 and the trans/cis -10,12 isomers (Dunshea et al., 2005).

Effects of Conjugated Linoleic Acid on Carcass Composition

Early research with conjugated linoleic acid in mice showed that CLA can increase lean body mass by reducing fat deposition and increasing lipolysis (Park et al., 1997). The bulk of research with CLA in swine diets has been to investigate the effects on growth and carcass composition. It has been found that CLA improves growth rate in swine, but has limited effects on feed conversion. Conjugated linoleic acid seems to have more uses increasing pork quality as researchers have found CLA increases marbling in muscle and fat hardness (Dugan et al., 2004). Once CLA was approved as a food source in the late 1990's, CLA became a popular research topic as pork producers wanted to know if CLA could improve production economics by improving pork quality and animal performance. Dietary CLA works by increasing the saturated fatty acids (14:0, 16:0, and 18:0) while decreasing levels of 18:1 and 18:2 fatty acids (Eggert et al., 2001; Ramsay et al., 2001). Usually, CLA oil comprised of 60% active CLA isomers will make up 1.0-2.0% of the diet (Schinckel et al., 2002).

Carroll et al. (1999) supplemented CLA containing 60% conjugated linoleic acid at different durations (79.8-116.1 lbs and 65.3-113.4 lbs) with genetically lean gilts. This resulted in a significant ($P < 0.1$) improvement in belly firmness. Weber et al. (2001) considered the influences of CLA, ractopamine, and added dietary animal fat on belly firmness and also found that CLA increased belly fat saturation resulting in firmer bellies. Gatlin et al. (2002) investigated if dietary CLA supplementation could increase the saturated to unsaturated ratio of pork fat. Conjugated linoleic acid was supplemented with corn oil, yellow grease, and tallow. The addition of CLA increased the levels of 14:0, 16:0, 18:0 and 18:1 trans-9 and reduced the levels of 18:1cis-9 and 20:1cis-11($P < 0.001$) in belly fat. CLA also was found to increase belly weights ($P < 0.05$). Thiel-Cooper et al. (2001) found that belly firmness (skin side up and skin side down) increased linearly as CLA was increased in the diet.

Effects of Conjugated Linoleic Acid on Sensory Characteristics of Bacon

Several studies have been done to evaluate how CLA will affect bacon sensory characteristics. Dunshea et al. (2005) reported that CLA supplementation caused a small decrease in flavor intensity, juiciness and tenderness in pork meat quality. Larsen et al. (2008) supplemented pig diets with 1.25% CLA and investigated how this influenced sensory characteristics of bacon aroma, flavor intensity, off flavor intensity, brittleness and lean color intensity. Larsen et al. (2008) reported no differences in aroma ($P > 0.34$), lean color intensity ($P > 0.53$), flavor ($P > 0.33$), off-flavor intensity ($P > 0.41$), or brittleness ($P > 0.22$).

Gatlin et al. (2006) investigated sensory aspects by feeding linoleic and conjugated linoleic acid with 0% supplemental fat, 4% yellow grease and 4% tallow. In this study aroma, flavor, and aftertaste attributes were evaluated with a professional six member flavor profile panel. Bacon samples from pigs with supplemental fat were ranked sweeter ($P < 0.04$) than pigs that were not supplemented with fat. The sweet sensation was described as the taste on the tongue stimulated by sugars. Salty flavor intensity increased ($P < 0.02$) in bacon samples from pigs that were fed linoleic acid compared to those fed CLA. Fat flavor intensity tended to increase ($P < 0.09$) in samples fed CLA and 4% supplemental fat versus samples that had 0% supplemental fat. Fat flavor is described as the aromatic cooked fat portion of the meat sample that contains curing agents. Lean flavor of bacon samples tended to be reduced ($P < 0.10$) with diets that included CLA. Lean flavor was described as the aromatic of the cooked lean portion of the meat sample that contains curing agents. Burnt flavors tended to be higher with CLA supplemented bacon from pigs fed 0% supplemented fat or 4% yellow grease than 4% tallow supplemented fat ($P < 0.09$). Salt aftertaste tended to be more intense in samples that were from animals fed with linoleic acid and yellow grease ($P < 0.07$) and tallow ($P < 0.01$) than samples from animals with just linoleic acid. Salt aftertaste with samples from animals fed supplemental fat and CLA were not different ($P < 0.02$) from samples fed CLA alone (Gatlin et al., 2006).

Wiegand et al. (2002) supplemented swine diets with CLA at 0.75% and 1.25% for different time periods before slaughter. Sensory characteristics of tenderness, juiciness, flavor intensity, and pork flavor were evaluated on pork loin chops. Similar to previously mentioned studies, CLA did not change **(***P* > 0.05) tenderness, juiciness, flavor intensity, nor pork flavor.

Dried Distillers Grains' with Solubles

Overview of Dried Distillers Grains with Solubles

The last few years there has been an increased demand for ethanol as a fuel source due to the desire for renewable fuel sources. In the United States it was expected that 7.2 billion gallons of ethanol would be produced at the beginning of 2008 (Saunders and Rosentrater 2009). Commercial Ethanol production utilizes corn and the processing methods yield several products: 1/3 ethanol, 1/3 distillers grains, and 1/3 carbon dioxide (Saunders and Rosentrater 2009). More specifically the distillers grain portion is composed of two co-products: dried distillers grains (DDG) and dried distillers grains with solubles (DDGS). Dried distillers grains and DDGS are included in livestock diets as they are a good source of nutrition. Also, DDGS have been included in ruminant and monogastric livestock diets for more than two decades (Ganesan et al., 2008). DDG can provide 13% crude fiber and 27-30% protein. While, DDGS contain 5-11% crude fiber, 27-34% protein, 5-6% starch and 39-62% carbohydrates and is relatively high in fat content (Saunders and Rosentrater 2009). Dried distillers grains with solubles contain high levels of linoleic acid (C18:2), an unsaturated fatty acid. These nutritional aspects are more concentrated in these byproducts than in regular corn as cereal starch is fermented to produce ethanol and carbon dioxide during the fermentation process (Widyaratne and Zijlstra 2007). An initial problem with using DDGS as a feed source for livestock was that there was variability in nutritional value. However, with new plants being built with modern fermentation and drying technologies, this problem has been addressed (Widyaratne and Zijlstra 2007). Wheat is also a viable source of DDGS, but the digestible nutrient content is lower than that of DDGS derived from corn.

Influences of Dried Distillers Grains on Pork Quality

About 15% of DDGS being produced is used in swine diets. The majority of DDGS being used is added to grower-finish diets. By including 10% DDGS in diets, pork producers can expect equal growth performance in grower-finish animals as pigs fed regular corn-soybean meal diets (Vansickle 2007). Whitney et al. (2006) investigated the growth performance and carcass characteristics of grower-finisher pigs fed DDGS at 0, 10, 20, and 30% in a 5-phase grower-finisher feeding program. In this study, Whitney found that the iodine number increased ($P < 0.01$) linearly with increasing dietary DDGS concentration. This corresponded with a decreasing ($P < 0.05$) belly firmness with increasing DDGS concentration from 0-30%. Widmer et al. (2008) investigated carcass quality and palatability of pork from pigs fed DDGS at 10 and 20% DDGS. Widmer et al. (2008) also found that belly firmness decreased linearly ($P < 0.05$) with increasing ($P < 0.05$) iodine values. Additionally, Widmer et al. (2008) found that cooking loss ($P > 0.09$), shear force ($P > 0.90$), bacon distortion ($P > 0.07$), nor palatability of bacon ($P > 0.06$), was affected by DDGS inclusion. Moreno et al. (2008) similarly reported that adding DDGS to diets reduce the total saturated fatty acid concentrations while increasing total unsaturated fatty acid concentrations resulting in softer bellies. In general the optimum range for including DDGS in swine diets would be less than 20% as this is the recognized threshold for satisfactory belly firmness.

Glycerol

Overview of Glycerol

Crude glycerol is the main co-product of biodiesel production, as 79 g of crude glycerol is generated for every one L of biodiesel produced (Lammers et al., 2008). As of 2007 with the current biodiesel capabilities it is possible to produce over 400 million kg of crude glycerol annually in the U.S. (Lammers et al., 2008). There has been interest in utilizing glycerol in animal diets due to the potential to reduce feed costs. However there is still much to learn on the nutritional value of glycerol and its effect on carcass characteristics.

Effect of Glycerol on Carcass Characteristics

Duttlinger et al. (2009) fed pigs a supplement of 0 or 5% glycerol to determine sensory characteristics of glycerol on pork loins. The sensory characteristics that were investigated were pork flavor intensity, off-flavor intensity, myofibrillar tenderness, overall tenderness, and juiciness. It was reported that feeding glycerol alone did not change pork flavor intensity ($P > 0.86$), off-flavor intensity ($P > 0.20$), myofibrillar tenderness ($P > 0.74$), overall tenderness ($P > 0.73$), or juiciness ($P > 0.83$).

Della Casa et al. (2008) investigated how pure glycerol would affect growth performance and meat quality. Animals were fed a maize based diet without glycerol (0%), a supplement of 5 or 10% in the both the growing and finishing stages, and 5 or 10% just during the finishing stage. Sensory factors that were evaluated were: odor intensity, flavor intensity tenderness, juiciness and masticability. Della Casa's results agree with Duttlinger et al. (2009) in that there were no significant glycerol effects on the previously mentioned sensory characteristics. Mourot et al. (1994) investigated how glycerol would affect fatty tissue by using two levels of glycerol (0 and

5%) in combination with tallow and rapeseed oil. It was reported that the proportion of oleic acid increased (50.4 vs. 47.8%) and the un-saturation index decreased (1.18 to 1.15) in pork backfat.

Effect of Glycerol on Fatty Acid Synthesis

It is well known that glycerol; the reduced form of glyceraldehydes is an important component of lipids. Glycerol in diets can increase the activity of glycolitic and lipogenic enzymes important to fatty acid synthesis as it is a carbohydrate that is readily converted to glucose. Glucose, as mentioned earlier is the driving force behind adipocyte lipid metabolism (Mersmann and Smith 2004). Despite being a source of glucose, the acting mechanisms as a result of glycerol inclusion in diets is not well understood. Giměnez et al. (1985) showed that glycerol inclusions significantly increased fatty acid synthetase activity. Lin et al. (1976) showed that glycerol inclusion inhibited glucose conversion to fatty acids in rat livers, but did not affect the conversion in chicken liver slices. Furthermore, there was no significant difference in adipose tissue lipogenic enzyme activity in rats fed glycerol diets. Lin et al. (1976) also concluded that lipogenic responses to glycerol would depend on species and specific organs. Therefore, it might be possible to encourage more de novo fatty synthesis in pigs due to the addition of glycerol in diets to be used as a substrate for fatty acid synthesis. Thereby increasing the saturation level in porcine because de novo fatty synthesis producing saturated fatty acids.

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CHAPTER 3 - INFLUENCE OF DIETARY DRIED DISTILLERS GRAINS WITH SOLUBLES ON BACON QUALITY

Abstract

The objective of this study was to determine the impact of 0 and 20% dried distillers grains with solubles (DDGS) and increasing levels of glycerol (0, 2.5, and 5.0%) in grow-finishing rations on bacon quality. A total of 84 barrows (PIC, initially 31.03 kg) were fed corn-soybean meal-based diets organized in a 2 x 3 factorial with primary effects of DDGS (0 or 20%) and glycerol (0, 2.5, or 5%) as fed. Belly length was measured from flank end to blade end. Belly thickness was measured at 8 locations evenly spaced around the perimeter of the belly. Belly firmness was measured by centering bellies perpendicularly (skin side up and skin side down) over a stainless steel smokestick and measuring the flex between the edges on the ventral and dorsal edges of the belly. Bellies were injected at 12% of the skinned belly weight resulting in a final concentration of 1.74% salt, 0.5% sugar, 0.3% sodium phosphate, 120 ppm sodium nitrite, and 500 ppm sodium erythorbate in the bellies. Bellies were cooked to an internal temperature of 53^{o}C, then chilled, pressed, and sliced for evaluation. Belly slice yield was calculated by determining the yield of #1 type bacon slices. Proximate analysis and fatty acid analysis were evaluated by taking every 10th bacon slice, beginning from the caudal end, to make a composite sample for each belly. Iodine value was calculated using the resulting fatty acid content results. Twenty bacon slices were removed one-third the length of the belly from the cranial end for sensory analysis and cooking yields. Sensory characteristics were evaluated on an 8-point scale for brittleness, bacon flavor intensity, saltiness, and off flavor. There were no significant DDGS x glycerol interactions on any parameters measured (*P* > 0.08). Inclusion of

20% DDGS in pig diets decreased belly firmness (*P* < 0.04), as measured by the belly flop fat side down method. Twenty percent DDGS decreased the percentage of myristic acid, palmitic acid, palmitoleic acid, stearic acid, oleic acid, vaccenic acid, total saturated fatty acids, and total monounsaturated fatty acids (*P* < 0.01). In contrast, 20% DDGS increased the percentage of linoleic acid, α-linolenic acid, eicosadienoic acid, total polyunsaturated fatty acids, unsaturated: saturated fatty acid ratios, polyunsaturated: saturated fatty acid ratios, and iodine values (*P* < 0.01). The inclusion of 0, 2.5, and 5% glycerol in swine diets did not affect any measured parameters in this study. In conclusion, feeding DDGS at a level of 20% decreased belly firmness and changed the fatty acid profile; however, it did not affect belly processing or sensory characteristics. Glycerol fed at 2.5 or 5.0% did not affect belly quality, fatty acid profile, or sensory characteristics of bacon.

Key words: bacon, belly quality, dried distillers grains, glycerol, pork

Introduction

Increased demand for biofuel has increased the availability of feed co-products from ethanol manufacturing. Dried distillers grains with solubles (DDGS) is a co-product that remains after ethanol is removed from fermented corn mash, that contain high levels of nutrients in comparison with corn (Duttlinger et al., 2008a). With rising corn prices, it is possible for producers to dramatically reduce feed production costs by including DDGS in swine diets. Dried distillers grains with solubles contain approximately 10% oil which consists of 81% unsaturated fatty acids (Xu et al., 2010). Of that 81% unsaturated fatty acid content, 54% is linoleic acid (Xu et al., 2010). It is well known that feeding high levels of unsaturated fatty acids to pigs results in a lower percentage of belly saturated fatty acids and softer bellies (Shackelford et al., 1990). Widmer et al. (2008) found that belly firmness decreased linearly as dietary DDGS concentration increased, this is especially important as bellies have become one of the most valuable pork products produced domestically. Softer bellies can result in greater variation, decreased slicing yields, a shorter shelf life, more fat separation and more fat smearing of bacon products (Apple et al., 2007). As unsaturated fat content increases, so does softness, which can cause fat to separate from lean and be more susceptible to lipid oxidation.

At the time of this study, glycerol was an economical option to include in swine diets as it would reduce feed costs. Furthermore, it has been shown that feeding glycerol to pigs can have a beneficial effect on fat, as it lowers the concentration of unsaturated fatty acids in carcass fat (Mourot et al., 1994). Glycerol can be used as a substrate to instigate glycolitic and lipogenic activity important to fatty acid synthesis. Therefore, adding glycerol to swine diets containing DDGS could improve belly quality, as glycerol provides glucose, which is an important substrate in de novo fatty acid synthesis thereby encouraging more saturated fatty acids to be deposited (Mersmann and Smith 2004). Thus, the objective of this study was to investigate the effect of dietary glycerol and DDGS on firmness, smokehouse and slice yield, bacon cooking yield, sensory characteristics of bacon, and fatty acid composition.

Materials and Methods

Procedures used in this experiment that involved live pigs were approved by the Kansas State University Institutional Animal Care and Use Committee and the Institutional Review Board. Pigs were fed in southwest Minnesota in a commercial swine facility with a slatted floor, each pen was equipped with a 4-hole dry self-feeder and 1 cup waterer. The facility was a double-curtain sided, deep-pit barn, which operated on mechanical ventilation during the summer and automatic ventilation during the winter. Pigs were fed in late summer and fall of 2007. Sensory panel studies were accepted by the Kansas State University Institutional Review Board.

Animal Diets

A total of 84 barrows (PIC, 337 x 1050, initially 31.03 kg) were fed for 70 d. Pigs were initially blocked by weight and randomly assigned to one of six dietary treatments, with seven pens per treatment. Each pen contained 27 to 28 barrows. Animals were fed corn-soybean meal-based diets in four phases. All diets were formulated to contain an identical ileal digestible (SID) lysine:ME ratio in each phase. The NRC (1998) ME value of corn for both DDGS and glycerol (1,551 kcal/lb) was used for diet formulations. Multiple lots of glycerol from the same soybean biodiesel facility (Minnesota Soybean Processors, Brewster, MN) were used in this study. Phase one diets were fed to pigs weighing 30.8 to 54.4 kg, phase two diets were fed to pigs weighing 54.4 to 77.1 kg, phase three diets were fed to pigs weighing 77.1 to 99.8 kg, and phase four diets were fed to pigs weighing 99.8 to 123.8 kg (Duttlinger et al., 2008a).

Treatments were arranged in a 2x3 factorial with main effects of DDGS (0 or 20%) and glycerol (0, 2.5, and 5%) as fed. Pigs were fed ad libitum.

Slaughter Process

After 70 d, the two heaviest barrows from each pen were visually selected, individually tattooed, and shipped to a commercial swine harvest facility (JBS SWIFT & Company processing plant, Worthington, MN) for slaughter. Following slaughter and chilling (24 h), bellies were removed from the right side of the carcass, as according to the Institutional Meat Purchasing Specification guidelines for a 408 fresh pork belly. Bellies were transported to the Kansas State University Meat Laboratory and placed in frozen storage at -23^{o}C until evaluation.

Fresh Belly Analysis

Initial belly weight (belly with skin on) was the first measurement taken. Belly length was measured from flank end to blade end on both ventral and dorsal belly edges. Thickness was measured (skin side down) at eight locations (four ventral and dorsal) on the belly using procedures similar to Scramlin et al. (2008). Firmness was measured by centering the belly skin side up and skin side down (Larsen et al., 2009), on a 106.7 cm long bell shaped stainless steel smokestick that ran perpendicular to the length of the belly. For both skin up and skin down orientation measurements, a measurement was taken on the dorsal and ventral sides of the belly. The measurements for firmness were measured between the two closest points of the flexed belly (tissue to tissue distance for the skin up orientation or skin to skin distance for the skin down orientation). Bellies were placed on the bar one min 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 -0.2^{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 belly weight with a solution (pickle) consisting of 78.25% water, 13% salt, 4.2% sucrose, 2.5% neutral pH sodium phosphate (Brifisol®450 Super; Bk Giulini Corp., Sim Valley, CA. U.S.A), 1.6% curing salt (containing 0.1% sodium nitrite), and 0.45% sodium erythorbate. This equaled to a concentration of 1.7% salt, 0.5% sugar, 0.3% sodium phosphate, 0.012% sodium nitrite (120 ppm), and 0.05 % sodium erythorbate (500 ppm). All bellies were weighed before and after injection, and hung on smokehouse trucks for two h before smoking/cooking in a one truck smokehouse (D7752 Mauer Inc., Reichenau, Germany). Pump % was calculated for all bellies using the following formula: [(pumped weight-belly skin-off weight)/green weight) x100]. The final endpoint temperature of bellies was 53.0^{o}C. Upon completion of thermal cycles, bellies were immediately stored in a cooler at 2.0^{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/belly skin-off weight) x100]. Bellies were placed in oxygen impermeable vacuum package bags (not vacuum sealed), 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 bellies were pressed with an ANCO Model 1111 bacon press (ANCO Slicing Technologies., Chicago, IL, U.S.A), sliced (-3.3^{o}C) with an ANCO Model 827 bacon slicer (ANCO Slicing Technologies., Chicago, IL, U.S.A) to a slice width of 4-mm, vacuum packaged using a Koch Ultravac Model 2100 vacuum packaging machine (Koch Equipment., Kansas City, MO, U.S.A). Bellies were then placed back into coolers and transported to the Kansas State University Meat Laboratory.

Bacon Quality Analysis

Bacon slice yield was calculated by weighing the sliced bacon slab, removing the less valuable slices then weighing the remaining #1 slices [(belly weight-(weight of #2 and #3 slices)/belly weight) x 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 bacon slice thickness no less than 1.9 cm.

Proximate Analysis

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

Fatty Acid Analysis

Samples for fatty acid analysis were taken from the same composite sample that was prepared for proximate analysis. Fatty acid results are reported as a percentage of total fatty acids in each belly sample. Iodine values, which represent the concentration of unsaturated fat in the belly, were calculated by using 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).

Bacon Sensory Evaluation

Bacon slices used for sensory evaluation were removed from the belly at a point one-third the length of the belly from the cranial end. Bacon was placed on cooking racks in a Blodgett dual-air-flow oven (DFD-201, G.S. Blodgett Co.,InC., Burlington, VT) set at 176^{o}C. Slices were cooked for five min on each side. After cooking, slices were blotted with paper towels to remove excess grease (Waylan et al., 2003). Bacon samples were cut into sub slices and the end portions were discarded, resulting in more uniform bacon slices. Before sensory panels began, all panelists participated in orientation sessions designed to acquaint the panelists with the scale used for each trait. A minimum of eight panelists were used for each session of sensory evaluation. Panelists were placed in individual booths with a combination of red and green light (<107.6 lumens) and were required to consume a piece of apple, a piece of cracker, and water between each bacon sample to cleanse their palates. For each session, seven samples were provided for evaluation. First, a warm-up sample was provided to allow for discussion on what would be a good response for that particular sample. The warm-up sample was from bacon manufactured by the KSU Meat Laboratory. After the warm-up sample and discussion, samples from each of the six treatments were randomly served to panelists. The panelists scored brittleness, bacon flavor intensity, saltiness, and off flavors 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). Scales were: brittleness 1 = extremely soft, 2 = very soft, 3 = moderately soft, 4 = slightly soft, 5 = slightly crisp, 6 = moderately crisp, 7 = very crisp, 8 = extreme crisp; bacon flavor intensity: 1 = extremely bland, 2 = very bland, 3 = moderately bland, 4 = slightly bland, 5 = slightly intense, 6 = moderately intense, 7 = very intense, 8 =extremely intense; saltiness: 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, 8 = extremely salty; and off flavor: 1 = extremely intense, 2 = very intense, 3 = moderately intense, 4 = slightly intense, 5 = slight, 6 = traces, 7 = practically none, 8 = none.

Cooking Yield

Ten 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 selected randomly to be cooked using the same procedures described for sensory analysis. Pre and post cook weights were recorded using an Explorer Pro scale model EP2102C (Ohaus Corporation Pine Brook, NJ., U.S.A) and cooking yield was calculated as [(cooked weight/raw weight) x100].

Statistical Analysis

A 2x3 factorial design was used for the feeding trials investigating interactions between DDGS and glycerol, with main effects of DDGS and glycerol. The factorial arrangement was as follows: 2 dietary DDGS levels (0 and 20%) coupled with 3 dietary glycerol levels (0, 2.5, and 5%), with each pen of pigs selected for this experiment being an experimental unit. Data was analyzed by using the PROC GLM and PROC CORR procedures of SAS 9.1.3. Dried distillers grains with solubles x glycerol interactions, DDGS main effects and glycerol main effects were separated when f-tests were significant at a level of $P < 0.05$.

Results and Discussion

Dried Distillers Grains with Solubles x Glycerol Interactions

There were no DDGS x glycerol interactions (Appendix C) for any measurement taken ($P > 0.81$). Belly weights and observed belly processing characteristics results also agree with Stevens et al. (2009) who also observed no DDGS x glycerol interactions.

Dried Distillers Grains with Solubles Main Effects

There were no significant DDGS main effects (Table 3.1) on belly length ($P > 0.22$), belly thickness ($P > 0.68$), belly skin-on weight ($P > 0.76$), or belly skin-off weight ($P > 0.37$). However, the 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 ($P > 0.07$).

Table 3.1 Effects of feeding DDGS[a] on fresh belly characteristics

Belly Characteristics	0% DDGS	20% DDGS	SE	P-value
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
Skin-on belly weight, kg	7.94	7.89	0.25	0.76
Skin-off belly weight, kg	6.65	6.51	0.25	0.37

[a]Dried Distillers Grains with Solubles

Stevens et al. (2009) observed similar results with 20% DDGS inclusion in swine diets having no significant affect on belly length, nor belly weights, but did find decreased belly firmness. Observed belly thickness results did not agree with Whitney et al. (2006) who reported a decrease in belly thickness with a 20% or more DDGS inclusion. However, this was concluded using a 90% confidence interval while this study maintains a 95% confidence level. In contrast, the observed belly thickness results agree with Widmer et al. (2008) who reported that the addition of 20% DDGS did not affect belly thickness. Whitney et al. (2006) found that 20% inclusion of DDGS did not decrease belly firmness versus no inclusion. However, a decrease in belly firmness was reported at a 30% DDGS inclusion level. Belly firmness results of this study agree with Widmer et al. (2008), who reported that an inclusion of 20% DDGS significantly decreased belly firmness. Legan et al. (2007) found similar results in that belly weights were not affected by inclusion of DDGS. A decrease in belly firmness is expected with increased levels of unsaturated fat. In this study it was observed that including 20% DDGS in pig diets decreases fat saturation, thereby reinforcing the observance of decreased belly firmness with DDGS.

The inclusion of 20% DDGS (Table 3.2) tended to increase pump percentage ($P > 0.06$), but did not significantly affect ($P > 0.16$) the injected weight, belly cooked weight, belly smokehouse yield, #1 type bacon slice yield weight, #1 type bacon slice yield, or bacon cooking yields. Stevens (2009) reported that samples from animals fed 20% DDGS had increased pump percentage, decreased bacon slice cook yield, and no change in smokehouse yields. According to other studies, and shown in this one, DDGS inclusion in swine diets will cause belly fat to become more unsaturated. As a result, belly fat containing more unsaturated fatty acids will be softer. Therefore it is possible the injection pressure will cause more brine to be injected and retained into the belly because the fat is more pliable.

Table 3.2 Effects of feeding DDGS[a] on belly processing characteristics

Processing Characteristics	0% DDGS	20% DDGS	SE	P-value
Pump %	10.35	10.79	0.16	0.06
Injected weight, kg	7.34	7.21	0.28	0.48
Belly cooked weight, kg	6.67	6.55	0.26	0.48
Smokehouse yield, %	100.15	100.50	0.22	0.26
Slice yield, kg	4.79	4.60	0.22	0.18
#1 Bacon slice yield,%	71.78	70.33	0.72	0.16
Bacon cooking yields, %	33.30	33.60	0.75	0.78

[a]Dried Distillers Grains with Solubles

The addition of 20% DDGS (Table 3.3) showed a trend of increasing moisture content ($P > 0.07$). However, there were no significant changes to protein ($P > 0.34$), fat ($P > 0.16$), nor ash ($P > 0.45$) content. Similarly, Moreno et al. (2008) reported that DDGS did not affect the chemical composition of pork longissimus muscles. It is possible that the inclusion of DDGS will affect fat content. It is generally known that protein and ash are relatively constant in meat, however moisture and fat content are relatively mobile in that an increase in moisture content will cause a decrease in fat content and vice versa.

Table 3.3 Effects of feeding DDGS[a] on proximate analysis of bacon slices

Composition[a]	0% DDGS	20% DDGS	SE	P-value
Moisture, %	40.68	42.78	0.78	0.07
Protein, %	13.12	13.53	0.30	0.33
Fat, %	43.81	41.54	1.12	0.16
Ash, %	2.56	2.18	0.33	0.42

[a]Percentage of moisture, protein, fat and ash

Inclusion of DDGS (Table 3.4) at 20% decreased ($P < 0.01$) myristic acid, palmitic acid ($P < 0.01$), palmitoleic acid ($P < 0.01$), stearic acid ($P < 0.01$), oleic acid ($P < 0.01$), vaccenic acid ($P < 0.01$) and total SFAs ($P > 0.29$). Inclusion of DDGS at 20% increased linoleic acid ($P < 0.01$), α-linolenic acid ($P < 0.01$), arachidic acid ($P > 0.06$), eicosadienoic acid (P < 0.01), total

MUFAs ($P < 0.01$), unsaturated: saturated fatty acid ratios ($P < 0.01$), polyunsaturated: saturated fatty acid ratios ($P < 0.01$), and iodine values ($P < 0.01$).

Table 3.4 Effect of feeding DDGS[a] on belly fatty acid composition

Item[b]	0% DDGS	20% DDGS	SE	P-value
Myristic acid (14:0),%	1.47	1.36	0.01	0.01
Palmitic acid (16:0), %	24.20	22.66	0.01	0.01
Palmitoleic acid (16:1),%	2.68	2.29	0.01	0.01
Margaric acid (17:0),%	0.47	0.46	0.01	0.68
Stearic acid (18:0), %	11.71	10.87	0.01	0.01
Oleic acid (18:1c9),%	39.88	38.34	0.01	0.01
Vaccenic acid (18:1n7),%	3.38	3.03	0.01	0.01
Linoleic acid (18:2n6),%	12.28	16.92	0.01	0.01
α- Linolenic acid (18:3n3),%	0.54	0.60	0.01	0.01
Arachidic acid (20:0), %	0.22	0.20	0.01	0.06
Eicosadienoic acid (20:2),%	0.64	0.80	0.01	0.01
Arachidonic acid (20:4n6),%	0.09	0.09	0.01	0.09
Other fatty acids, %	2.40	2.34	0.01	0.15
Total SFA, %[1]	38.42	35.81	0.01	0.01
Total MUFA,%[2]	47.02	44.57	0.01	0.01
Total PUFA, %[3]	13.06	17.94	0.01	0.01
Total TFA, %[4]	0.50	0.49	0.01	0.90
UFA:SFA ratio[5]	1.57	1.75	0.02	0.01
PUFA:SFA ratio[6]	0.34	0.50	0.01	0.01
Iodine value, g/100g[7]	63.66	69.88	0.01	0.01

[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).

[a]Dried Distillers Grains with Solubles

[b]Percentage of total fatty acid content

In agreement with observed results, Duttlinger et al. (2008a) found that belly fat from pigs fed 20% DDGS had lower percentages of myristic acid, palmitic acid, palmitoleic acid, palmitoleic acid, stearic acid, oleic acid, vaccenic acid, UFA, and MUFA, but higher percentages of linoleic acid, α-linolenic acid, eicosadienoic acid, total PUFA, resulting in higher ratios of UFA: SFA, PUFA: SFA, and iodine values than pigs fed no DDGS. In contrast, Legan et al. (2007) reported no differences in Palmitic, and oleic acids, and iodine value, an increase in arachidonic acid and a lower SFA: UFA ratio with the inclusion of DDGS. Moreno et al. (2008) found that the only fatty acid that decreased was palmitic acid, which decreased linearly as dietary DDGS increased, while the only fatty acid that increased in concentration was linoleic acid. Moreno et al. (2008) also reported that there was a linear reduction in total saturated fatty acid concentrations as DDGS increased. Whitney et al. (2006) reported similar results as iodine values increase with increasing DDGS levels. Stevens (2006) found that myristic, palmitic, and stearic acid concentrations were lower with DDGS inclusion, while oleic, vaccenic, α-linolenic, linoleic acid concentrations, and iodine values increased.

As DDGS contains 10% oil, comprised of 81% unsaturated fatty acids that also contains a concentration of linoleic acid (C18:2) approaching 54%, the fat that will be deposited in belly fat, will be more unsaturated. Furthermore, the fatty acid profile of the diet will change the triglyceride composition that is stored in adipocytes. During low energy intake, the rate of lipolysis increases, freeing fatty acids to be oxidized (Gerrard and Grant 2003). The opposite is true during high energy intake periods, as unneeded energy is stored as triglycerides. High fat diets will inhibit fatty acid synthesis in non-ruminants, essentially shutting down or limiting de novo fat synthesis (Mayes, 1996). Therefore, pigs will be depositing the unsaturated fat being consumed through the diet in lieu of saturated fatty acids. As a result, the total saturated fatty acid content will decrease. In contrast, unsaturated fatty acid and polyunsaturated fatty acid content would increase, thereby increasing iodine values.

The addition of 20% DDGS to swine diets did not have any effects on bacon brittleness ($P > 0.62$), bacon flavor intensity ($P > 0.24$), saltiness ($P > 0.66$), or off flavor ($P > 0.10$) (Table 3.5). Results agree with Xu et al. (2009) who observed that DDGS inclusion at 10, 20, and 30% in pig diets did not significantly affect bacon flavor, brittleness, nor off flavor. Likewise, Widmer et al. (2008) found that DDGS at 20% inclusion did not negatively affect bacon brittleness, flavor intensity, or off flavors. In theory, a higher unsaturated fat level would leave bacon samples more susceptible to lipid oxidation and result in more off flavors. It would be expected that these bacon samples from pigs fed 20% DDGS would have more off flavors, as bellies were stored for a year and a half, allowing some lipid oxidation. However, this was not the case in this study.

Table 3.5 Effect of feeding DDGS[a] on bacon sensory characteristics

Sensory characteristic	0% DDGS	20% DDGS	SE	P-value
Brittleness[1]	5.17	5.28	0.15	0.62
Bacon Flavor Intensity[2]	5.87	5.67	0.12	0.24
Saltiness[3]	5.7	5.73	0.06	0.66
Off Flavor[4]	7.77	7.54	0.09	0.10

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

[2]Bacon flavor intensity: 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: 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, 8 = Extremely salty.

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

[a]Dried Distillers Grains with solubles

Glycerol Main Effects

Increasing dietary glycerol (Table 3.6) by 2.5 and 5% showed a trend toward increasing belly length ($P > 0.08$). Otherwise there were no significant effects ($P > 0.13$) on fresh belly characteristics, belly processing characteristics (Table 3.7), proximate analysis (Table 3.8), fatty acid composition (Table 3.9), or sensory characteristics (Table 3.10).

Table 3.6 Effect of feeding glycerol on fresh belly characteristics

Belly Characteristics	0% GLY	2.5% GLY	5% GLY	SE	P-value
Belly length, cm	67.98	69.48	69.57	0.54	0.08
Belly thickness, cm	3.12	3.06	3.07	0.05	0.71
Flop skin down, cm	18.31	17.15	18.42	0.61	0.28
Flop skin up, cm	15.87	15.11	15.83	0.44	0.41
Belly skin-on weight, kg	7.97	7.92	7.86	0.31	0.87
Belly skin-off weight, kg	6.64	6.56	6.55	0.30	0.88

Stevens (2009) reported similar results, in that glycerol at any level (5, 10, or 15%) did not affect belly length, nor belly firmness (via the belly flop test), but did find that increasing glycerol from 0 to 15% would increase belly weights. Schieck et al. (2009) reported that glycerol at a level of 8% did not change belly thickness, but did increase belly firmness (via the belly flop test).

Table 3.7 Effects of feeding glycerol on belly processing characteristics

Belly Characteristics	0% GLY	2.5% GLY	5% GLY	SE	P-value
Pump %	10.66	10.47	10.58	0.19	0.79
Injected weight, kg	7.34	7.25	7.24	0.34	0.86
Belly cooked weight, kg	6.66	6.59	6.57	0.32	0.90
Smokehouse yield, %	100.31	100.30	100.36	0.26	0.98
Slice yield, kg	4.80	4.67	4.62	0.27	0.56
#1 Bacon slice yield,%	72.02	70.89	70.27	0.88	0.37
Bacon cooking yields, %	32.85	33.72	33.78	0.82	0.73

Observed effects of glycerol on belly processing characteristics agree with Stevens (2009) in that 5% glycerol did not affect smokehouse yield, or cooking yield, but did differ as glycerol at 10 and 15%, versus 0%, did increase pump yields. Previous research has indicated that glycerol has osmotic properties which allow greater water holding capacity, which might explain why Stevens observed greater pump yields (Riedsel et al., 1987).

Table 3.8 Effects of feeding glycerol on proximate analysis of bacon slices

Composition[a]	0% GLY	2.5% GLY	5% GLY	SE	P-value
Moisture, %	41.62	41.32	42.26	0.96	0.78
Protein, %	13.94	12.97	13.07	0.36	0.13
Fat, %	41.63	43.66	42.74	1.37	0.58
Ash, %	2.88	2.12	2.11	0.41	0.32

[a]Percentage of moisture, protein, fat and ash

Duttlinger et al. (2008b) in opposition of observed results, reported that increasing glycerol decreased linoleic acid and total PUFA concentrations, as well as PUFA:SFA ratios. Stevens (2009) found that fatty acid samples from pigs fed glycerol showed a decrease in linoleic acid, otherwise observed similar results to our study. Mourot et al. (1994) reported that glycerol decreased linoleic and linolenic acid, and increased oleic acid, content while decreasing the total unsaturated fatty acid index in pork backfat. Though glycerol provides a substrate for de novo fatty acid synthesis, it is likely that glycerol showed no effects on any measurements because the fat in the diet was provided from DDGS, resulting in little de novo fat synthesis.

Della Casa et al. (2008) investigated how pure glycerol would affect the sensory aspects of the longissimus muscle and agreed there were no significant glycerol effects on sensory characteristics. This also agrees with Duttlinger et al. (2008), who found no differences in off-flavors or pork flavor intensity in loins from pigs fed glycerol. Also, in agreement with observed results, Schieck et al. (2009) reported that there were no significant changes on pork flavor or off flavors of pork longissimus muscles with 8% glycerol included in swine diets. As the de novo fatty acid synthesis in pigs is limited when a fat source is added into the diet, it can be expected that glycerol will not be used as a substrate for fatty acid synthesis. Therefore, glycerol will not have an effect on the fat saturation and as a result would not affect flavor.

Table 3.9 Effects of feeding glycerol on belly fatty acid composition

Item[a]	0% GLY	2.5% GLY	5% GLY	SE	P-value
Myristic acid (14:0),%	1.38	1.42	1.45	0.01	0.13
Palmitic acid (16:0), %	23.26	23.4	23.64	0.01	0.45
Palmitoleic acid (16:1),%	2.44	2.49	2.5	0.01	0.66
Margaric acid (17:0),%	0.47	0.44	0.49	0.01	0.13
Stearic acid (18:0), %	11.38	11.20	11.3	0.01	0.82
Oleic acid (18:1c9),%	38.82	39.42	39.10	0.01	0.30
Vaccenic acid (18:1n7),%	3.16	3.22	3.25	0.01	0.48
Linoleic acid (18:2n6),%	15.13	14.44	14.23	0.01	0.33
α- Linolenic acid (18:3n3),%	0.58	0.57	0.57	0.01	0.58
Arachidic acid (20:0), %	0.22	0.21	0.21	0.01	0.49
Eicosadienoic acid (20:2),%	0.73	0.71	0.72	0.01	0.62
Arachidonic acid (20:4n6),%	0.09	0.10	0.09	0.01	0.31
Other fatty acids, %	2.33	2.38	2.40	0.01	0.41
Total SFA, %[1]	36.96	37.03	37.36	0.01	0.64
Total MUFA,%[2]	45.31	46.04	45.80	0.01	0.28
Total PUFA, %[3]	16.08	15.27	15.15	0.01	0.33
Total TFA, %[4]	0.48	0.50	0.50	0.01	0.88
UFA:SFA ratio[5]	1.67	1.67	1.64	0.02	0.64
PUFA:SFA ratio[6]	0.44	0.42	0.40	0.02	0.40
Iodine value, g/100g[7]	67.36	66.79	66.18	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).

[a]Percentage of total fatty acid content

Table 3.10 Effect of feeding glycerol on bacon sensory characteristics

Sensory characteristic	0% GLY	2.5% GLY	5% GLY	SE	P-value
Brittleness[1]	5.47	5.15	5.06	0.19	0.28
Bacon Flavor Intensity[2]	5.95	5.68	5.69	0.14	0.32
Saltiness[3]	5.7	5.71	5.74	0.07	0.94
Off Flavor[4]	7.61	7.68	7.67	0.12	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, 8 = Extremely crisp.

[2]Bacon flavor intensity: 1 = Extremely bland, 2 = Very bland, 3 = Moderately bland, 4 = Slightly bland, 5 = Slightly intense, 6 = Moderately intense, 7 = Very intense, 8 =Extremely intense

[3]Saltiness: 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, 8 = Extremely salty.

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

Conclusions

Feeding pigs dried DDGS at 20% decreased belly firmness and changed the fatty acid profile but did not affect any other belly processing or sensory characteristics. Feeding pig 2.5 or 5% glycerol in swine diets did not affect any belly processing characteristics, belly fatty acid composition, nor sensory panelist’s characteristics of bacon. Therefore, feeding 20% DDGS and glycerol at 0, 2.5, and 5% showed no negative or beneficial effects on bacon quality.

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CHAPTER 4 - Statistical Correlations of Measured Characteristics

Abstract

The objective of this study was to determine the relationship between belly firmness and slicing yield for commercially produced bacon. A total of 84 barrows (PIC, initially 31.03 kg) were fed corn-soybean meal-based diets organized in a 2 x 3 factorial with primary effects of Dried distillers grains with solubles (0 or 20%) and glycerol (0, 2.5, or 5%) as fed. Belly length was measured from flank end to blade end. Belly thickness was measured at 8 locations evenly spaced around the perimeter of the belly. Belly firmness was measured by centering bellies perpendicularly (skin side up and skin side down) over a stainless steel smokestick and measuring the flex between the edges on the ventral and dorsal edges of the belly. Bellies were injected at 12% of the skinned belly weight resulting in a final concentration of 1.74% salt, 0.5% sugar, 0.3% sodium phosphate, 120 ppm sodium nitrite, and 500 ppm sodium erythorbate in the bellies. Bellies were cooked to an internal temperature of 53^{o}C, chilled, pressed and sliced for evaluation. Belly slice yield was calculated by determining the yield of #1 type bacon slices. Proximate analysis and fatty acid analysis were evaluated by taking every 10th bacon slice beginning from the caudal end to make a composite sample for each belly. Iodine value was calculated using the resulting fatty acid content results. Twenty bacon slices were removed from the belly one-third the length of the belly from the cranial end for sensory analysis and cooking yields. Sensory characteristics were evaluated on an 8-point scale for brittleness, bacon flavor intensity, saltiness and off-flavor. Statistical correlation analysis of belly processing characteristics showed that by increasing initial belly weight there will be an increase in smokehouse yields (R = 0.81), increasing smokehouse yields will increase slice yield (R = 0.71),

increasing belly thickness results in firmer bellies ($R = 0.94$) and increasing belly firmness will increase slice yields ($R = 0.60$). Fatty acid content did not correlate with any belly processing characteristic ($R < 0.50$). Iodine values were highly correlated with total MUFA ($R = 0.83$) total PUFA ($R = 0.79$), total TFA ($R = 0.75$), and UFA: SFA ratio, and PUFA: SFA ratios ($R = 0.83$).

Key words: bacon, belly quality, dried distiller grains with solubles, glycerol, pork

Introduction

The emphasis of any business is to maximize profits while minimizing expenses. This is especially true in the pork industry as many production operations seek to decrease production costs by using more economical ingredients for feed formulations. There are many different ingredients used in swine diets that can influence carcass composition or belly quality. Different fat sources (vegetable based or animal based) are known to affect porcine fat quality and each have different economical values. Dried distillers grains with solubles (DDGS) is another option for swine diets that can be used in lieu of corn and soybean meals to reduce costs. There are many studies with different diet components and the effects of these inclusions on carcass and belly quality (Apple et al., 2008; Duttlinger et. al., 2008; Larsen et al., 2009; Waylan et al., 2003). However, these studies do not address the relationship between belly firmness and slicing yield for commercially produced bacon, nor how quality measurements relate to bacon quality. Thus, the objective of this study was to investigate how measurement parameters of the previous study interact with bacon production processes.

Materials and Methods

Procedures used in this experiment to collect measurements were the same as in chapter three. A 2x3 factorial design was used for the feeding trials investigating interactions between DDGS and glycerol with main effects of DDGS and glycerol. The factorial arrangement was as follows: 3 dietary glycerol levels (0, 2.5 and 5%) coupled with 2 dietary DDGS levels (0 and 20%) with each pen of pigs selected for this experiment being an experimental unit. Measurements that were analyzed were belly length, belly thickness, belly flop skin side down, belly flop skin side up, belly skin-on weight, belly skin-off weight, pump percentage, injected weight, belly cooked weight, smokehouse yield, #1 bacon slice yield, bacon cooking yield, fatty acid content, total saturated fatty acid (SFA), total monounsaturated fatty acid (MUFA), total polyunsaturated fatty acid (PUFA), unsaturated fatty acid: saturated fatty acid (UFA:SFA) and polyunsaturated fatty acid: saturated fatty acid (PUFA:SFA) ratios, and iodine values. Data was analyzed by using the PROC CORR procedures of SAS (2007). Correlation effects were deemed significant at a level of $P < 0.05$.

Results and Discussion

Belly characteristic and processing correlations

Thicker bellies (Table 4.1) correlated with heavier belly skin-on and skin-off weights ($R = 0.55$), heavier injected weights ($R = 0.56$), heavier belly cooked weight ($R = 0.60$), greater smoke house yield ($R = 0.69$), greater slice yields ($R = 0.58$). Increasing firmness by the belly flop skin side down method related to increasing ($R = 0.91$) firmness measurements with the belly flop skin side down method, heavier belly skin-off weights ($R = 0.54$), heavier injected weights ($R = 0.52$), heavier cooked belly weights ($R = 0.54$), and greater slice yields ($R = 0.64$). Increasing belly firmness using the belly flop skin up method related to heavier belly skin-off weights ($R = 0.58$), injected weights ($R = 0.57$), belly cooked weights ($R = 0.59$), and slice yields ($R = 0.72$). Belly skin-off weight was positively correlated with injected weight ($R = 0.99$), belly cooked weight ($R = 0.99$) and slice yield ($R = 0.86$). Pump percentage was positively correlated with smokehouse yields ($R = 0.57$). Increasing injected weights resulted in an increase in belly cooked weight ($R = 0.99$), and slice yields ($R = 0.86$). Heavier belly cooked weights correlated with higher smokehouse yields ($R = 0.54$) and slice yields ($R = 0.87$). Increasing smokehouse yields resulted in greater slice yields ($R = 0.53$). Finally, slice yields correlated with greater #1 bacon slice yields ($R = 0.61$).

Table 4.1 Fresh belly and belly processing correlations

	Belly length	Belly thickness	Flop skin down	Flop skin up	Belly skin-on weight	Belly skin-off weight	Pump %	Injected weight	Belly cooked weight	Smokehouse yield	Slice yield	#1 bacon slice yield	Bacon cooking yields
Belly length	1.00	-0.32*	-0.20	-0.30*	0.19	0.16	-0.12	0.14	0.12	-0.26	-0.13	-0.44	0.12
Belly thickness		1.00	0.38*	0.46*	0.55*	0.55*	0.26	0.56*	0.60*	0.69*	0.58*	0.19	-0.13
Flop skin down			1.00	0.91*	0.44*	0.54*	-0.03	0.52*	0.54*	0.29	0.65*	0.45	-0.03
Flop skin up				1.00	0.48*	0.58*	0.03	0.57*	0.59*	0.37*	0.72*	0.50	0.02
Belly skin-on weight					1.00	0.98*	0.23	0.98*	0.97*	0.41*	0.81*	0.08	0.19
Belly skin-off weight						1.00	0.21	0.99*	0.99*	0.44*	0.86*	0.13	0.22
Pump %							1.00	0.28	0.26	0.57*	0.17	-0.08	0.30*
Injected weight								1.00	0.99*	0.49*	0.86*	0.12	0.24
Belly cooked weight									1.00	0.54*	0.87*	0.14	0.22
Smokehouse yield										1.00	0.53*	0.18	0.15
Slice yield											1.00	0.61*	0.26
#1 bacon slice yield												1.00	0.17
Bacon cooking yields													1.00

*Values are significant at $P < 0.05$

It can be expected that thicker bellies would result in heavier belly weights both skin on and skin off. Thicker bellies would result in heavier cooked weights because there is more product contributing to the weight. As belly flop skin side down is highly correlated with the belly flop skin side down method it can be concluded that as an investigative method, either method can be used for similar results. The belly flop skin side down and the skin side up method are highly correlated with greater slice yields meaning that as investigative methods can be representative in differences in slice yields. Increasing belly skin-off weights being correlated with injected weight, belly cooked weight and slice yield can be explained by increasing product weight equaling higher yields. Increasing pump percentages being correlated to higher smokehouse yield can be a result of the pump level as the cooking process results in water loss, therefore more water would result in less cooking loss. It is to be expected that greater slice yields would result in a greater yield of # 1bacon slices as the category definitions for the most valuable bacon slice hinges on successful slice yields.

Fatty acid correlations

There were no correlations between any belly measurements and individual fatty acid (Table 4.2) or total fatty acids (Table 4.3) in this study. Increasing myristic acid (Table 4.4) resulted in increasing palmitic acid ($R = 0.79$), palmitoleic acid ($R = 0.71$) and vaccenic acid ($R = 0.69$), while decreasing linoleic acid ($R = 0.62$) and α-linolenic acid ($R = 0.55$). Raising palmitic acid content correlates with an increasing palmitoleic acid ($R = 0.68$), stearic acid ($R = 0.58$) and vaccenic acid concentration ($R = 0.68$), while decreasing linoleic acid ($R = -0.83$), α-linolenic acid ($R = -0.75$) and eicosadienoic acid ($R = -0.73$). Palmitoleic acid content correlated with increasing vaccenic acid ($R = 0.92$), a decrease in linoleic acid ($R = -0.58$), and eicosadienoic acid ($R = -0.57$). Stearic acid concentrations correlated with a decrease in linoleic acid (R = -

0.53). Increasing Oleic acid content resulted in an increase in vaccenic acid (*R* = 0.69) while decreasing linoleic acid (*R* = -0.80), α-linolenic acid (*R* = -0.76), and eicosadienoic acid (*R* = -0.74). Vaccenic acid was inversely related to linoleic acid (*R* = -0.71), α-linolenic acid (*R* = -0.58), and eicosadienoic acid (*R* = -0.65). Linoleic acid was positively related to α-linolenic acid (*R* = 0.95) and eicosadienoic acid (*R* = 0.94) while inversely related arachidic acid (*R* = -0.69), arachidonic acid (*R* = -0.61), and the minor fatty acids (*R* = -0.61). Increasing α-linolenic acid resulted in a decrease in arachidic acid (*R* = -0.75) and arachidonic acid (*R* = -0.68), while increasing eicosadienoic acid (*R* = 0.91). Arachidic acid was negatively related to eicosadienoic acid (*R* = -0.72) while positively related to arachidonic acid (*R* = 0.90). Increasing eicosadienoic acid resulted in decreasing arachidonic acid (*R* = -0.71).

The lack of belly measurements correlating with individual or total fatty acid is surprising. Some measurements such as belly length, and belly weights (skin-on and skin-off) should not be correlated with any one individual fatty acid or total fatty acid content as the factors controlling these measurements aren't necessarily related to fat content. It would be expected that the belly flop test would be highly correlated with fatty acid content especially in this trial as DDGS was being investigated. It is known that DDGS changes fatty acid content thereby resulting in softer bellies due to the change in fatty acid content. Other measurements such as pump percentage, injected weight, belly cooked weight, smokehouse yields, slice yields, and bacon cooking yields would be expected to not be correlated to fatty acid content as DDGS inclusion and the resulting change in fatty acid content did not affect those results, and not a function of fatty acid content.

Table 4.2 Belly measurements and fatty acid correlations

	Myristic	Palmitic	Palmitoleic	Margaric	Stearic	Oleic	Vaccenic	Linoleic	α- Linolenic	Arachidic	Eicosadienoic	Arachidonic
Belly length	0.12	0.21	0.24	0.17	0.03	0.04	0.17	-0.11	-0.03	-0.11	-0.17	-0.05
Belly thickness	0.18	0.07	0.13	-0.20	-0.14	-0.01	0.11	0.03	-0.01	-0.10	0.09	-0.11
Flop skin down	0.39*	0.43*	0.35*	-0.05	0.22	0.31*	0.43*	-0.35*	-0.34*	0.04	-0.22	-0.03
Flop skin up	0.31*	0.36*	0.28	-0.10	0.20	0.37*	0.41*	-0.31*	-0.30	-0.03	-0.14	-0.09
Belly skin-on weight	0.21	0.21	0.24	-0.09	0.06	0.12	0.29	-0.13	-0.10	-0.09	-0.02	-0.10
Belly skin-off weight	0.26	0.30	0.25	-0.08	0.17	0.18	0.34*	-0.20	-0.16	-0.07	-0.06	-0.12
Pump %	-0.12	-0.26	-0.11	0.10	-0.25	-0.13	-0.13	0.27	0.22	-0.23	0.25	-0.15
Injected weight	0.24	0.26	0.24	-0.07	0.14	0.16	0.32*	-0.17	-0.14	-0.09	-0.04	-0.13
Belly cooked weight	0.26	0.28	0.25	-0.08	0.13	0.17	0.33*	-0.18	-0.15	-0.09	-0.04	-0.13
Smokehouse yield	0.07	-0.04	0.11	-0.01	-0.22	-0.01	0.13	0.15	0.09	-0.29	0.21	-0.26
Slice yield	0.21	0.25	0.24	-0.17	0.16	0.25	0.37*	-0.18	-0.15	-0.10	-0.04	-0.17
#1 bacon slice yield	0.02	0.05	0.11	-0.21	0.06	0.21	0.23	-0.07	-0.03	-0.08	0.01	-0.14
Bacon cooking yields	-0.04	-0.13	-0.03	-0.03	0.04	-0.03	0.09	0.10	0.18	-0.15	0.13	-0.14

*Values are significant at $P < 0.05$

Table 4.3 Belly measurements and total fatty acid correlations

	SFA	MUFA	PUFA	TFA	UFA:SFA	PUFA:SFA	Iodine value
Belly length	0.15	0.10	-0.17	0.21	-0.17	-0.17	-0.17
Belly thickness	-0.02	0.04	-0.02	-0.07	0.01	-0.02	-0.02
Flop skin down	0.39*	0.38*	-0.46*	0.01	-0.39*	-0.46*	-0.45*
Flop skin up	0.33*	0.41*	-0.44*	-0.02	-0.33*	-0.44*	-0.43*
Belly skin-on weight	0.17	0.19	-0.22	0.19	-0.18	-0.22	-0.22
Belly skin-off weight	0.27	0.24	-0.32*	0.16	-0.29	-0.32*	-0.33*
Pump %	-0.29	-0.14	0.24	-0.03	0.28	0.25	0.26
Injected weight	0.24	0.22	-0.29	0.15	-0.25	-0.30	-0.30
Belly cooked weight	0.25	0.24	-0.30	0.13	-0.26	-0.31	-0.31*
Smokehouse yield	-0.34*	0.04	0.03	-0.18	0.11	0.04	0.04
Slice yield	0.24	0.30	-0.33*	-0.01	-0.25	-0.34*	-0.33*
#1 bacon slice yield	0.05	0.22	-0.17	-0.18	-0.06	-0.14	-0.14
Bacon cooking yields	-0.07	-0.02	0.04	0.02	0.06	0.05	0.04

*Values are significant at $P < 0.05$

Myristic acid (Table 4.5) was inversely related to UFA:SFA ratios (*R* = -0.58), PUFA:SFA ratios(*R* = -0.61), and iodine values (*R* = -0.61). Palmitic acid was positively correlated with MUFA (*R* = 0.55), but negatively correlated with UFA:SFA ratios (*R* = -0.75), PUFA:SFA ratios (*R* = -0.93), and iodine values (*R* = -0.93). Increasing palmitoleic acid resulted in increasing MUFA content (*R* = 0.56), but decreasing PUFA:SFA ratios (*R* = 0.-60) and iodine values (*R* = -0.56). Increasing stearic acid content would result in a decrease in UFA:SFA ratios (*R* = -0.60), PUFA:SFA ratios (*R* = -0.67), and iodine values (*R* = -0.72). Oleic acid was positively correlated with MUFA content (*R* = 0.84), but negatively correlated with UFA:SFA ratios(*R* = -0.53), PUFA:SFA ratios (*R* = -0.70), and iodine values (*R* = -0.64). Vaccenic acid was positively correlated with MUFA content (*R* = 0.71), but negatively correlated with PUFA:SFA ratios (*R* = -0.67) and iodine values (*R* = -0.63). Linoleic acid was inversely related to MUFA content (*R* = -0.89), but positively related with UFA:SFA ratios (*R* = 0.91), PUFA:SFA ratios (*R* = 0.83), and iodine values (*R* = 0.82). Increasing α-linolenic acid resulted in a decrease in MUFA content (*R* = -0.89) and PUFA content (*R* = -0.59) while increasing UFA:SFA ratios (*R* = 0.91), PUFA:SFA ratios (*R* = 0.73), and iodine values (*R* = 0.72). Arachidic acid was negatively correlated with SFA (*R* = -0.71), and UFA:SFA ratios (*R* = -0.84), but positively correlated with MUFA (*R* = 0.74) and PUFA content (*R* = 0.87). Eicosadienoic acid content was negatively correlated with MUFA content (*R* = -0.90) and PUFA content (*R* = -0.61) but positively correlated with UFA:SFA ratios (*R* = 0.89), PUFA:SFA ratios (*R* = 0.69) and iodine values (*R* = 0.67). Increasing arachidonic acid content resulted in decreasing SFA (*R* = -0.90) and UFA:SFA ratios (*R* = -0.76) while increasing MUFA content (*R* = 0.77) and PUFA content (*R* = 0.99). Saturated fatty acid content is inversely related to MUFA (*R* = -0.56) and PUFA content (*R* = -0.94). Increasing MUFA content would result in increasing PUFA content (*R* = 0.70) but would decrease UFA:SFA ratios (*R* = -0.79) and PUFA:SFA ratios (*R* = -0.55). PUFA content was negatively correlated with UFA:SFA (*R* = -0.68). Increasing UFA:SFA resulted in increasing PUFA:SFA (*R* = 0.65) and iodine values (*R* = 0.66). Finally PUFA:SFA content was positively correlated with iodine values (*R* = 0.99).

In pork belly fat from pigs fed a diet of increasing DDGS, the fatty acid content changes from more saturated to more unsaturated. In this study the saturated fatty acids and monounsaturated fatty acids move separately from the polyunsaturated fatty acids as they are inversely related. This is to be expected as DDGS is a source of polyunsaturated fatty acids and is high in linoleic acid. Increasing levels of DDGS will increase levels of polyunsaturated fatty acids while decreasing saturated and monounsaturated fatty acids resulting in higher iodine values.

Sensory panel correlations

Increasing brittleness scores (Table 4.6) would result in more off flavor scores (R = -0.68). Sensory characteristics did not correlate with any fatty acid or total fatty acid content (Table 4.7). In this study there were many off flavor responses that indicated burnt flavors were detected. Higher brittleness scores would indicate that bacon slices were more thoroughly cooked than less crispy slices. Therefore, it is likely that burnt off flavors are detected.

Table 4.4 Fatty acid correlations

	Myristic	Palmitic	Palmitoleic	Margaric	Stearic	Oleic	Vaccenic	Linoleic	α- Linolenic	Arachidic	Eicosadienoic	Arachidonic
Myristic	1.00	0.79*	0.71*	-0.08	0.15	0.28*	0.69*	-0.62*	-0.55*	0.32*	-0.54*	0.27
Palmitic		1.00	0.68*	-0.14	0.58*	0.52*	0.68*	-0.83*	-0.75*	0.35*	-0.73*	0.21
Palmitoleic			1.00	-0.12	-0.11	0.51*	0.92*	-0.58*	-0.45*	0.12	-0.57*	0.14
Margaric				1.00	-0.03	0.27	-0.08	0.12	0.15	0.03	0.12	-0.05
Stearic					1.00	0.27	0.02	-0.53*	-0.50*	0.31*	-0.41*	0.08
Oleic						1.00	0.69*	-0.80*	-0.76*	0.39*	-0.74*	0.36*
Vaccenic							1.00	-0.71*	-0.58*	0.26	-0.65*	0.25
Linoleic								1.00	0.95*	-0.69*	0.94*	-0.61*
α- Linolenic									1.00	-0.75*	0.91*	-0.68*
Arachidic										1.00	-0.72*	0.90*
Eicosadienoic											1.00	-0.71*
Arachidonic												1.00

*Values are significant at $P < 0.05$

Table 4.5 Total fatty acid correlations

	SFA	MUFA	PUFA	TFA	UFA:SFA	PUFA:SFA	Iodine value
Myristic	0.02	0.45*	0.19	0.05	-0.58*	-0.61*	-0.61*
Palmitic	0.21	0.55*	0.09	0.09	-0.75*	-0.93*	-0.93*
Palmitoleic	0.05	0.56*	0.05	0.21	-0.36*	-0.60*	-0.56*
Margaric	0.02	-0.15	-0.03	-0.02	0.06	0.11	0.09
Stearic	0.29	0.18	-0.01	-0.03	-0.60*	-0.67*	-0.72*
Oleic	-0.15	0.84*	0.26	0.02	-0.53*	-0.70*	-0.64*
Vaccenic	-0.04	0.71*	0.16	0.10	-0.47*	-0.67*	-0.63*
Linoleic	0.24	-0.89*	-0.50*	-0.07	0.91*	0.83*	0.82*
A-Linolenic	0.34*	-0.89*	-0.59*	0.02	0.91*	0.73*	0.72*
Arachidic	-0.71*	0.74*	0.87*	0.03	-0.84*	-0.26	-0.26
Eicosadienoic	0.39*	-0.90*	-0.61*	-0.12	0.89*	0.69*	0.67*
Arachidonic	-0.90*	0.77*	0.99*	-0.02	-0.76*	-0.07	-0.06
Other Fatty Acids	-0.90*	0.77*	0.99*	-0.01	-0.76*	-0.07	-0.07
SFA	1.00	-0.56*	-0.94*	0.04	0.40*	-0.34*	-0.36*
MUFA		1.00	0.70*	0.03	-0.79*	-0.55*	-0.51*
PUFA			1.00	-0.04	-0.68*	0.06	0.07
TFA				1.00	-0.03	-0.09	-0.08
UFA:SFA					1.00	0.65*	0.66*
PUFA:SFA						1.00	0.99*
Iodine value							1.00

*Values are significant at $P < 0.05$

Table 4.6 Sensory characteristic and belly processing correlations

	Brittleness	Bacon Flavor Intensity	Saltiness	Off flavor
Belly length	-0.29	-0.14	-0.19	0.15
Belly thickness	0.07	0.30	0.30	0.04
Flop skin down	-0.10	0.23	0.21	0.01
Flop skin up	-0.20	0.37*	0.27	0.14
Belly skin-on weight	-0.26	0.19	0.32*	0.11
Belly skin-off weight	-0.33*	0.23	0.32*	0.16
Pump %	-0.03	0.17	0.38*	0.05
Injected weight	-0.32*	0.24	0.35*	0.16
Belly cooked weight	-0.32*	0.22	0.35*	0.15
Smokehouse yield	-0.10	0.07	0.39*	0.03
Slice yield	-0.22	0.28	0.29	0.13
#1 bacon slice yield	0.08	0.20	0.04	-0.01
Bacon cooking yields	-0.38*	0.09	0.21	0.11
Brittleness	1.00	0.17	0.03	-0.68*
Bacon Flavor Intensity		1.00	0.15	0.11
Saltiness			1.00	-0.11
Off flavor				1.00

*Values are significant at $P < 0.05$

Table 4.7 Sensory characteristics and fatty acid correlations

	Myristic	Palmitic	Palmitoleic	Margaric	Stearic	Oleic	Vaccenic	Linoleic	α- Linolenic	Arachidic	Eicosadienoic	Arachidonic	Other Fatty Acids
Brittleness	-0.14	-0.30	0.05	0.05	-0.41*	-0.17	-0.05	0.18	0.15	0.11	0.05	0.18	0.18
Bacon Flavor Intensity	-0.21	-0.21	-0.06	0.19	-0.06	0.07	-0.01	0.08	0.11	-0.01	0.11	-0.07	-0.07
Saltiness	0.17	0.07	0.37*	-0.14	-0.26	0.19	0.34*	-0.10	-0.07	0.03	-0.02	0.04	0.04
Off flavor	0.18	0.32*	0.07	0.11	0.32*	0.2	0.11	-0.18	-0.12	-0.09	-0.07	-0.22	-0.22

*Values are significant at $P < 0.05$

Table 4.8 Sensory characteristics and total fatty acid content

	SFA	MUFA	PUFA	TFA	UFA:SFA	PUFA:SFA	IV
Brittleness	-0.34*	0.01	0.22	0.05	0.13	0.37*	0.38*
Bacon Flavor Intensity	-0.01	-0.01	-0.06	0.02	0.14	0.07	0.09
Saltiness	-0.07	0.20	0.03	0.23	0.02	-0.07	-0.04
Off flavor	0.38*	0.01	-0.27	-0.12	-0.10	-0.40*	-0.40*

*Values are significant at $P < 0.05$

Conclusions

The belly flop test is a commonly accepted test to measure belly firmness that has several variations in methodology. As slice yield is important to the industry, it is important to have a test indicative of slice yield. Belly firmness measured both skin-side up and skin side down, will indicate the amount of slice yield in pork bellies and is therefore a viable option for belly firmness tests. Furthermore, in porcine tissue it appears that when changing fat content that saturated and monounsaturated fatty acids will change inversely with polyunsaturated fatty acids. Thus, when changing fat content through the diet, it would be expected that polyunsaturated fatty acids are the major cause of loss in belly firmness as opposed to monounsaturated fatty acids contributing to less firm bellies.

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Appendix A - **Feed Rations**

Table A.1 Phase 1 diet composition (as-fed basis)[1]

Item	Dried distillers grains with solubles, %					
	0			20		
	0% glycerol	2.50% glycerol	5% glycerol	0% glycerol	2.50% glycerol	5% glycerol
Ingredient, %						
Corn	68.17	65.46	62.76	55.14	52.44	49.74
Soybean meal, 46.5% CP	26.63	26.83	27.03	19.69	19.89	20.09
Crude glycerol	---	2.5	5	---	2.5	5
Dried distillers grains with solubles	---	---	---	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[2]	0.08	0.08	0.08	0.08	0.08	0.08
Trace mineral premix[3]	0.1	0.1	0.1	0.1	0.1	0.1
Optiphos 2000[4]	0.03	0.03	0.03	0.03	0.03	0.03
L-Lys HCl	0.15	0.15	0.15	0.3	0.3	0.3
DL-Met	0.01	0.02	0.02	---	---	---
Total	100	100	100	100	100	100
Calculated composition						
Standardized ileal digestible (SID) amino acids, %						
Lys	0.98	0.98	0.98	0.98	0.98	0.98
Met:Lys	28	28	29	30	30	29
Met & Cys:Lys	57	57	57	61	61	60
Thr:Lys	60	60	60	61	61	60
Trp:Lys	19	19	19	18	18	18
CP, %	18.33	18.2	18.06	19.57	19.44	19.3
Total Lys, %	1.1	1.1	1.1	1.13	1.13	1.13
ME, kcal/kg	3,479	3,479	3,479	3,488	3,488	3,488
Lys:ME, g/Mcal	2.82	2.82	2.82	2.81	2.81	2.81
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 31.0 to 54.4 kg.
[2]Provided per kilogram of diet: 6,614 IU of vitamin A; 827 IU of vitamin D; 26 IU of vitamin E; 2.6 mg of vitamin K; 0.02 mg of vitamin B_{12}; 30 mg of niacin; 17 mg of pantothenic acid; and 5 mg of riboflavin.
[3]Provided per kilogram of diet: 16.53 mg of Cu from Cu sulfate; 0.298 mg of I from Ca iodate; 165 mg of Fe from Fe sulfate; 39.7 mg of Mn from Mn oxide, 0.298 mg of Se from Na selenite; and 165 mg of Zn from Zn oxide.

[4]Provided per kilogram of diet: 500 phytase unit (FTU) of phytase.

[5]Includes expected P release of 0.10% from added phytase.

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

	Dried distillers grains with solubles, %					
	0			20		
Item	0% glycerol	2.50% glycerol	5% glycerol	0% glycerol	2.50% glycerol	5 % glycerol
Ingredient, %						
Corn	74.3	71.6	68.87	61.2	58.5	55.8
Soybean meal, 46.5% CP	20.7	20.9	21.06	13.72	13.92	14.12
Crude glycerol	---	2.5	5	---	2.5	5
Dried distillers grains with solubles	---	---	---	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[2]	0.06	0.06	0.06	0.06	0.06	0.06
Trace mineral premix[3]	0.08	0.08	0.08	0.08	0.08	0.08
Optiphos 2000[4]	0.03	0.03	0.03	0.03	0.03	0.03
L-Lys HCl	0.15	0.15	0.15	0.3	0.3	0.3
Total	100	100	100	100	100	100
Calculated composition						
Standardized ileal digestible (SID) amino acids, %						
Lys	0.83	0.83	0.83	0.83	0.83	0.83
Met:Lys	29	29	28	32	32	32
Met & Cys:Lys	60	59	58	66	65	64
Thr:Lys	61	61	61	62	62	61
Trp:Lys	19	19	19	17	17	17
CP, %	16.1	15.9	15.79	17.31	17.17	17.04
Total Lys, %	0.93	0.93	0.93	0.97	0.96	0.96
ME, kcal/kg	3,483	###	3,483	3,494	3,494	3,494
Lys:ME, g/Mcal	2.38	2.38	2.38	2.38	2.38	2.38
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 54.4 to 77.1 kg.
[2]Provided per kilogram of diet: 5,511 IU of vitamin A; 689 IU of vitamin D; 22 IU of vitamin E; 2.2 mg of vitamin K; 0.02 mg of vitamin B_{12}; 25 mg of niacin; 14 mg of pantothenic acid; and 4 mg of riboflavin.
[3]Provided per kilogram of diet: 13.64 mg of Cu from Cu sulfate; 0.246 mg of I from Ca iodate; 136 mg of Fe from Fe sulfate; 32.7 mg of Mn from Mn oxide, 0.246 mg of Se from Na selenite; and 136 mg of Zn from Zn oxide.

[4]Provided per kilogram of diet: 500 phytase unit (FTU) of phytase.

[5]Includes expected P release of 0.10% from added phytase.

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

	Dried distillers grains with solubles, %					
	0			20		
Item	0% glycerol	2.50% glycerol	5% glycerol	0% glycerol	2.50% glycerol	5% glycerol
Ingredient, %						
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
Crude glycerol	---	2.5	5	---	2.5	5
Dried distillers grains with solubles	---	---	---	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[2]	0.05	0.05	0.05	0.05	0.05	0.05
Trace mineral premix[3]	0.07	0.07	0.07	0.07	0.07	0.07
Optiphos 2000[4]	0.03	0.03	0.03	0.03	0.03	0.03
L-Lys HCl	0.15	0.15	0.15	0.25	0.25	0.25
Total	100	100	100	100	100	100
Calculated composition						
Standardized ileal digestible (SID) amino acids, %						
Lys	0.72	0.72	0.72	0.72	0.72	0.72
Met:Lys	31	30	30	35	35	35
Met & Cys:Lys	63	62	61	72	71	71
Thr:Lys	62	62	62	66	66	65
Trp:Lys	19	19	19	17	17	17
CP, %	14.4	14.27	14.13	16.2	16.06	15.93
Total Lys, %	0.81	0.81	0.81	0.85	0.85	0.85
ME, kcal/kg	3,488	3,488	3,488	3,496	3,496	3,496
Lys:ME, g/Mcal	2.06	2.06	2.06	2.06	2.06	2.06
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 77.1 to 99.8 kg.
[2]Provided per kilogram of diet: 4,409 IU of vitamin A; 551 IU of vitamin D; 18 IU of vitamin E; 1.8 mg of vitamin K; 0.02 mg of vitamin B_{12}; 20 mg of niacin; 11 mg of pantothenic acid; and 3 mg of riboflavin.
[3]Provided per kilogram of diet: 10.75 mg of Cu from Cu sulfate; 0.193 mg of I from Ca iodate; 107 mg of Fe from Fe sulfate; 25.8 mg of Mn from Mn oxide, 0.193 mg of Se from Na selenite; and 107 mg of Zn from Zn oxide.

[4]Provided per kilogram of diet: 500 phytase unit (FTU) of phytase.

[5]Includes expected P release of 0.10% from added phytase.

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

	Dried distillers grains with solubles, %					
	0			20		
Item	0% glycerol	2.50% glycerol	5% glycerol	0% glycerol	2.50% glycerol	5% glycerol
Ingredient, %						
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
Crude glycerol	---	2.5	5	---	2.5	5
Dried distillers grains with solubles	---	---	---	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[2]	0.04	0.04	0.04	0.04	0.04	0.04
Trace mineral premix[3]	0.05	0.05	0.05	0.05	0.05	0.05
Optiphos 2000[4]	0.03	0.03	0.03	0.03	0.03	0.03
L-Lys HCl	0.15	0.15	0.15	0.25	0.25	0.25
Total	100	100	100	100	100	100
Calculated composition						
Standardized ileal digestible (SID) amino acids, %						
Lys	0.64	0.64	0.64	0.64	0.64	0.64
Met:Lys	31	31	31	37	36	36
Met & Cys:Lys	65	64	63	75	74	73
Thr:Lys	63	62	62	67	67	66
Trp:Lys	19	19	18	17	17	17
CP, %	13.65	13.51	13.37	15.44	15.31	15.17
Total Lys, %	0.76	0.76	0.76	0.79	0.79	0.79
ME, kcal/kg	3,488	3,488	3,488	3,496	3,496	3,496
Lys:ME, g/Mcal	1.92	1.92	1.92	1.92	1.92	1.92
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 99.8 to 123.8 kg.
[2]Provided per kilogram of diet: 3,307 IU of vitamin A; 413 IU of vitamin D; 13 IU of vitamin E; 1.3 mg of vitamin K; 0.01 mg of vitamin B_{12}; 15 mg of niacin; 8 mg of pantothenic acid; and 2 mg of riboflavin.
[3]Provided per kilogram of diet: 8.27 mg of Cu from Cu sulfate; 0.149 mg of I from Ca iodate; 83 mg of Fe from Fe sulfate; 19.8 mg of Mn from Mn oxide, 0.149 mg of Se from Na selenite; and 83 mg of Zn from Zn oxide.

[4]Provided per kilogram of diet: 500 phytase unit (FTU) of phytase.

[5]Includes expected P release of 0.10% from added phytase.

Appendix B - **Sensory Panel Evaluation**

Taste Panel Evaluation

Name ___________________ Date __________________ Time ________________

Sample No.	Brittleness	Flavor Intensity	Saltiness (rate after 5-6 chews)	Off flavor	Comments
Warm up					
A					
B					
C					
D					
E					
F					

<u>Brittleness</u>	<u>Flavor Intensity</u>	<u>Saltiness</u>	<u>Off flavor</u>	<u>Examples: off flavors</u>
8. Extremely crisp	8. Extremely intense	8. Extremely salty	8. None	Rancid
7. Very crisp	7. Very intense	7. Very salty	7. Practically none	“Piggy” boar taint
6. Moderately crisp	6. Moderately intense	6. Moderately salty	6. Traces	Metallic
5. Slightly crisp	5. Slightly Intense	5. Slightly salty	5. Slight	Bitter
4. Slightly soft	4. Slightly bland	4. Slightly unsalty	4. Slightly intense	Putrid
3. Moderately soft	3. Moderately bland	3. Moderately unsalty	3. Moderately intense	Earthy
2. Very soft	2. Very bland	2. Very unsalty	2. Very intense	Burnt
1. Extremely soft	1. Extremely bland	1. Extremely unsalty	1. Extremely intense	

Appendix C - **Interaction effects of DDGS[a] and Glycerol**

Table C.1 Mean effects of DDGS[a] and glycerol on belly processing characteristics

	0% DDGS			20% DDGS				P-value		
	Glycerol %			Glycerol %						
Belly Characteristics	0	2.5	5	0	2.5	5	SE	DxG	DDGS	Glycerol
Belly Length, cm	68.30	69.75	70.14	67.65	69.22	68.99	0.76	0.91	0.22	0.08
Belly Thickness, cm	3.12	3.06	3.03	3.11	3.06	3.11	0.07	0.81	0.68	0.71
Flop skin down, cm	18.98	17.91	19.20	17.64	16.40	17.64	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
Belly skin on 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, %	100.16	100.05	100.24	100.47	100.54	100.48	0.37	0.94	0.26	0.98
Slice Yield Weight, g	10.86	10.53	10.29	10.30	10.05	10.07	0.38	0.89	0.18	0.56
#1 Bacon Slice Yield, %	72.22	72.25	70.88	71.82	69.52	69.65	1.25	0.64	0.16	0.37
Bacon cooking yields, %	32.05	33.81	34.03	33.64	33.62	33.52	1.31	0.69	0.78	0.73

[a]Dried Distillers Grains with solubles

Table C.2 Mean effects of DDGS[a] and glycerol on proximate composition of bacon

	0 % DDGS			20% DDGS				P-value		
	Glycerol %			Glycerol %						
	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

[a]Dried Distillers Grains with solubles

Table C.3 Effects of DDGS[a] and glycerol on belly fatty acid composition

	0% DDGS			20% DDGS				P-value		
	Glycerol			Glycerol						
Item[b]	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	38.26	38.86	35.76	35.80	35.85	0.01	0.34	0.29	0.33
Total MUFA,%[2]	46.60	47.41	47.04	44.03	45.13	44.56	0.01	0.67	0.01	0.28
Total PUFA, %[3]	13.60	13.15	12.44	18.57	17.39	17.87	0.01	0.35	0.77	0.40
Total trans fatty acids, %[4]	0.49	0.50	0.51	0.48	0.50	0.49	0.01	0.69	0.01	0.50
UFA:SFA ratio[5]	1.58	1.58	1.53	1.76	1.75	1.74	0.35	0.80	0.01	0.64
PUFA:SFA ratio[6]	0.36	0.34	0.32	0.52	0.49	0.50	0.13	0.65	0.01	0.40
Iodine value, g/100g[7]	64.21	64.17	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).

[a]Dried Distillers Grains with solubles

[b]Percentage of total fatty acid content

Table C.4 Mean effects of DDGS[a] and glycerol on bacon sensory characteristics

	0% DDGS			20% DDGS							
	Glycerol %			Glycerol %				P-value			
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.
[a]Dried Distillers Grains with solubles