INVESTIGATION OF FACTORS THAT INFLUENCE BELLY QUALITY AND OF
COOKED BACON CHARACTERISTICS

by

BRANDON LEE GOEHRING

B.S., Iowa State University, 2007
M.S., Kansas State University, 2010

AN ABSTRACT OF A DISSERTATION

submitted in partial fulfillment of the requirements for the degree

DOCTOR OF PHILOSOPHY

Department of Animal Sciences and Industry
College of Agriculture

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Abstract

One experiment was conducted to determine the collagen and adipocyte characteristics in pork belly fat with different iodine values (IV) and if these factors contribute to belly firmness. An additional two experiments were conducted to create an objective method to score bacon distortion during cooking and to determine how IV and cooking method contribute to bacon distortion. Experiment 1 sorted pork bellies (n=72) into three IV categories: High 76.5 g/100g, Intermediate 70.5 g/100g, and Low 64.9 g/100g. Belly characteristics and firmness were measured before processing into bacon. After processing, 3 bacon slices were selected from the belly and analyzed for histochemistry and collagen analysis. No differences were observed between belly characteristics, while High IV bellies showed softer bellies. Adipocyte characteristics remained unchanged between IV groups. High IV bellies showed greater amounts of collagen. Experiment 2 cooked bacon slices (n=585) on three different appliances (griddle, microwave, and oven) and scored the resulting distortion using a subjective scale. Raw and cooked bacon characteristics were measured to determine which response variables contributing to distortion. Bacon slices were removed from 6 different locations within each belly sampled. Two distortion measurements were created to objectively describe distortion response (crest frequency and bacon distortion index. Subjective distortion scores, crest frequency, bacon distortion index, and raw and cooked bacon characteristics were shown to change between locations of the belly. Accuracy of predictive equations developed to predict distortion scores were low. Experiment 3 evaluated how IV interacts with cooking methodology to influence cooking characteristics, fat quality and distortion of bacon. Bacon slices (n=300) were organized into two IV categories, Low (61.52 to 65.54 g/100g) and High (78.83 to 85.34 g/100g) and cooked using three different appliances (oven, microwave, and griddle). Bacon from the Low IV group had the greatest amount of fat. Cooking bacon on a griddle showed the greatest distortion scores, while the oven produced bacon with the lowest distortion scores. Bacon with higher IV produced bacon with increased distortion scores. Bacon from the High IV group showed smaller cooked dimensions than the Low IV bacon. Neither cooking method nor IV level affected the cooked fatty acid composition.

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Major Professor
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Dedication

This thesis is dedicated to my brother Devin, who convinced me that quitting was a bad idea time after time.

Preface

This dissertation is written with the intention of publishing this work in Meat Science, the official scientific journal of the American Meat Science Association. This dissertation discusses covers multiple topics. **Chapter 2** focuses on a comprehensive review of literature explaining bacon production and factors that contribute to bacon quality. **Chapter 3** describes a study investigating if collagen content in bacon fat and adipocyte characteristics. **Chapter 4** details a study attempting to create an objective method to score bacon distortion. **Chapter 5** investigates how fat quality and cooking appliance impact cooked bacon performance. **Chapter 6** provides a commentary on how this work contributes to bacon literature and how future research can be built off this dissertation.

Chapter 1 - INTRODUCTION

Modern pork production feeding practices attempt to maximize gain and efficacy at the lowest cost possible. A consequence of these processes can be the development of soft bellies which have been linked to low slicing yields (Seman et al. 2013). When corn prices are high, cord dried distillers grains (DDGs) is a potential option to reduce feed prices. Dried distillers grains is higher in total fat content than regular corn which causes a higher unsaturated: saturated fatty acid ratio (Xu et al. 2010). Outside of DDGs, the addition of fat with high levels of unsaturated fatty acid will have a similar effect and contribute to the discussion of soft fat (Shackelford et al., 1990; Apple et al., 2007). There is no doubt that the fat component plays a role in belly and bacon quality, however some researchers feel that there might be other factors impacting belly firmness as simple correlations show that the fat component only contributes seventeen to twenty-one percent of the variation observed in slice yields (Seman et al. 2013). The collagen content in the fat component could play a role in belly firmness as collagen is a key component that supports the various fat depots (Enser 1984). Furthermore, the physical characteristics such as adipocyte size could also play a role in belly firmness. Factors that impact fat deposition also play a role in collagen formation as animals on high energy diets have increased quantities of total collagen. Similarly high energy diets are also associated with the addition of fat in swine diets (Ewan 2001).

Equally important to belly firmness and slice yields is the fat component effect on cooked bacon slices. The variability in fat unsaturation can lead to a range of melting points for belly fat which is evident in the differences in melting points between leaf fat (43-48°C), back fat (30-40°C), and bacon fat (34-48°C) (Cornelia et al., 2009, Smith and Smith 2011). Furthermore, the total amount of fat plays a role in cook yields as Jabaay et al. (1975) noticed that bacon from the fatter areas of the belly had lower cook yields. Bacon distortion is also affected by the fat component as Mandigo (2000) and Robles (2004) observed that distortion and cook yields were affected by the point of origin within the belly, which coincided with changes in fat composition. Several studies confound the issue by using different sampling methods and cooking methodologies. Thus the objectives of this study were to investigate how collagen and adipocyte

characteristics on belly firmness and the effects fat saturation have on bacon distortion and cooking yields.

References

Apple, J.K., C.V. Maxwell, J.T. Sawyer, B.R. Kutz, L.K. Rakes, M.E. Davis, Z.B. Johnson, S.N. Carr, and T.A. Armstrong. 2007. Interactive effect of ractopamine and dietary fat source on quality characteristics of fresh pork bellies. J. Anim. Sci. 85: 2682-2690.

Enser, M. 1984. The relationship between the composition and consistency of pig backfat. Special Report, Meat Research Institute. 2: 53-57.

Ewan, R.C. 2001. Energy utilization in swine nutrition. In A.J. Lewis, and L.L. Southern editors, Swine Nutrition 2nd edition. Boca Raton, FL; CRC Press. p85-94.

Cornelia, P. C. Adriana, T. Adrian. 2009. Effect of storage condition on the chemical properties of pork bacon. Anelele Universitatii din Oradea, Fasciculua: ecotoxicology, zootennie si tehnologii de inustrie alimentara. p. 565-572.

Jabaay, R.W., J.C. Forrest, E.D. Aberle, H.V. Courtenay, and M.D. Judge. 1975. Bacon quality criteria and associated carcass traits. J. Anim. Sci. 41:431-437.

Mandigo, Roger. 2000. Quality lean growth modeling- bacon quality assessment. http://old.pork.org/filelibrary/researchdocuments/97-1999-mandigo.pdf. (Accessed 1 December 2014.)

Robles, C.C. 2004 The effect of fresh and frozen bellies on bacon processing characteristics and bacon quality. MS Diss. University of Nebraska, Lincoln.

Seman, D.L., W.N.G. Barron, M. Matzinger. 2013. Evaluating the ability to measure pork fat quality for the production of commercial bacon. J. Meat Sci. 94: 262-266.

Shackelford, S.D., M.F. Miller, K.D. Haydon, N.V. Lovegren, C.E. Lyon, and J.O Reagan. 1990. Acceptability of bacon as influenced by the feeding of elevated level of monounsaturated fats to growing-finishing swine. J. Food Science. 55: 621-624.

Smith, S.B., and D. R. Smith. 2011. Analysis of rendered fats. In: L.M.L. Nollet and F. Toldra, editors, Handbook of analysis of edible animal by-products. CRC Press Boca Raton, Fl. p. 40.

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. It was "bakkon," in the Germanic language that 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 term for fresh pork diminished. 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 were domesticated in Egypt 10,000 B.C.E. and in Europe about 7,000 B.C.E. (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 nearly anything. These characteristics made it more convenient for explorers to travel with pigs. Hernando de Soto brought the first pigs to North America in 1525 when he landed near what is now known as Tampa Bay, Florida (Pruess, 2006). Eventually, pigs escaped from the settlers and the natives began consuming them. 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 built on salt including the Roman Empire where 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 currently know it today because salt impurities such as sodium nitrate 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 millennia B.C.E. 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 seasoning that adds 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 United States, Southerners ate mostly bacon and corn bread along with the rare fruit and vegetable, which was partially due to the emancipation of slaves under the 13th Amendment (Pruess, 2006). They 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 American Civil War (Pruess, 2006). Bacon was also a staple in British diets during the First World War when food rationing programs were 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 (2006), 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 United States, 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 due to the high nitrite content. The discovery of nitrosamine formation influenced the current government regulations on nitrite. 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. Bacon is often mentioned in popular media and 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 in Craig Morgan's hit country song "Little Bit of Life." 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 and 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 received.

Curing Process

There are two main ingredients for curing: salt and sodium nitrite (NO_2). The Egyptians, being one the first to domesticate pigs, 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 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 to 120 ppm in 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_2O). 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

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

Sebranek and Fox, 1985.

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 to make an acceptable bacon product only sodium nitrite and sodium chloride are required (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

Modern Bacon Labeling Regulations

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 (USDA, 2005) 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 $64^{o}C$ during processing. 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 can include 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.

In addition to standards of identity legislation, there are also several laws in the Federal Code of Regulations that govern how bacon is packaged. Regardless of the type of package, bacon in the retail store needs to be visible to the consumer in some way. The reasoning is to allow consumers to evaluate product color and leanness of the product. To do this, any packaging that is transparent or semitransparent that covers sliced bacon is not allowed to have

coloring whether it be words, lines, or marketing designs that might influence a consumer's evaluation of the leanness or color of the product. Packages containing sliced bacon that has that required transparent/semitransparent window need to display the cut surface of a representative slice. If the bacon is shingle packed, the viewing panel needs to be large enough so that at the minimum 70 percent of the displayed slice length is visible and be 3.81 cm (1.5 inches) wide. This display window needs to be placed within 1.59 cm (0.625 inches) of the top or bottom edge of a 0.45 kg (1 lb) and smaller package or within 1.9 cm (0.75 inches) of the top or bottom edge of a package larger than 0.45 kg package. It the package is a stack-packed slice layout, then the viewing window just needs to meet the size requirements and not the placement requirements of shingle-packaged bacon (CFR, 2014).

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. The strength of the brine is determined by the level of salt added and is measured in degrees via a salometer at a particular temperature (usually 40^oF/4.4^oC). The addition of other ingredients such as sugars, phosphates, nitrite, and sodium erythorbate will also affect the salometer reading. In general, brine strength will range from 60° to 70°, with 70° 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 and other ingredients, which is called a cover pickle. With a cover pickle, the ingredients will infiltrate the muscle fibers much quicker than in 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 curing environment. Another major disadvantage to this process is that it is a slow process requiring 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 19th 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 equally spaced needles, while injecting curing solution into many channels throughout the belly. Injection systems typically use a 70° (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.

Currently, most commercial bacon operations brine-cure bellies via injection. There are no rules as to how much curing brine is injected into fresh bellies, provided that after cooking bellies return to green weight. Processors will typically inject curing brine somewhere between 10-18% of belly green weight (Mandigo, 2009). Bellies are then stored in a cooler, thereby allowing the nitrite reactions take place to form 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 can occur in the finished bacon product. After the designated curing time, bellies are affixed to a bacon comb and hung in a smokehouse.

Belly Tumbling

An additional processing method that is often 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 and the removal of oxygen makes the curing reaction more efficient (Aberle et al., 2001). A small disadvantage is the increased production time needed for tumbling processes and increased floor space to accommodate the equipment.

Smoking Bacon

In general, there are no set smokehouse schedules for smoking of bacon as different processors use different cooking cycles. A smoking stage can also be included in all or part of the cooking schedule depending on processor designs or desires. The smoking cycle can be as short as 60 min or can be as long as several days depending on what the processor wants to do. The smoke-cycle time could be a relatively short time to obtain a "traditional /conventional smoke," or longer times can be programmed to obtain a "Double Smoked" product or a "Deep Smoked," product. Tables 2.2-2.4 (Hanson, 2009) (Sebranek and Bacus, 2007) illustrates examples of two different "conventional" smoke cycles and a "deep smoked" cycle.

Deposition of Wood Smoke on Meats

There are several factors that influence smoke deposition on cured bellies. Smoke density, air velocity in the smokehouse, and relative humidity in the smokehouse must be balanced for desirable smoked characteristics. Smoke density is important because the more concentrated the smoke is in the air in the smokehouse, the more smoke is available to adhere to the cured bellies. Air velocity in the smokehouse circulates the smoke, thereby bringing more smoke into contact with belly surfaces. Properly balancing smoke density and air velocity is a key consideration in depositing smoke because a high air velocity will prohibit a high smoke

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density (Pearson and Gillett, 1996). Relative humidity will influence how a product takes up smoke. A moist, damp surface will readily take up smoke. Too much moisture will cause the smoke to form unattractive splotches or dark muddy colors (color defects) on belly surfaces. If there are large spots of moisture on the surface, the smoke will adhere, in higher concentrations, causing darker unattractive splotches. To get the desired color, it is important to balance smoke density, air velocity, and humidity during smoking cycles (Pearson and Gillett, 1996).

Table 2-2 Conventional Bacon Smoke Cycle[1]

Step	Type	Time (hr)	Dry Bulb (°C)	Wet Bulb (°C)	Dampers	Main Fan	Smoke
1	Pre-dry	1	51.66	-	Auto	50%	Off
2	Smoke	4	54.44	-	Closed	50%	On
3	Cook[2]	1	55.56	-	Auto	100%	Off

[1]Hanson, 2009.

[2]Finish to 51.66°C.

Table 2-3 Deep Smoked Bacon Cycle[1]

Step	Type	Time (hr)	Dry Bulb (°C)	Wet Bulb (°C)	Dampers	Main Fan	Smoke
1	Smoke	2	40.56	-	Closed	25%	On
2	Smoke	2	43.33	-	Closed	25%	On
3	Smoke	2	46.11	-	Closed	25%	On
4	Smoke	2	48.89	-	Closed	25%	On
5	Color Set	2	51.67	-	Auto	50%	On
6	Cook[2]	2	54.44	46.11	Auto	100%	On

[1]Hanson, 2009.

[2]Finish to 51.66°C.

Table 2-4 Natural Bacon Smoke Cycle[1]

Dry Bulb (°C)	Wet Bulb (°C)	RH%	Time (minutes)
42	35	70	75

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63	-	-	60
63	-	-	15
57	-	-	90
60	49	55	Finish to 53°C[2]

[1]Sebranek and Bacus 2007

[2]Estimated 180 minutes

The Importance of Smoking to Bacon

The smoking process provides several advantages to bacon. Smoke is highly complex and can contain over 300 different compounds (Pearson and Tauber, 1984), some of which can help preserve bacon. 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 maximize the Maillard browning reaction, it is important to control the humidity on the surface of the bacon. Maximum color development will occur with a surface moisture content of 12-15% (Pearson and Tauber, 1984).

Steps for Maximizing the Smoking Process

As previously mentioned, there are several factors that need to be controlled for smoke deposition, which means that different types of smokehouses or different types of smoke generators can influence how those factors (air velocity, smoke density, etc.) are employed to smoke bacon. Regardless of equipment set up, there are steps that can be taken to maximize the

process. Some of these steps can be combined or are not needed, depending on what the processor wants to accomplish. A first step is a reddening/condition stage. In this stage, the smokehouse is set at a temperature that will bring the surface temperature to 40.55-46.11°C. Evaporative cooling will cause the exterior surface to become moist and tacky, allowing for smoke to bind to the moisture on the product exterior. If bellies are injected and immediately entered into the smokehouse it is possible that there is natural variation in surface moisture due to the variability in the injector. It is also a common procedure for processors to inject bellies and hold them in curing coolers to allow color development, in which case it is possible that there could be cooler shrink. Depending on cooler loading, and variability in belly weight and thickness, it is possible that variation will exist in belly moisture. The rise in temperature in this step essentially acts as a method to reduce variation in surface moisture. A second step would be the pre-drying step. This step essentially controls smoke absorption and color because this step allows further control over the humidity in the smokehouse (Hanson, 2009). After the pre-drying step, smoking can begin. During the smoking process the surface temperature must be under 63°C. As temperatures climb above 63°C, myofibrillar proteins start to denature, which can lead to surface dehydration (Aberle et al., 2001). The surface of the proteins must be in a state to take smoke, which as previously mentioned requires some humidity on the belly surface, though for most commercial processes, this high temperature is unlikely to be a problem. After smoking, the belly surface must be dried so that the smoke color is set and does not wash away. In some instances, such as at the Kansas State Meat Laboratory (Manhattan, KS), there might be a lethality step in the Hazard Analysis and Critical Control Point (HACCP) plan that requires the bellies be cooked to high temperatures (64°C). As a result, the cooked bellies need to be quickly chilled. One way to do this is with a cold water shower. If the smoke is not set, it could fade or be washed off. The drying step can be accomplished by raising the dry bulb temperature, which would drop the humidity in the smokehouse to allow for drying (Hanson, 2009).

Thermal Processing of Bacon

Pearson and Tauber (1984) report that it is common for processors to use multi-temperature/stage cooking with the goal of an internal temperature of 52.2 to 55.5^{o}C or single temperature programs targeting 54.4^{o} to 60°C (Pearson and Tauber, 1984)**.** The previously mentioned temperatures serve as a good summary for belly cooking. However, it is more

common for commercial processors that cook large quantities of bacon to target an end-point temperature in the range of 50 to 53.3°C (Bob Hanson, HansonTech, Hudson, WI, personal communication). In comparison, small processors such as the Kansas State University meat laboratory would choose to cook to higher temperatures such as 64.4°C. A possible reason for this is that cooking cured meat to higher internal temperatures helps develop and stabilize cured color (Pearson and Tauber, 1984). Another important fact for considering end point temperatures and the reason bacon is thermally treated instead of fully cooked is the melting point of fat. In a conversation with Hormel (Brian Andrews, Hormel, Austin, MN, personal communication), smokehouse temperatures near 54°C (130°F) are when it is possible to observe fat rendering in bellies. Unfortunately there are differences in reported melting point for pork fat. Ockerman and Basu report that the solidification point for pork fat is in the range of 36-40°C (97-104°F), meaning that the melting point is above this range. To be more specific, in terms of the melting point of anatomical location in pork fat, pork leaf fat has been described having a melting point in the range of 43- 48°C (110° -118°F), and back fat in the range of 30-40°C (86-104°F) (Smith and Smith, 2011). To date there is limited information on the melting point of bacon fat. Cornelia et al. (2009) claims that the melting point of bacon fat has been established in the range of 34 - 48°C (93.2-118.4°F), but no data or citation was provided and this information does not show up in bacon literature. Regardless, it is reasonable to expect that the melting point of belly fat is closer to that of back fat than the leaf fat due to how fat saturation influences melting point. Graham et al. (2014) reported that leaf fat from pigs fed standard corn-soybean diets displayed a much lower iodine value (52 g/100g) when compared to the belly (59 – 61 g/100g) and back fat (64 – 67 g/100g) depots. This is corroborated by the fact that multiple publications report that the difference between belly and back fat iodine value is even smaller than what is reported by Graham (Asmus et al. 2014, Benz et al. 2008, Duttlinger 2008, and Kellner, et al. 2014).

Processing After the Smokehouse

After cooking, bellies are stored in tempering coolers with the goal of reducing internal temperature to -3.3 to -2.2°C. After the tempering stage, bellies are pressed and sliced. By reducing the internal temperature to -3.3 to -2.2°C, bellies retain their shape when pressed. Pressing the bellies allows greater uniformity and higher slicing yields. Bellies are sliced by

high-speed slicers and the resulting pieces are mechanically shingled or arranged in whatever layout desired for packaging. Slices are commonly cut to one of 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 for retail markets (Pearson and Tauber, 1984). There are several ways in which bacon is marketed and sold. The most recognizable arrangement in retail stores in shingled bacon. The shingling layout minimizes the packaging material needed while simultaneously providing a clear view of the product (Figure 2-1). Another arrangement that has gained popularity in the retail market is a stack pack arrangement (Figure 2-2). In addition to the retail markets, the food service sector has several different arrangements that are commonly referred to as HRI (Hotel, Restaurant, and Institution). One of the more popular configurations is the single slice layout (Figure 2-3). With this layout, seven to ten slices of bacon are laid out in a single row on a sheet of paper, and boxes are filled with multiple sheets of bacon and covered with a plastic poly-liner. The platter style layout (Figure 2-4) is similar to the single slice layout but the bacon is shingled over a divider sheet. The last HRI configuration is bulk box bacon (Figure 2-5). In this configuration, the slices are not shingled or separated; all of the slices are stacked together on cardboard dividers (Mandigo, 2009).

Figure 2-1 Example of shingling

Figure 2-2 Stack pack bacon

Figure 2-3 HRI Single slice layout

Figure 2-4 HRI Platter style layout

Figure 2-5 HRI Bulk boxed bacon

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 enhance browning via Maillard browning reactions. Browning can also occur if there is a large amount of reducing sugar during cooking. 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 in 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.

Pre-Cooked Bacon

The popularity of bacon in the modern mainstream media has contributed has increased demand in the foodservice industry. This has led to growth in bacon markets because the foodservice sector started including bacon in new foods. The market for pre-cooked bacon has continued to grow. In 2003, there were 234 million pounds of pre-cooked bacon produced. In 2006 this number grew to 291 million pounds (National Pork Board, 2007). In 2007, 47.5% of pre-cooked bacon was being bought by quick-service restaurant chains. Bacon has been included in sandwiches, salads, and used as a flavor enhancer, which meant that there was an increase in pre-cooked bacon sales to meet demand (National Pork Board, 2007).

As previously mentioned, USDA labeling laws require pre-cooked bacon slices to have a minimum of 60% cook loss (maximum 40% yield) in order to be labeled as pre-cooked. To achieve this, cooking processes have a set time and temperature setting to meet the required cooking loss. There are several types of commercial cooking processes to produce pre-cooked bacon. A patent search shows that microwave ovens, belt grills, linear ovens, and spiral ovens are common methods for cooking bacon. In fact, Armour and Company filed a patent for machinery that was able to produce a continuous oven system to cook bacon as early as 1961 (Nelson, 1969). In one of the earliest pre-cooked bacon studies (Robles, 2004), a dual conveyor system was used where the sections (platens) forming the conveyor belt could be set to specific temperature and specific distances from the bacon.

Many cooking processes have a contact surface placed on top of the bacon to reduce curling and distortion, but doing so risks burning slices and thereby reducing product yields because the burnt pieces are sorted off the process. This leads to the most distinguishing characteristic of retail pre-cooked bacon, which is that slices are very thin and flat, and are visibly different from pan-fried slices. Despite limited consumer information on the desirability of commercial pre-cooked bacon versus pan-fried bacon, some companies such as Unitherm

Food Systems and Hormel Foods Corporation believe that there is market for pre-cooked slices that look "wavy and natural," like pan-fried slices. In their marketing campaign for this product, Hormel also implies that most pre-cooked bacon products don't taste like pan-fried bacon, either. These two companies (currently in a legal battle for patent infringement claims) created a cooking process that produces slices that look like pan-fried slices and are currently marketing this product as "Hormel Bacon 1, Perfectly Cooked Bacon" (Food Processing, 2014).

Microbiological Activity in Bacon

When considering the previous section reviewing the thermal processing of bacon and Tables 2.3 and 2.4 explaining common smokehouse cycles, it is obvious that bacon prepared for retail is commonly a heat-treated product. This means that with the exception of products looking to label bacon as "roasted," or "partially cooked," bacon is not considered a fully cooked product. This means that retail and HRI bacon is not shelf stable and is intended to be refrigerated and further cooked by the consumer (Taormina and Bartholomew, 2005). Several authors (Taormina and Bartholomew, 2005; Gardner, 1982) agree that despite not being a fully cooked product, bacon has rarely been linked to outbreaks of foodborne illnesses. However, this does not exclude bacon from microbial activity. As there are no standard lengths or temperatures for bacon smokehouse cycles, it is possible that extended times in the smokehouse with temperatures above 8°C may serve as an incubation period for bacteria populations (Kukay et al., 1996). Several types of nonpathogenic bacteria can be found in bacon (Jay et al., 2005) as well as several pathogenic microorganisms such as *Salmonella, Staphylococcus aureus, campylobacter, Yersinia enterocolitica, and Listeria monocytogenes* (USDA, 2013). In addition, there are several parasites that are associated with pork products such as *Toxoplasmosis gondii, Trichinella spiralis, and Tenia solium*.

Spoilage Bacteria in Bacon

Spoilage bacteria readily grow on all meat products due to favorable moisture content, pH, and an abundance of nutrients. In order to cause spoilage, the microbial population must reach a certain population level. Spoilage of processed meat can be detected by sliminess, souring, and/or greening. It is common that slime contains Yeasts and *Lactobacillus, Enterococcus, Weissella,* and B. *thermosphacta* species. Moist surfaces such as those in meat products provide a favorable environment for slimes to develop. Souring is generally caused by

lactobacilli, enterococci, or similar organisms (Jay et al., 2005). Greening can occur in two ways, but the compound that specifically causes greening in processed meats is H_2O_2. The formation of H_2O_2 commonly occurs when meat in vacuum packaging is exposed to oxygen. The compound H_2O_2 then reacts with the nitrtosohemochrome pigment to form a green-colored oxidized porphyrin (Jay et al., 2005). A second way to produce H_2O_2 is during cooking. When heat is applied, nitrite can inactivate the enzyme catalase, which is an enzyme found in all living organisms. Catalase drives the chemical reaction that decomposes hydrogen peroxide to water and oxygen. In the absence of Catalase, the accumulating peroxides interact with meat pigments to form a green pigment called choleglobin. Finally, H_2O_2 can be produced by *Lactobaciullus fructivorans*, *Lactobacillus jensenii,* and *Weissella viridescens*. However, these organisms only produce H_2O_2 in environments with low oxidation reduction potential. *Weissella viridescens* would be the most common causative organism in this case because it is resistant to sodium nitrite at levels over 200 ppm and can grow in environments that contain up to 4% sodium chloride (Jay et al., 2005).

A study investigating the microbiology of sliced, vacuum-packaged bacon (Cavett 1962) found that the microbial population consisted of micrococci, staphylococci, and several lactic acid-producing bacteria such as lactobacilli and pediococci. This study demonstrates the roles salt and temperature play in determining the types of bacteria dominating the environment. When high (8-12%) and low (5-7%) salt bacon samples were held at 20°C, after 22 days micrococci was the dominant species. When low salt bacon samples were stored at 20°C for 22 days, staphylococci was still the dominant species, but at 30°C micrococci were the dominant species. The major reported microbial populations in this study (micrococci and lactic acid bacteria) were confirmed in other microbial studies (Tonge et al., 1964, Dempster, 1972).

However, due to the salt content, nitrite content, and smoking processes, bacon is resistant to spoilage when compared to other meat products. The importance of the relationship between salt content and bacteria populations was studied by Aaslyng et al. (2014). In this study, 3 levels of salt were used: a reference level (2.8%); a moderately reduced salt content (2.06%); and a greatly reduced salt treatment (1.41%). This study found the high salt content (reference treatment, 2.8%) contained significantly higher counts of total bacteria and lactic acid bacteria when compared to the reduced salt treatments. It also found that the yeast population was the highest in the reference salt treatment and decreased in total counts when salt was

reduced. It was inferred that the higher salt content limited bacteria growth, thereby allowing yeast growth.

Salmonella in Bacon

Salmonella spp. is a widespread food-borne pathogen that occurs on a global scale (Wang et al. 2015). The CDC estimated that salmonella causes 1.2 million illnesses every year in the United States (Centerd for Disease Control, 2014). The symptoms of this disease are diarrhea, fever, and abdominal cramps. The principle vector for contamination on food products is via food contact surfaces (Shi and Zhu, 2009). Salmonella is a mesophilic, rod-shaped, gram-negative, facultative anaerobe, pathogenic bacteria. In a study by Wang et al. (2015) investigating the *Salmonella* spp. transfer rate from stainless steel to processed meat, it was reported that bacon showed a higher *Salmonella* transfer rate when compared to sliced ham, Cantonese sausage, and roast pork. It was concluded that the rate of *Salmonella* transfer is dependent on the receiving surface, and that the high fat content that is exposed contributes to *Salmonella* uptake. However, the processing methodology of bacon does limit the potential for *Salmonella* growth. While *Salmonella* spp. are tolerant of salt concentrations up to 9%, nitrite and the smoking process are known to limit *Salmonella* growth. Nitrite is most effective at limiting growth when meat products are at a low pH (Jay et al., 2005). Pegg and Shaidi (2000) reported that pH is very important to the efficacy of nitrite as an antimicrobial. At pH of 7.0, no antimicrobial action is likely to occur; however, pH in the range of 5.7 and 6.0 reduced cell growth. Wood smoke produces phenolic and carbonyl compounds (Lingbeck et al., 2014). Phenolic compounds interact with the cytoplasmic membrane and cause intracellular fluid leakage (Davidson, 1997). Carbonyl compounds will inactivate enzymes in the cytoplasm and cytoplasmic membrane, thereby reducing growth potential (Milly et al., 2003). The concept that bacon processing methods limit *Salmonella* growth potential was illustrated in a study by Kukay et al. (1996) who investigated the application of HACCP concepts in small and medium processors. This study reported that over nine different sampling repetitions, *Salmonella* was not found growing on bacon from small- and medium-sized processors.

Staphylococcus aureus in Bacon

Staphylococcus spp. is gram-positive cocci that is mesophilic and is a facultative anaerobe. Unfortunately, *Staphylococcus* can be found in bacon (Gardner 1982, Dempster

1972). It is of particular concern in bacon production because it is salt tolerant and can grow in sodium chloride solutions as high as 10%. In addition to being salt tolerant, *Staphylococcus* produces heat-stable enterotoxins. The *S. aureus* strain can grow in temperature ranges of 7-48°C, with an optimum temperature of 37°C (Stewart, 2003). The average decimal reduction unit (the time and temperature which would cause a reduction of 1 $\log_{10}$) is at 4.8-6.6 minutes at 60°C (140°F). However, 60°C is a temperature that most likely is outside the temperature range of common bacon smokehouse thermal cycles. Due to the large range in growth temperatures and potentially long smokehouse cycles that keep belly temperatures above 7°C, there is cause to be concerned about *S. aureus* growth. To determine how *S. aureus* grows in bacon processing operations, Taromina and Bartholomew (2005) inoculated intact bellies and ground bellies with *S. aureus*. The study was set up in a 2×2 factorial with smoked, non-smoked, and cooling regimens. All bellies were cooked to an internal temperature to 48.9°C in 6 hours. The first cooling treatment was a 3 hour cool down to 7.2°C. The second cooling treatment cooled temperatures from 48.9°C to 26.7°C in 5 hours and then cooled from 26.7°C to 7.2°C in 10 hours. It was found in the ground belly model that under a 3 hour cooling cycle there was a 2.38 log increase in *S. aureus* growth, but only a 0.68 log increase in the smoked ground bellies. With the 15 hour cooling time it was found that the smoke-free ground belly treatment had a log increase of 4.05 while the smoked ground bellies has a 3.97 log increase in *S. aureus* counts. With these treatments no enterotoxin was found on the smoked ground bellies in the 15 hour cooling cycle. The smoke-free ground belly treatment with the 15 hour cooling cycle had enterotoxin present in 5 out of 6 samples. This study was replicated with a whole belly production model, and the authors found that with this model no *S. aureus* grew and there were no enterotoxins present. This was explained by the broad spectrum antimicrobial potential of the phenols that come from the smoking process as well as the smoking process reduces surface moisture, thereby concentrating the sodium chloride content resulting in a massive decrease in surface water activity (Taormina and Bartholomew, 2005).

Clostridium spp. in Bacon

Clostridium is a gram-positive rod-shaped bacteria. This organism is anaerobic, and forms spores that are very heat resistant. The specific foodborne pathogens of note are *C. botulinum* and *C. perfringens* (Jay et al., 2005). The effect of sodium nitrite on toxin production

of *C. botulinum* in bacon was investigated by Christiansen et al. (1974). In this study, sodium nitrite was included in curing treatments at 0, 30, 60, 120, 170, and 340 ppm in pork bellies. Storage temperature treatments were at 7 and 27°C and storage sampling dates were at day 7, 14, 28, 54, and 84. Two inoculum levels were used: a low (52/g) and a high (4,300/g). Results of this study showed that at 7°C (temperature abused bacon), the addition of sodium nitrite effectively eliminated *C. botulinum* growth in all nitrite formulation across the entire 84 d storage period. At storage temperatures at 27°C, the addition of nitrite reduced bacteria growth but did not eliminate it. Twenty-four of the 25 samples that were in the low inoculum, no nitrite treatment showed *C. botulinum* growth. Samples with the low inoculum level showed a reduction in growth at 120 ppm (8 of 25 showed growth) and no contamination in samples over the 120 ppm level. With the high inoculum levels, samples that had no nitrite showed all samples were contaminated. A reduction was seen with the addition of nitrite; with the highest level of nitrite (340 ppm) reducing growth so that only three samples were found to be contaminated.

In addition to studying *S. aureus*, Taormina and Bartholomew (2005) also investigated how *C. perfringens* grows on bacon. This study cooked bacon for 6 hours to reach an internal temperature of 48.9°C with a 3 or 15 hour cooling time. Similar to the *S. aureus* study, ground belly and whole belly models were used. Bellies were subjected to two different processing treatments, one where the bellies were processed with a smoke application and one where the bellies weren't smoked. Under a 3 hour cooling cycle, smoke-free bellies displayed a 0.84 log increase in cell growth, while the bellies processed with a smoking application showed a 0.24 log growth. Under the 15 hour cooling cycles, smoke-free bellies showed a 3.93 log increase in cell count, but the smoke ground belly samples displayed a 0.33 log increase. When whole belly models were used there was no *C. perfringens* growth regardless of cooling cycle with smoke-treated samples. Without a doubt, the phenols originating from smoke application can greatly reduce *C. perfringens* growth. In addition to the antimicrobial activity of phenols, it is reported ingoing nitrite levels between 100-180 ppm can inhibit *C. perfringens* (O'Leary and Solberg, 1976).

Listeria monocytogenes in Bacon

Listeria monocytogenes is a gram-positive non-sporeforming rod. This organism is a facultative anaerobe that readily grows at temperatures between 7°C and 10°C (Jay et al., 2005). Listeria is also resistant to a wide range of pH values and can withstand high concentrations of sodium chloride and sodium nitrite (Rocourt et al., 2000). A potential control for *L. monocytogenes* is the adding of lactic acid bacteria that produced bacteriocins to inhibit the growth of *L. monocytogens* (Abee et al., 1995). Kouakou et al. (2009) investigated the possibility of using *Lactobacillus curvatus* strain CWBI-B28mt and CWBI-B28wt in meat systems with different fat content and levels of nitrite added. Low fat (13%) and high fat (43%) meat blocks combined with sodium nitrite (20 ppm) and without nitrite treatments were sampled once a week over the course of 6 weeks while stored at 4°C. Preliminary examinations for this study showed that over 6 weeks, *L. monocytogenes* increased colony forming units regardless of the presence of nitrite, illustrating that nitrite in itself is not an effective method to limit *L. monocytogenes* growth. In this study, increasing the fat content increased the ability of *L. curvatus* strains to grow, while nitrite had no significant effect on growth. This shows that bacon would provide an ideal environment for *L. curvatus* to grow in. This study found that the CWBI-B28wt strain drastically reduced Listeria counts regardless of the presence of sodium nitrite, while the CWBI-B28mt strain failed to reduce Listeria counts due to nitrite. Overall, there is much potential for bacteriocin producing *Lactobacillus* species to be used as a methodology to control Listeria in bacon.

Parasites Associated with Pork Production

The most well-known parasite associated with pork production is *Trichinella spiralis*. This parasite is a roundworm that is unique in that it is transmitted directly from host to host and has no stages of its life cycle that requires living outside of the host (Jay et al., 2005). *Trichinella spiralis* lives in the duodenal and jejunal mucosas of mammals. Upon hatching, the larvae migrate through the intestinal wall into muscle. Larvae encyst in the muscle and can live up to 10 years in a host (Jay et al., 2005). Upon the host's digestion, the calcified wall that makes up the cyst is dissolved in the stomach, and then the worms migrate into the intestines. Developed countries like the United States that have modern pork-producing systems have effectively eliminated *T. spiralis* from the pork supply (Pyburn et al., 2005). As early as 1970 it

was found that the prevalence of this parasite in pigs was around 0.12% of the world's tested population (Gamble, 1997). Symptoms of infection include nausea, abdominal pain, diarrhea, and vomiting (Jay et al., 2005). Prevention of *T. spiralis* can be controlled by effective rodent control that keeps rodents away from feeds, and by avoiding feeding uncooked house scraps or infected meat scraps. If meat waste is fed to pigs, it has to be cooked and any institution doing so must have a state license (Jay et al., 2005, Pyburn et al., 2005). Freezing meat products will destroy *T. spiralis.* Cooking meats to an internal temperature of 60°C will kill larvae. Unfortunately, it is not common for bacon to be cooked to internal temperatures reaching 60°C, making bacon a higher risk for infection comparatively. Unlike with bacteria, the effectiveness of the curing process is dictated by a combination of salt, temperature, and time, and therefore this is not recommended as an effective control for cured meats (Gajadhar et al., 2009).

     Taenia solium is a flatworm that causes Taeniasis. This worm is unique in that the larval stage resides in a herbivore, while the adult stages predominate in a human host. Symptoms are asymptomatic; however, if humans ingest eggs, cysticerci develop in muscle tissue. This parasite is endemic in Central and South America, Eastern Europe, Central and Southern Africa, India, and South East Asia (Gamble, 1997). In general, infectious cases reported in the U.S. are mainly due to immigration from endemic areas (Gamble, 1997). Prevention of this organism involves proper disposal of waste and is effectively eliminated with modern production systems. Cooking meat to 60°C or freezing meat to -10°C for 10-15 days can kill *T. solium.*

     Toxoplasma gondii is a protozoan parasite that causes toxoplasmosis. This parasite is considerably more common compared to other parasites due to cats being a vector of infection. Most commonly, this infection is asymptomatic; however, if symptoms do occur it will be in the form of fever, headaches, muscle pain, and swelling of the lymph nodes (Jay et al., 2005). The life cycle begins when oocysts are ingested. The oocysts are then degraded in the intestine, effectively releasing sporozoites. The sporozoites then migrate to other muscles and form tissue cysts. Infection rate of pigs in the U.S. was estimated at 23.9% of pigs in 1983-1984 (Gamble 1997). Control of this parasite entails avoiding environmental contamination with cat feces and avoiding the consumption of contaminated meat products. *T. gondii* can be killed by cooking meat to internal temperatures of 49°C for 336 seconds (Gamble, 1997). This parasite is instantly killed when frozen at temperatures at -9.4°C.

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 was no quality grade for bacon, consumers still discriminated against some bacon products based on subjective visual evaluation criteria. Due to these consumer demands, the USDA 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 prompted investigations into what consumers deemed to be 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 is 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).

Measuring Belly Firmness

As previously mentioned, soft bellies are associated with poor slicing yields. To quantify belly firmness, the most recognized method is the belly bar test. In this methodology, the belly is centered over a bar (metal rod or smokehouse stick) at the midpoint of the length of the belly. The distance between the ham and shoulder is measured with a longer distance representing a firmer belly and a smaller distance representing a soft belly (Cooper et al., 2001). Over time, several variations of this methodology have been used. Rentfrow et al. (2003) affixed a 7.6 cm diameter polyvinyl chloride pipe perpendicular to a board that had a 2.54 cm grid matrix drawn on it. Firmness was quantified by counting the boxes between the ham and shoulder ends. Again, a larger distance between ends represented a firmer belly while a smaller distance signified a softer belly (Figure 2-1).

Figure 2-6 Rentfrow Firmness Methodology

a. This illustrates a lower lateral, higher vertical flex; firmer belly.
b. This illustrates a higher lateral, lower vertical flex; softer belly.
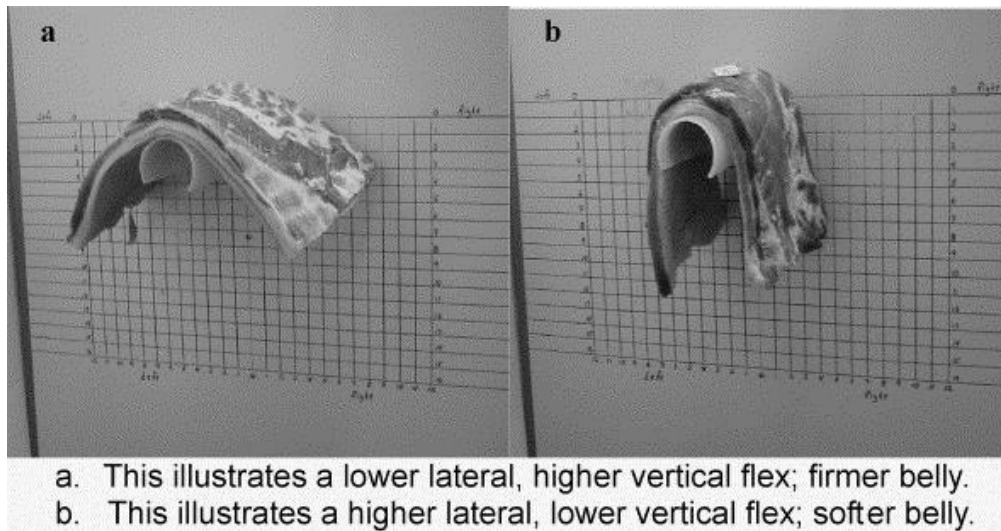
Another variation of the belly bar test was designed by Whitney et al. (2006), which again required the belly to be centered over a bar as previously described. The distance between the ham and shoulder ends of the belly is still measured and the firmness score is expressed as the upper angle of the isosceles triangle that is formed by hanging the belly over a central bar. The firmness score is equal to $\cos^{-1} \{[0.5(L^2) - D^2]/ [0.5(L^2)]\}$ where L = length of belly and D = the distance between the ends (Figure 2-2).

Figure 2-7 Whitney Firmness Methodology
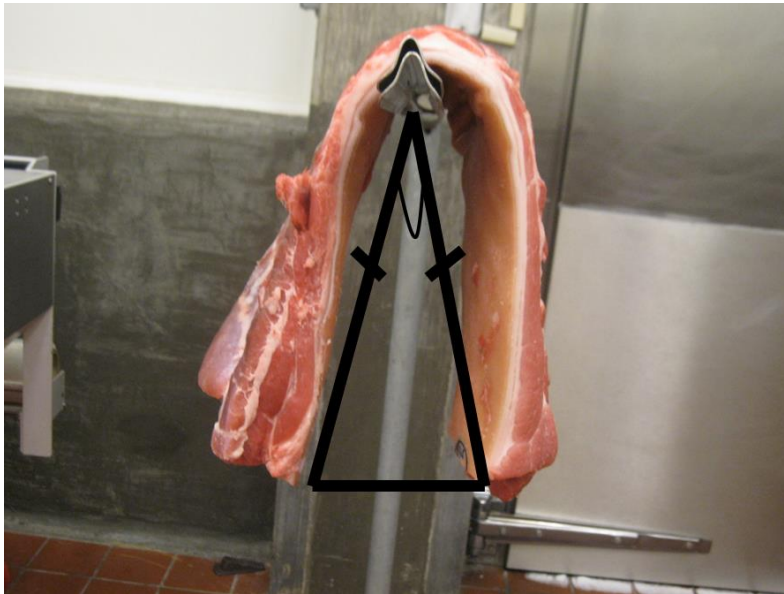
Meadus et al. (2010) expressed belly firmness as a cosine angle. However, this methodology is a modification of Whitney's as bellies were centered over a 7.62 cm tube lengthwise and the degree of bend quantified from the right triangle formed by measuring 4.25 cm from the point of the belly flexing (middle of the suspension bar) to the underside of the flexing belly. The triangle is completed by measuring the distance from where the 4.25 cm vector lands on the underside of the belly to a point straight below the middle of the suspension bar and measuring from that point back to the point of belly flexing (Figure 2-3).

Figure 2-8 Meadus Firmness Methodology
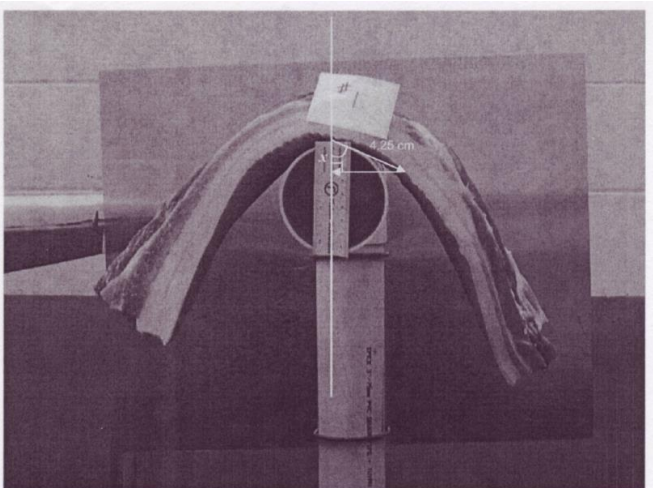
Other methodologies to evaluate belly firmness include a strain gauge (Durometer), subjective fat scores (FQS), compression testing, puncture/penetration testing, and a Fourier transformed near infrared reflectance spectrophotometer (FTNIR) to predict Iodine values (IV) (Semen et al., 2013).

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 3 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 2.5 lists fatty acids found in pork fat. During bacon production, the length of processing and temperature of the room can 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.

Table 2-5 List of Common Fatty Acids in Pork Fat[1]

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% |

Cameron and Enser, 1991.

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 IV is based on how iodine binds to double bonds within the fat (Gupta and Kanwar, 1994). Increasing the amount of double bonds allows more Iodine to 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 g/100gand 100 g/100g (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 $\leq$ 70 g/100g (Boyd et al., 1997; Hansen 2001). Iodine value 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).

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. 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). White adipose tissue 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 then 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 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 discrepancy between older and younger animals is due to the fat cells growing in size as the animal gets older 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 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 2-6 Heritability of Fatty Acids[1]

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

[1]Cameron and Enser, 1991.

Over the years genetic lines have changed as it was once common for genetic lines in the 1950's and 1960's 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 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.

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 pig's 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 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 saturated and monounsaturated fatty acids, while vegetable oils will have higher levels of polyunsaturated fatty acids.

Effects 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 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

To improve belly firmness, researchers have evaluated Conjugated linoleic acid (CLA) as a diet ingredient that could increase belly firmness. 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 (CLA) 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 in increasing pork

quality as researchers have found that 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 area 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 ($P < 0.10$) 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 Conjugatde 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 ($P > 0.22$), lean color intensity, flavor, off-flavor intensity, or brittleness bacon slices.

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 6-member flavor profile panel. Bacon samples from pigs fed 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 swine diets that included CLA. Lean flavor was described as the aromatic portion of the cooked lean portion of bacon. Burnt flavors detected in bacon slices tended to be higher in bacon samples from pigs that were supplemented with CLA and 0% supplemented fat or 4% yellow grease compared to 4% tallow supplementation ($P < 0.09$). 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, or pork flavor of loin chops. However adaptation of CLA in commercial diets is very limited due to product cost.

In conclusion, CLA used as a food source for pigs increases the saturated fatty acid content in pork, resulting in firmer bellies. Outside of it being an expensive feed source, CLA yields pork and bacon with acceptable favors with the exception of increase burnt flavors in bacon. Feeding CLA was also shown to increase belly weights which would be a major factor contributing to increasing belly firmness.

Dried Distillers Grains' with Solubles

Overview of Dried Distillers Grains with Solubles

During the last decade 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 estimated that 7.2 billion gallons of ethanol were produced in 2008 (Saunders and Rosentrater, 2009). In 2014, the ethanol industry was capable of producing 14.88 billion gallons of ethanol (Renewable Fuels Association 2014). 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 2 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). On average DDGS produced in North America contain an average of 28.60% protein, 9.48% crude fiber, 27-30% protein, 8.77% fat (Stein 2008). 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 produced is used in swine diets. The majority of DDGS used in the pork industry 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 IV 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) reported tendencies for cooking loss ($P > 0.09$), bacon distortion ($P > 0.07$), and palatability of bacon ($P > 0.06$) due to DDGS inclusion, but no differences in shear force ($P > 0.90$). 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 by the pork industry for satisfactory belly firmness.

In response to the increased use of DDGS, several management strategies have been investigated. Previous literature has shown that the reduction of C18:2 concentrations in pork fat can be attained 2 weeks after a dietary change (Wiseman and Agunbiade, 1998; Warnants et al., 1999). Xu et al. (2010) investigated how pork fat would change if DDGS was withdrawn from the diets prior to slaughter. Nine dietary treatments were used: control (0% DDGS), 15% DDGS with a 0, 3, 6, and 9 week withdrawal period, and 30% DDGS with a 0, 3, 6, and 9 week withdrawal period. Xu observed that there was a linear decline of the IV of belly fat by as the withdrawal time before slaughter increased. This study showed that a reduction of IV values can be obtained with a minimum of a 3 week withdrawal time.

Overview of Glycerol

Crude glycerol is the main co-product of biodiesel production, as 79 g of crude glycerol is generated for every 1 liter 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 ($P > 0.20$) pork flavor intensity, off-flavor intensity, myofibrillar tenderness, overall tenderness, or juiciness.

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, increasing the saturation level in fat depots because *de novo* fatty synthesis produces more saturated fatty acids.

Bacon Cookery

As previously mentioned, more unsaturated fats will have lower melting points when compared to fats with more saturated fats. Fatty acid composition is an important consideration when discussing bacon cookery due to the high demand for pre-cooked bacon and a business-wide goal of maximizing product yields. When discussing pre-cooked bacon, it is important to remember that every industrial cooking process will have a certain level of non-uniformity. Producing cooked bacon would mean that the cooking process needs to be set (time/temperature) to achieve a minimum of a 60% cook loss (USDA FSIS, 2005). For the sake of discussion, assume that the average microwave oven has a standard deviation of four percent. This would mean that the target average yield would have to be 28%. At this target, 66% of bacon slices

would hit yields between 24 and 32%. Ninety-five percent of bacon slices would achieve yields between 20 and 36%. Ninety-nine percent of bacon slices would achieve yields between 16 and 40% (Gunawardena et al. 2014). The question then becomes, how much of the non-uniformity is contributed by the fat saturation differences of the bacon? Would it be possible to lower the theoretical variation in this example to allow for increasing the target yield by cooking bacon slices that contain high IV separately from bacon slices that contain a low IV? Another area of concern in this theoretical example is that this scenario doesn't account for the yield of acceptable slices that can be sold as pre-cooked bacon. It is entirely possible that slices on the lower end of product yields are viewed as unacceptable by consumers or the specific specification implemented. In terms of cookery, melting point is considerably more complicated than a simple unsaturated versus saturated fatty acid statement. In general, the melting point will increase as more carbons are added to the fatty acid chain, but will decrease as more unsaturated links are included (Hugo and Roodt, 2007). The melting point is decreased more by Cis isomers than Trans isomers. Conjugated Linoleic acid can exist as 28 different isomers that can exist in Cis or Trans configurations and allow this compound to affect the melting point differently depending upon the isomer. Further complicating the melting point notion is the concept of fat crystallization, which can occur in various forms that impact the melting point of pork fat (Bothma et al., 2014).

Fat Crystallization

Crystal formation is common in many foods including ice, sugars, salts, and fats (Walstra, 2003). Food products that have a significant portion of their composition consisting of fat such as chocolate, butter spreads, and peanut butter depend on the crystallization concept to influence textural attributes (Narine and Marangoni, 2002). The consistency, mouth feel, and physical stability can all be affected by crystallization. In food it is most common that crystals are formed through a combination of ionic bonds (hydrogen bonds and van der Waals attraction). Fat crystallization could be very influential in bacon because of the inclusion of salt which can trigger ionic crystal formation. The high lipid component of bacon provides ample opportunity for crystallization reactions throughout the bacon production process. Multiple production processes such as carcass chilling, curing time, thermal processing, belly tempering all provide

the potential to form different polymorphisms that could impact the total microstructure of the fat component in bacon (Narine and Marangoni, 2002).

It is well known that the triglyceride molecules in porcine fat are quite varied. This directly contributes to the types of polymorphs that can form in pork fat. The polymorphs that form in the fat network will be very important to the melting point (Narine and Marangoni, 2002). In addition to affecting the melting point, the crystal size, shape, and aggregation of crystals will affect the elasticity of the fat network (Narine and Marangoni, 2002). Thus, theoretically it is possible that crystallization does play a role in belly firmness and sliceability. Fat crystallization with animal fats most commonly forms three different types of polymorphisms: α, β', and β. The Alpha polymorph is the least stable polymorph due to its loose structure that is the least densely packed crystalline structure with the lowest melting temperature (Walstra, 2003). Of the three polymorphs, the Beta prime polymorph exhibits an intermediate crystalline density due to the loose chair structure formed by the fatty acids. The structure and density characteristics of the β' polymorph gives this form an intermediate stability and melting point when compared to the other forms. The Beta polymorph is created by a densely packed fatty acid structure formed into a tight fitting chair shape. The Beta polymorph is the most stable form with the highest melting point. Usually there is a transition phase in polymorphisms with the α-form transitioning to the β' before converting to the β-form. The transition is irreversible in temperature below the melting point, but it is possible to revert the β' and β-form back to the α-configuration by re-melting the fat network (Walstra, 2003). To demonstrate the effect of polymorphism forms on melting point, consider the triglyceride Tristearin. In the α- form the melting point is 55°C (131°F). The melting point increases to 63°C (145°F) in the β'-configuration and to 73°C (163°F) in the β-form. Thus Tristearin demonstrates the vast change in melting point that can occur due to different crystalline forms (Walstra, 2003).

Crystallization processes included three events: nucleation, crystal growth, and crystal ripening. In order for nucleation to begin, conditions must be sufficient to initiate nucleation. Nucleation theory states that sufficient supersaturation or supercooling in an environment will increase the rate of association over the rate of dissociation to form a cluster which then changes from a random grouping of molecules into a crystal structure (Hartel, 2001). The rate of nuclei formation can be heavily influenced by temperature. Figure 2-9 (adapted from Hartel, 2001)

illustrates how temperature impacts the nucleation rate of the different polymorphs. This concept would be particularly important to bacon products as bellies are subjected to multiple cooling curves. After slaughter, pork carcasses temperature drops from a range of 38.7-39.8°C (101.6-103.6°F) to near freezing temperatures. During bacon processing, bellies are cooked to temperatures to 49°C or more before going through a cooling phase to freezing temperatures for food safety and processing requirements, all of which provide ample opportunity for various crystal forms to develop. Animal fats are complex due to many different triglyceride species that contribute to complex crystal patterns that contain multiple forms. To date, it is not possible to link specific fatty acid molecules to specific crystal formations, but the types can be influenced by general fatty acid types (Bothma et al. 2014).

Figure 2-9 General form of nucleation rate of lipids adapted from Hatrel 2001
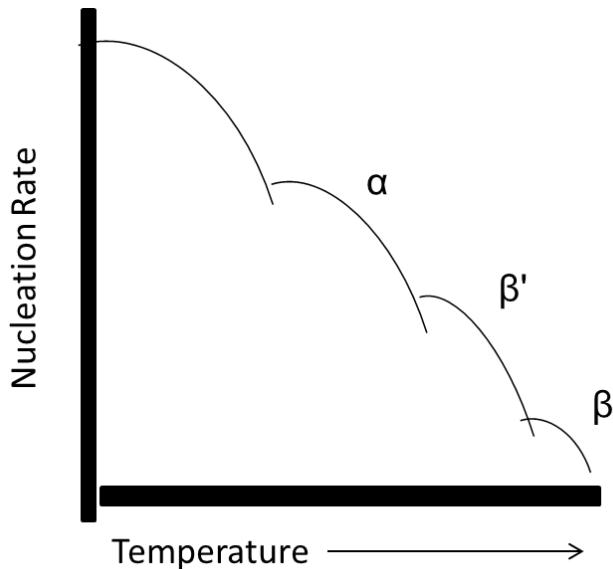
A limited numbers of studies have been published that investigate the behavior of crystallization in pork fat, especially after heat treatments. Svenstrup et al. (2005) investigated the melting and crystallization behavior of pork fat. Using differential scanning calorimetry (DSC), the melting points between lard and leaf fat were measured. Two different cooling rates (1.0 and 10.0°C/min) were used to create 2 different crystalline profiles that would impact melting thermographs. As expected, the clear melting points (the temperature at which the fat sample is completely melted) was higher for leaf fat (48°C) than lard (39°C). However, melting points for the slowly cooled treatments (1.0°C/min), regardless of the source of the fat, were higher than the rapidly cooled treatments. In this instance, the clear melting points where the

same, but the temperatures of melting displayed throughout the period of measurement were higher with the slowly cooled treatments. Svenstrup et al. (2005) notes that this effect was expected because rapid cooling results in the formation of unstable crystals with low melting points. Another possible explanation proposed was that unsaturated fatty acids form unstable crystals due to the bent Cis double bonds and that this contributes to the low melting point.

In a study by Corona et al. (2014), it was the goal to determine if it was possible to detect differences in fat type according to the crystallization patterns of the fat using ultrasonic measurements. Subcutaneous fats were selected from Montanera and Cebo breeds of pigs. These breeds were selected because it was previously understood that the saturated fatty acid content was greater in the Cebo breed (45.1%) than Montanera breed (41.8%). Five different cooling rates (0.2, 0.5, 1, 5, and 10°C/min) were selected due to the expectation that the cooling rates would change the crystalline behavior of the fat. The authors of this study showed that with DSC there are 2 separate peaks in the thermograph of pork fat that are associated with unsaturated fats and saturated fats. In general, the unsaturated fats melting points are closer to the onset temperature (temperature at which the thermal event starts to occur) than what the more saturated fats are. Results of this study found that there was a significant decrease in onset melting temperatures between each cooling rate for fat samples from each breed. When the cooling rate increased from 0.2 to 10°C, the onset temperature for the saturated fatty acid peak decreased 38% with the Cebo breed and 74% with the Montanera breed, while the average onset temperature of the unsaturated fatty acid decreased 353% for the Cebo breed and 1725%. Interestingly enough, the authors claimed that it is possible to detect different crystallization patterns with ultrasonic measurements.

The concept of crystallinity in pork fat during storage temperatures was measured by Motoyama et al. (2013) using Raman spectrometric analysis. In this study the percent crystallinity was measured over long periods of time (up to 200 h) as pork carcasses chilled in a carcass cooler. The end carcass temperature of 4.5°C was achieved at 24 h while a temperature of 4.3°C was achieved at 50 h. In this study 40% crystallinity was achieved after 5 hours of cooling. Between hour 5 h and 250 h the total percent crystallinity only rose 6% to a final fat crystallinity of 46%. It was also noted that between hours 5 and 10 of storage, the maximum percentage of the crystals that were in the β'-polymorph was 10% and very slight decrease was observed by the end of the storage time. Outside of being able to use Raman spectrometric

analysis to detect crystallinity, it is exciting for bacon processors to know that crystallinity can be detected and as a function of that, determine a measure of fat saturation. Even though it is unclear how fat crystallization impacts belly slicing, it could be exciting future research.

Bacon Distortion

When bacon is cooked (regardless of cookery method), the slices tend to curl, shrink, and become "wavy" to some degree. This is what is referred to as bacon distortion. To date, bacon distortion has been evaluated using a subjective (1-5) scoring system (Figure 2-10) developed during the Quality Lean Growth Modeling-Bacon Quality Assessment project conducted by the University of Nebraska on a grant funded by the National Pork Board (Mandigo, 2000; Robles 2004). A score of 1 describes a flat slice that has no distortion, while a score of 5 indicates that the slice was highly distorted (Robles, 2004). The score of a 2 represents an estimated 25% distortion of the slice, a score of 3 describes a slice that show 50% distortion, and a score of 4 illustrates a bacon slice that shows 75% distortion (Robles, 2004). Since the original creation of this subjective methodology, there have been very few journal publications investigating bacon distortion. Those publications that have investigated distortion have used a similar distortion scale (Figure 2-11) (McClelland et al. 2012, Rentfrow et al. 2003, and Widmer et al. 2008). However, an issue with this methodology is that the scales between studies are not standardized (Figure 2-10 vs. Figure 2-11) due to the subjectivity of the scoring. Compare this with similar objective methodologies such as pork color and sensory evaluation, like the distortion scale, pork color is evaluated on a numerical system and guidelines are available from the National Pork Board to provide a baseline for panelists. In sensory evaluation, panelists are trained by providing samples to demonstrate a corresponding number on the evaluation scale. Further hindering the repeatability of the current methodology is that all studies that measured bacon distortion (Mandigo 2000, Robles 2004, Rentfrow et al. 2003, Widmer 2008, and McClelland et al. 2012) use a single respondent to score the bacon instead of a trained panel.

Figure 2-10 UNL bacon distortion scale
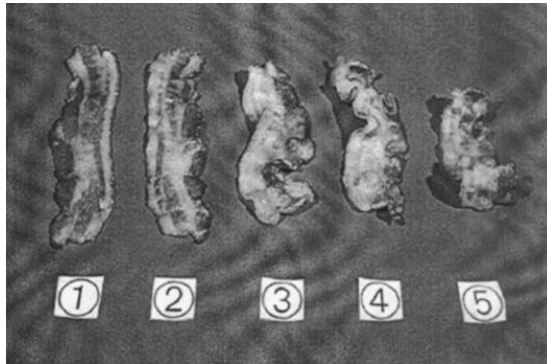
Figure 2-11 Mizzou bacon distortion scale
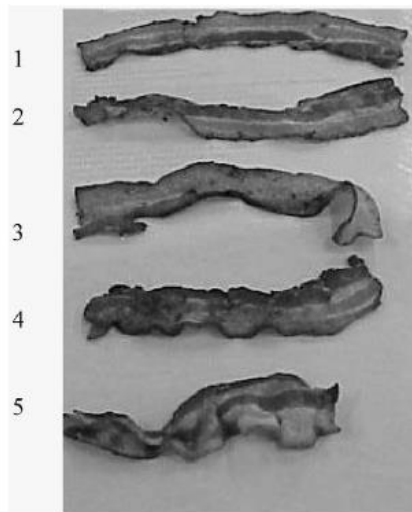
In addition to designing a distortion scoring system, the Quality Lean Growth Modeling-Bacon Quality Assessment project (Mandigo, 2000) also investigated several factors that could influence slice distortion. This study evaluated how genetic line, gender, slaughter weight group, type of bacon (foodservice vs. retail), and cookery method (microwave vs. belt) affect bacon distortion. As previously mentioned, the distortion scoring system was on a 1-5 numerical scoring system using one evaluator. Six genetic lines were used but the specific type was not given and was assigned to numerals (1-6). Slaughter weights were at 114 kg, 132 kg, and 150 kg. It was explained that the food service slices were cut to a thickness of 0.2 cm and retail slices cut to a thickness of 0.28 cm. Slices cooked in the microwave were cooked with a modified Litton Menumaster 70/80 (Litton Industries, Minneapolis, MN), and the belt-cooked bacon slices were cooked with a Magi-Grill PGB-60 double belt conveyor cooker (Magikitch'n,

Quakertown, PA). Bacon slice selection was taken starting at the anterior end at 0, 20, 40, 60, and 80% of the distance to the posterior end.

In the results of this study, it was found that the distortion scores that were observed most frequently were scores of 2 and 3. It is also suggested that the fat portion influences distortion. The author concluded from the data that fatter lines of pigs show more distortion, barrows and heavier pigs produce more distortion, but the fattest locations in the belly showed the lowest distortion. Select distortion results from this study were reproduced in Tables 2-7, 2-8, and 2-9. When looking at distortion by raw fat content, bacon type, and cookery method (Table 2-7), it seems that microwave cooking produces statistically lower distortion scores in almost every fat range when compared to belt cooking. The exception to this is the 38-42.99% fat content in the Retail bacon. In general, it looks like Retail bacon showed less distortion than Food Service bacon. Unfortunately, statistical analysis wasn't provided between the fat contents ranges, but it does appear possible that statistical differences can be observed based off the given standard error. It is interesting to note that while most of the statistical significant results that occur are in the same numerical category (2), the microwave cooking process produced distortion scores that fall in the 1 category.

Table 2-7 Distortion by fat grouping, bacon type, and cookery method[1]

Range of raw fat content,%	Food Service[2]		Retail	
	Belt	Microwave	Belt	Microwave
23.00 - 37.99	2.30^c	2.04^b	2.13^{bc}	1.79^a
38.00 - 42.99	2.43^c	2.04^{ab}	2.19^{ab}	1.97^a
43.00 - 46.99	2.49^c	1.95^a	2.22^b	2.04^a
47.00 – 52.99	2.31^{bc}	1.87^a	2.34^c	2.21^b
53.00 – 56.99	2.40^b	1.98^a	2.55^b	2.13^a
57.00 – 69.00	2.28^b	1.89^a	2.31^b	2.32^b

[1]Adapted from Mandigo, 2000.

[2]Different superscripts within a row indicate significance (at least $P < 0.02$), SEM = 0.07.

When looking at the average bacon distortion by location within the belly, bacon type, and cookery method data (Table 2-8), it appears the average distortion scores do change by location within the belly. Similar to Table 2-7, statistical analysis was not provided between the

locations on this project. However, when considering the given standard error of this data set and the average differences between belly locations, the data suggests that it is a possibility that distortion is influenced by location within the belly. From previous research (Trussell et al. 2011) it is known there is a fatty acid gradient within fresh bellies, thereby providing the hypothesis that fatty acid composition could play a role in bacon distortion. Additionally, it is well known that the proximate content of pork bellies also changes throughout the length of the belly. It is unclear from this study how much fatty acid composition and proximate composition contribute together or separately to bacon distortion and this deserves further scrutiny. Similar to Table 2-7, the distortion scores within a type of bacon are influenced by cookery method. In the Food Service bacon, regardless of location, microwave cookery presented lower average distortion scores. Belly sampling locations at 20% or greater of the length of belly from the anterior end produced a numerical category decrease in distortion scores in the Food Service category. The same can be said of the sampling locations that are 40 and 60% of the length from the anterior edge within the Retail type bacon category.

Table 2-8 Distortion by location, bacon type, and cookery method[1]

Distance from anterior edge to posterior edge	Food Service[2]		Retail	
	Belt	Microwave	Belt	Microwave
0%	2.59^c	2.06^a	2.78^d	2.38^b
20%	2.29^c	1.92^a	2.29^c	2.10^b
40%	2.23^b	1.91^a	2.12^b	1.99^a
60%	2.20^c	1.94^{ab}	2.00^b	1.84^a
80%	2.53^c	1.97^a	2.26^b	2.08^a

[1]Adapted from Mandig0, 2000.

[2]Different superscripts within a row indicate significance (at least $P < 0.008$), SEM = 0.07.

Table 2-9 contains the least square means of the distortion scores of all interactions by locations. In this data set presented by the author, it is reported that there were significant interaction effects between location and genetic line, gender, slaughter weight, bacon type, and cookery method. However, superscripts indicating statistical differences were only provided for location D, which was a distance of 60% of the length of the belly. This corresponds to an area of the belly that produces a high proportion of valuable #1 bacon slices. Within location D, there

was a statistically significant decrease in numerical distortion scores between genetic line 1 when compared to genetic lines 2 and 3. Genetic line 3 displayed statistically and numerically lower distortion scores when compared to genetic lines 4-6. This section of the data is cause to look into fatty acid composition effects because the observed differences happened in one location (a very valuable location), meaning that the proximate composition effect is essentially the same and not a cause of this distortion effect. Furthermore, it is already well known that different breeds of pigs will show differences in the unsaturated:saturated fatty acid ratios (Robles, 2004).

Table 2-9 Least square means of average distortion scores for all interactions with location[1]

	A	B	C	D	E	SE	$P > F^{2,3}$
Line 1	2.57	2.27	2.20	2.10[a]	2.43	0.04	0.0001
Line 2	2.59	2.21	2.10	1.98[bc]	2.26	0.05	
Line 3	2.51	2.20	2.06	1.98[b]	2.21	0.04	
Line 4	2.55	2.28	2.15	2.03[ac]	2.24	0.03	
Line 5	2.62	2.32	2.18	2.04[ac]	2.32	0.04	
Line 6	2.75	2.28	2.18	2.02[ac]	2.24	0.03	
Barrows	2.70	2.38	2.24	2.11[a]	2.32	0.03	0.0001
Gilts	2.50	2.14	2.05	1.94[b]	2.25	0.02	
114 kg	2.49	2.23	2.10	1.99[a]	2.24	0.02	0.0001
132 kg	2.61	2.24	2.12	1.96[a]	2.25	0.03	
150 kg	2.69	2.31	2.22	2.13[b]	2.37	0.03	
Foodservice	2.57	2.28	2.18	2.12[a]	2.34	0.03	0.0001
Retail	2.63	2.24	2.11	1.93[b]	2.23	0.02	
Belt	2.94	2.49	2.33	2.22[a]	2.60	0.02	0.0001
Microwave	2.25	2.03	1.96	1.83[b]	1.97	0.02	

[1]Adapted from Mandigo, 2000.

[2]$P > F$ Indicates significance of interaction (at least $P < 0.05$).

[3]Different superscripts within a column indicate significance (at least $P < 0.05$).

Table 2-9 shows that in bacon slices from location D originating from gilts will have lower distortion scores than barrows. This again could support a fatty acid effect as the fatty acid content in barrows is known to be different from gilts (Robles, 2004). In this study, bacon from

pigs with the highest slaughter weight (150 kg) showed a higher distortion score than lighter pigs. This could simply be due to the author's claim of fatter pigs having more distortion. This doesn't exclude the fatty acid effect, but it is hard to use this section to support a fatty acid effect because it is unclear if the pigs in the 3 different weight groups are the same physiological age or how long they had been on feed, both of which can affect fatty acid deposition in pigs. When analyzing the bacon type results in Table 2-9, there is a statistical interaction with location D, in that retail type bacon showed lower distortion scores. This is surprising when considering that this is not exactly evident in Tables 2-7 and 2-8, but this suggests that cookery method plays a role in bacon distortion. The last information provided on this graph is the type of cookery. In location D, microwave cooking lowered the average distortion scores. This was also observed in Tables 2-7 and 2-9. When looking at this section of data and considering the magnitude of differences between the means, the results observed in Tables 2-7 and 2-9, and the relatively small standard errors, it is somewhat surprising that more significant results weren't seen in this data set.

The Quality Lean Growth Modeling-Bacon Quality Assessment project also led to other research projects such as investigating the effects of fresh and frozen bellies on bacon processing characteristics and bacon quality (Robles, 2004). Robles (2004) investigate the effects of gender, breed, location, and freezing have on distortion during cooking of bacon slices. Bacon slices were cooked on a double belt conveyor cooker, with a target cook yield of 37-39%. Bellies were divided into 5 zones (Locations A-E) starting from the posterior end of the belly and moving to the anterior, with slices selected from each zone. In this study no statistical differences in distortion scores were observed between genders (barrows vs. gilts), or breed. Bellies that were frozen before processing showed a statistically higher distortion score than fresh bellies; however, the average scores between fresh (2.35) and frozen (2.43) treatments were contained in the same numerical category. Four of the 5 belly zones showed statistically different distortion scores. The posterior edge (Location A) showed the highest (2.79) average distortion score while Location C had the lowest average distortion score (2.19). Distortion scores are summarized in Table 8. Similar to the fresh vs. frozen belly distortion scores, the distortion scores for specific belly zones, while statistically different, all fell in the same numerical category. When analyzing these distortion results it is important to consider how the proximal composition of each belly zone is statistically different (Table 8). Therefore, it is reasonable to

suspect from this study that proximal composition plays a role in distortion scores. Location E and D (anterior end) had the highest average fat (43%) composition and were statistically higher than locations C (41%), B (38.9%), and A (37.88%); (anterior end). Mirroring this were the results of the moisture content. Locations D and E had the lowest moisture content (41%) while C (43%), B (46%), and Location A (47%) had increased moisture content. Though no correlation statistics were run, these results show that it is possible that the fat and moisture content impact distortion scores.

Table 2-10 Average distortion score and composition of bellies by location[1,2]

Zone	Distortion Score	% Fat	% Moisture
Location A	2.79[a]	37.88[d]	46.75[a]
Location B	2.26[b]	38.90[c]	45.86[b]
Location C	2.19[c]	41.14[b]	42.82[c]
Location D	2.22[bc]	43.17[a]	41.26[d]
Location E	2.52[d]	43.42[a]	41.36[d]

[1]Table adapted from Robles 2004.

[2]Means within the same column with different superscripts differ ($P < 0.05$).

To date, 3 additional papers measured bacon distortion that have been published in peer-reviewed journals. Widmer et al. (2008) investigated pork quality and palatability via management strategies that included feeding pigs dried distillers grains with solubles (DDGs), high protein distillers dried grains (HP-DDGs), and corn germ. There were seven dietary treatments with a control treatment of corn and soybean meal (CSB), CSB + 10% DDGs, and CSB + 20% DDGs. The HP-DDGs were included at levels that would adequately replace 50 or 100% of the soybean component in the trial diet. The final 2 treatments included a CSB + 5 % corn germ, and a CSB + 10% corn germ diet. Bacon slices were selected from the middle of each belly and cooked using a microwave oven to a target yield of 37.5%. Distortion scores were used on a 5-point scale with a score of 5 showing the most distortion and 1 equivalent to the least amount of distortion. In this study, distortion was not statistically affected by diet, but feeding DDGs showed a linear trend in decreasing distortion scores from a distortion score of 2 to a distortion score of 1.

In a study by McClelland et al. (2012), pork quality of pigs fed corn dried distillers grains with solubles was investigated. Diets consisted of a base corn soybean meal diet with 0, 15, 30, and 45% DDGs. Sliced bellies were divided into 5 sections from cranial end to posterior end. From the cranial end of each section, 2 slices were taken for distortion evaluation. Slices were evaluated by a single evaluator on a 5-point subjective scale with a score of 1 describing a flat bacon slice. A score of 5 described a severely curled bacon slice using a scale created by Rentfrow et al. (2003). Bacon slices were cooked on a griddle with a surface temperature of 157°C (314.6°F) and were cooked to a target yield of 40%. No dietary treatment in this study influenced bacon distortion.

The final peer-reviewed paper investigating bacon distortion was conducted by Rentfrow et al. (2003). Rentfrow et al. (2003) fed pigs a control diet consisting of a corn-soybean meal diet (CSB). The test diets contained a CSB with choice white grease, CSB with high-oil corn, and a CSB with genetically enhanced corn that contained high concentrations of oleic acid. Like in the previous study McClelland et al. (2012), bellies were divided into 5 sections starting from the anterior end of the belly and running to the posterior end. One bacon slice from each section was selected to be cooked on a Magikich'n double-belt conveyor cooker. Cooked slice yields were targeted to be 40%. Like with the previous studies, distortion was scored on a 5-point scale with 1 being a flat slice and a 5 describing a slice that is completely curled with no flat areas on the slice. The results of this study showed that the dietary treatments did not affect bacon distortion scores.

In summary it there are multiple factors that influence bacon distortion. The composition of the bacon slice changes within the belly and this is reflected in the distortion scores. Furthermore the cooking method influences bacon in distortion in some way. It is possible that the heat transfer mechanics influence distortion. It appears that dietary management studies that change the fatty acid composition do not impact bacon distortion, but this may be because of the way that diets were balanced resulting in similar composition between bellies.

Factors affecting cook yields

As one would expect, cooking temperature and time influence bacon cooking yields. In a study by Gibis et al. (2015) investigating the formation of heterocyclic aromatic amines in fried bacon, cook yields were reported on pan-fried bacon. Slices were cooked for 3, 4, 5, and 6

minutes at pan temperatures of 150-170°C. Two additional cooking procedures were done with a Teflon pan rubbed with sunflower oil at pan temperatures in the range of 200-220°C. As expected, the percent yield of the bacon slices decreased as frying time increased within each cooking methodology. In the 150-170°C temperature treatment, the weight loss was at 39% of the raw weight and decreased ($P < 0.05$) with each additional minute per treatment, culminating with a weight loss of 53% at 6 minutes of cooking time. In the 200-220°C frying treatment, the weight loss increased ($P < 0.05$) from 42% to 52% as an additional minute was added. Comparing the temperature categories showed that there was no statistical difference in percent weight loss between cooking bacon for 3 minutes at 200-220°C and 6 minutes at 150-170°C ($P > 0.05$). Likewise cooking bacon slices for 2 minutes at 200-220°C showed statistically similar yields with four minutes at 150-170°C ($P > 0.05$).

While investigating bacon quality criteria, Jabaay et al. (1975) described how cooking yields of bacon slices originating from different locations in the belly change. In this study, 6 sampling locations were used with sampling location #1 located at the shoulder end of the belly and location #6 was identified as the slices taken from the flank end of the belly. Sampling locations #2 – 5 were located at equidistant positions from locations #1 and #6 (Figure 2-12). In this study, it was determined that slices originating from the shoulder region (Location #1) had the highest cooking yields at 27.1%. Slices from position #2 through #4 had the lowest cooking yields ranging from 24.2 to 23.5%. Intermediate to the other sampling locations, #5 and #6 had 26% and 26.5% cooking yields respectively. Jabaay et al. (1975) calculated cooking loss in this publication but reported in this document as cook yield in order to reduce confusion when compared to other studies. The authors of this paper quantified the lean-to-fat ration as a distribution score which was expressed as cm of fat to lean interfacing together (total distance of interface/slice length). Though the correlation between cooking loss and distribution score was relatively low (0.32, $P < 0.01$), it was the highest correlation compared to the other parameters (moisture and fat content). In addition to having the lowest cooked yields; sampling locations 2, 3, and 4 also had the 3 highest distribution scores of the slices in this study, leading to the conclusion that the interaction between lean and fat influences cook loss. The proximate analysis of these samples showed that slices from the middle of the belly had the highest percent of ether extract in this study. This agrees with the slice profile provided by the author (Figure 2-13), which in addition to showing how the lean and fat content change throughout the belly, also

shows that it appears that slices from the middle of the belly contained a higher ratio of fat. Mandigo (2000) showed similar results in proximate composition in that bacon slices from the center of the slab were significantly ($P < 0.05$) fatter than all the other locations and that fat content decreased as the slices move away from the center, resulting in the lowest yields observed from bacon in the middle of the bacon slab. Furthermore, this report illustrated cook yields as influenced by raw fat content. Bacon slices cut for food service that had fat content of 23 to 37.99 had the highest yields (58.72%) on a conveyor belt cooking system. Yields appeared to decrease in a step-wise fashion as fat content increased to the 57 to 69% range averaging a yield of 27%. Similarly, bacon cut for retail and cooked in the microwave followed in a similar pattern.

Figure 2-12 Sampling locations in Jabaay et al. 1975
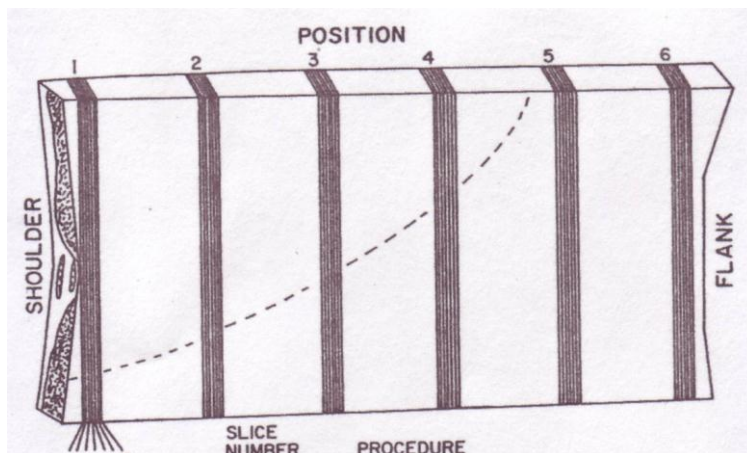
Figure 2-13 Slice profile of locations 1-6
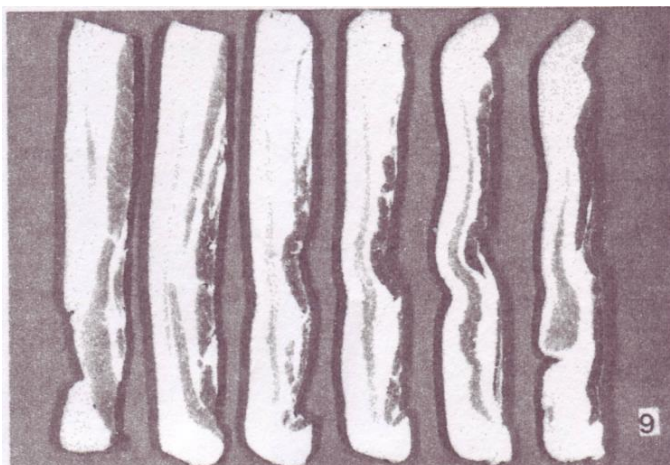
Publications by Lee et al. (1983) and James et al. (2006) provide additional information explaining why Jabaay et al. (1975) observed more cooking loss with fatter bacon slices. When investigating the temperature profile of bacon during frying, it was found that during cooking temperatures of the lean component of the slice did not exceed 145°C, while the fat portion reached temperatures up to 165°C. This is because fat has a low water content and low specific heat when compared to muscle, and results in more rapid heating and more rapid melting of fat off the bacon slices. James et al. (2006) looked at the characteristics of microwaved bacon and reported that the fat on the edge of the bacon generally heated up faster than the fat located more internally and heated much faster than any of the muscles. Fat has a lower specific heat capacity (the amount of heat needed to raise the temperature of a certain mass one degree Celsius) than water (the principle component of muscle). Thus, fat will heat up faster (James et al. 2006).

It has been shown that breed characteristics can influence yields due to differences in growth rate and fat deposition that impact lean-to-fat ratios and fatty acid composition. Robles (2004) reported on the differences in cook yields of bacon slices cooked on a belt cooker with 6 different pig breeds (Table 2-11). In this study, Berkshire and Poland China lines had the lowest ($P < 0.05$) cooking yields compared to the other breeds used. Agreeing with commentary previously provided about fat composition influencing bacon yields, the Berkshire and Poland China lines contained the highest fat to lean ratio among the breeds. In contrast, the breeds that proved to be leaner (Duroc and Yorkshire) had the highest ($P < 0.05$) cooking yields in the study at 36.69 (Duroc) and 37.49% (Yorkshire). In partial agreement with the Jabaay and Robles studies, Kemp et al. (1969) documented that despite no statistical differences ($P > 0.05$) in yield losses of bacon from fatter carcasses when compared to leaner carcasses, there was a numerical decrease in bacon cooking yields as carcasses increased in fatness.

Table 2-11 Influence of breed on cooking yields[1]

Breed	Cook Yield (%)[2,3]
Berkshire	31.90 ± 0.38^a
Chester White	33.90 ± 0.67^b
Duroc	36.69 ± 0.31^{cd}
Landrace	34.94 ± 0.85^{bc}
Poland China	31.14 ± 0.87^a
Yorkshire	37.49 ± 0.36^d

[1] Adapted from Robles, 2004.

[2] Superscripts differ *P < 0.05*

[3] Standard Error of the Means

Dietary management has been previously established in this document as a means to change the fatty acid profile in the belly fat of pigs. The resulting change in the chemical structure of the fat should logically lead to the conclusion that bacon slices with higher Iodine values should have greater yield losses due to lower melting points. This, however, is not convincingly supported in literature. Widmer et al. (2008) increased the inclusion of DDGs in standard corn-soybean meals by 10 and 20%. Bacon slices were cooked in a microwave oven and preliminary testing was done to establish the length of time to achieve yields of 37.5%. Results of this study showed that there was a statistical trend ($P = 0.089$) of a linear decrease in bacon cooking yields selected from the middle of the belly (28.5 to 26.5%) as DDGs content is increased in pig diets. This trend was observed between bellies from the control diet that had an IV of 69.8 and 20% dietary DDGs inclusion that resulted in a fresh belly IV of 72. In a study by Goehring (2010), also feeding up to 20% DDGs in swine diets, also failed to notice statistical differences in cooking yields of bacon cooked in a Blodgett oven set at 176°C for 10 minutes.

Rentfrow et al. (2003) evaluated bacon cooking yields from pigs fed diets of conventional corn-soybean meal with the addition of choice white grease, high-oil corn, and high-oil with high-oleic corn. In this study, the cooking loss and the total length shrink was quantified. Even with clear differences ($P > 0.05$) in the PUFA, MUFA, and SFA content within the bellies, no significant ($P < 0.05$) differences in cooking losses or cooking shrink using an industrial dual-belt conveyor oven were detected. Mclelland et al. (2012) fed pigs diets with 15, 20 and 45% added DDGs to a regular finishing diet. The authors of this study cooked bacon on a griddle set at 157°C and found no statistical differences ($P = 0.26$) in length shrinkage despite significant differences ($P < 0.001$) in the Iodine values (65.4, 69.7, 75.8, and 79.5 respectively). Brown et al. (2013) supplemented corn-soybean diets with 6 different added oil treatments: 1) corn soybean meal with 4.7% yellow grease all 5 phases; 2) corn soybean meal 5% beef tallow all 5 phases; 3) diets 5% beef tallow fed first 2 phases, and 4.7% yellow grease last 3 phases; 4) fed 5% beef tallow first 2 phases, 4.7% last 3 phases; 5) 4.7% yellow grease first 3 phases, 5% BT last 2 phases; 6) 4.7% yellow grease during first 2 phases, 5% beef tallow last three. Bacon was cooked in a Blodgett oven set at 204.4°C for 9 minutes and like the previous study revealed

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significant differences ($P < 0.05$) in IV (72.33, 70.46, 69.97, 69.34, 68.74, and 67.85 respectively), but was unable to detect differences in cook yield ($P > 0.55$). However, there was a trend of a decreased cooking yield when comparing yellow grease fed in the last 2 feeding phases and beef tallow fed in the last 2 feeding phases. Shackelford et al. (1990) supplemented corn-soybean meals with different types of fat (beef tallow, safflower oil, sunflower oil, and canola oil) at a level of 10%. While cooking slices on an electric skillet set at 148.9°C for 10 minutes, it was found that the addition of fat in the diets did not alter ($P > 0.05$) cooking yields despite differences in the fatty acid profile of the bacon.

Though the majority of the studies indicate that differences in fatty acid content in bacon fat do not contribute to changing the cook yield, it is worth considering the processing factors in these studies that could influence bacon cook yields. Unfortunately, not all of these studies completely listed belly processing methodologies (Table 2-12), but it is still possible to discuss factors that impact cooking yields. Among these studies, the smokehouse endpoint temperatures that were reported were 53.3 (128°F), 56.7 (134°F), and 64.4°C (148°F). As mentioned previously, it is most common that industrial processes don't exceed 50 to 53.3^{o}C during thermal processing (Bob Hanson, HansonTech, Hudson, WI, personal communication). It is possible that the high endpoint temperatures used by Goehring (2010) and Shackelford et al. (1990) during cooking caused more unsaturated fats to render off thereby causing the fatty acid profile to be more similar when cooking bacon slices thus hiding or reducing the shrinkage that would be observed. Furthermore, it is well known that salt changes the chemical attributes of water, and it is likely that in-going salt concentrations either from different pump rates or different brine inclusions could affect the melting point of fats either in the smokehouse or with the cooking methodologies. Another point worth considering is the sampling location of the bacon. In several of the discussed studies, bacon slices intended for cooking studies were selected from 5 different locations within the belly. As shown by the Trussell (2011), Jabaay (1975) and Robles (2004) studies, it is known that the fatty acid composition and fat:lean ratio changes throughout the belly. Therefore, it is possible that this selection method confounds the results of the cooking inquiry. Another interesting point to consider is that there is no literature to date that investigates how cookery method influences bacon yields.

In summary as cooking temperatures and cooking times increase, bacon cook yields decrease. Cooking yields are also influenced by location within the belly due to the composition.

Bacon with more fat will experience more weight loss due to the fat cooking off. Furthermore, the fat/lean composition will also influence heat transfer and cause some bacon slices to cook faster than others depending on the lean content.

Table 2-12 Processing methods of bacon cookery studies[1]

Study	End Temperature	Pump Rate	Salt Level	Smokehouse yield	Sampling location	Cooking Method
Widmer, 2008	53.3°C	112%	NA	NA	MB	Microwave
Shackelford, 1990	56.7°C	110%	19.0%	$P > 0.05$	NA	Electric Skillet
Rentfrow, 2003	NA	112%	1.5%	NS	ML	Belt Oven
Browne, 2013	NA	NA	NA	NS	MB	Blodgett Oven
Mclelland, 2012	NA	112%	15.0%	NS	ML	Griddle
Goehring, 2010	64.4°C	112%	13.0%	NS	MB	Blodgett Oven

[1]NA = item not reported, NS = no statistical differences observed, ML = Multiple sampling locations, MB = Slices located in belly middle

Collagen

Twenty to 30 percent of the protein contained in mammal bodies, regardless of species, is collagen (McCormick, 1989; Bailey and Light, 1989). The most common concern within the meat industry in regards to collagen is how it affects the eating quality of steaks. Specifically, attention is focused on intramuscular connective tissue and the role it plays in meat toughness (Purslow, 2005). Intramuscular connective tissue is comprised of multiple fibers of collagen and elastin proteins, and it is understood that the total collagen content in beef muscles can vary from 1 to 15 percent of the dry weight (Bendall, 1967). As an animal matures, the collagen molecules form more cross-links between collagen molecules, effectively increasing the stability of the collagen as a whole. The biological purpose of this is to provide structure and support to growing muscle (Archile-Contreras et al. 2010). Considerable work has been done investigating the role of intramuscular collagen in beef quality (Archile-Contreras and P. Purslow 2011; Archile-Contreras et al. 2010; Christensen et al. 2011; Davey et al. 1976; Harper et al. 1999; T.H. Powell et al., 2000; T.H. Powell et al., 2000b; Patten et al., 2008) while considerable less has been invested in exploring collagen in pork muscle as well as in pork fat, which will be discussed in subsequent sections.

The Structure of Collagen

Collagen is a main component of connective tissue. Currently 12 different types of collagen have been identified. Each of these types poses unique molecular weights, amino acid sequences, chemical characteristics, and location within the body (Bailey and Light, 1989). The major components of collagen are Glycine, Hydroxyproline, and Proline; with Glycine making up roughly 33%, and Hydroxyproline in combination with Glycine comprising another 33% of the amino acid content in collagen (Aberle et al. 2001). Collagen consists of three polypeptide chains containing sequences of repeating tripeptides. The repeating tripeptides can be represented as GLY—X—Y, with X most often being Proline, and Y representing an assortment of different amino acids but most commonly is Hydroxyproline. The differences in these repeating chains lead the different collagen types to have different chemical and physical properties (Bailey and Light, 1989). The repeating amino acid sequence forms a molecular chain (α – chain) that forms a left-handed polyproline type helix which is unstable by itself, but 3 of these α - chains will wrap around each other in a triple helix and become very stable (Bailey and Light, 1989). When these 3 chains are combined, they are referred to as tropocollagen, which is considered the structural unit of a collagen fibril. There are 19 different α – chain types that can combine in varies forms of triple helixes to form a unique tropocollagen unit that contributes to different collagen properties (Aberle et al. 2001). A tropocollagen unit typically has a molecular weight of 300,000 and a length of 280 nm (Weston et al. 2002). Tropocollagen molecules are arranged in a quarter-staggered arrangement, meaning that each molecule is arranged at three-quarters the length of the neighboring unit. Each unit bonds together at regular intervals, which is known as cross-linking, and results in a more stable molecule (Weston et al. 2002). The strength of collagen comes from its ability to form covalent crosslinks intermolecularly (bonds form between α-chains of different molecules) and intramolecularly (bonds form between α-chains of the same molecule). The crosslinking that occurs intermolecularly contributes more to stability than the crosslinks that form intramolecularly (Weston et al. 2001, Bailey and Light, 1989). Essentially the crosslinking occurs through 3 different mechanisms: disulphide bonding, divalent bonding, and complex bonding (joining more than two α-chains together) (Bailey and Light, 1989). This contributes to tenderness in muscle because as the animal ages, less collagen is created, and less collagen turnover occurs, thereby allowing crosslinking bonds to form. The collagen in young animals contains bonds that contain Schiff bases (carbon-nitrogen double bond

with the nitrogen molecule connecting to an aryl or alkyl group) which can be acted upon by pH changes, heating, or by the addition of denaturing agents (Weston et al. 2001). These are referred to as reducible bonds which are replaced with more stable crosslinks. It is suggested that the age effect of collagen in beef can be avoided by limiting animal maturity between 12 and 18 months at time of slaughter (Shimokomaki et al., 1972). This observation of tender beef in the range of 12 and 18 months old may be the reason why comparatively little research has been done with pork collagen due to the comparatively younger physiological age of swine.

Development of Connective Tissue during Pig Growth

Fang et al. (1999) investigated how connective tissue content changes during pig growth using one litter of Landrace pigs sampled at birth (n = 2), 1 month of age (n = 2), 3 months of age (n = 2), 5 months of age (n = 3), 6 months of age (n = 3) as well as 2 additional 55 month old Landrace pigs. Connective tissue morphology and collagen content was evaluated on the semitendinosus muscle 2 hours after death. The authors quantified the growth of the secondary perimysium, primary perimysium, and endomysium. In neonatal pigs, the endomysia and muscle fibers were not possible to differentiate from one another, but were readily observable in the 1-month-old animals. The secondary perimysium showed a linear increase as pigs aged to 6 months (6.1 to 23.6μm). Heat-soluble collagen made up 35% of the collagen content in neonatal pigs. This value dropped 20% of the total collagen at 3 months of age and dropped 24% of the total collagen in pigs at 6 months of age. Pigs at 55 months old had 5% soluble collagen, thus showing, like with cattle, non-reducible cross links develop as pigs increase in age. To contrast with cattle, Hill (1966) reports that Hereford steers in the 4-6 month range would possess 21.8% of heat soluble collagen and 4-6 month old Fresian steers possess an average of 21.1% heat soluble collagen in the sternomandibularis muscle. Fresian cattle in an equivalent age group to the 55-month-aged pigs would possess 3.7% heat soluble collagen. It is interesting to note the similarity in heat-soluble collagen between the semitendinosus muscle of pigs versus the sternomandibularis muscle of cattle, which is an area that is known to have extensive amounts of connective tissue.

Collagen Content in Porcine Muscle

Nakamura et al. (2003) investigated the collagen content of the *longissimus thoracis* (LT) and *pectoralis profundus* (PP) muscles of 12 female or castrated male Landrace × Duroc pigs. It

was found that the total collagen content in PP muscles was higher ($P = 0.01$) at 4.13 mg/g than LT at 2.66 mg/g. Type I and Type III collagen was quantified as the percent area of the perimysium using immunohistochemical methods to stain the cells and calculate the total collagen area via a microscope. It was observed that Type I and Type III collagen were present in greater amounts ($P = 0.001$) in the PP (Type I: 45.7%, Type III: 54.5%) muscle when compared to the LT muscle (Type I: 25.4%, Type III: 37.6%). Regardless of muscle, Type III collagen contributed to the largest amount of the Perimysium ($P = 0.001$).

Wheeler et al. (2000) documented collagen content in the *longissimus lumborum, biceps femoris, semimembranosus, semitendinosus, and triceps brachii* from 23 white composite barrows. It was observed that *biceps femoris* muscle had the highest ($P < 0.05$) amount of collagen with 7.1 mg/g, followed by the *triceps brachii* (6.0 mg/g), *semitendinosus* (5.3mg/g), and the *longissimus* and *semimembranosus* (4.1 and 4.5 mg/g). Kristensen et al. (2002) described the collagen content of the *longissimus dorsi* (LD) of Landrace × Yorkshire pigs on ad libitum and restricted feeding systems. There was no difference ($P > 0.05$) between restricted and ad libitum feeding strategies on LD collagen content with a range of 3.3 to 3.8 mg/g of tissue. The percentage of soluble collagen in the LD ranged between 34.5% and 36.9% but the pigs with the restricted feeding program having a statistically higher ($P < 0.05$) percentage at 39.2%. In a similar study by Therkildsen et al. (2002), the collagen content of LD and BF muscles from Landrace × Yorkshire pigs on multiple restricted feeding systems. Similar to the Kristensen study, the LD contained 3.1 mg/g of collagen/g of muscle which was significantly lower ($P < 0.05$) than the BF which had 4.4 mg/g of collagen.

In relation to swine, cattle generally have higher amounts of collagen. Patten et al. (2008) demonstrates this by reporting the collagen content of multiple muscles from select A-maturity steers: *gluteus medius* (GLM), *infraspinatus* (INF), *longissimus* (LD), *triceps brachii long head* (LTB), *triceps brachii lateral head* (MTB), *psoas major* (PSO), *rectus femoris* (REF), *teres major* (TER), and *tensor fascia latae (*TFL*). The INF muscle had the highest collagen content out of this group of muscles with 25.86 mg/g of muscle. While there was no statistical analysis between muscles in this study, the quantities of collagen content (mg/g of muscle) will be listed in descending order: MTB (9.62), GLM (9.10), TER (8.73), LD (8.45), LTB (8.19), REF (7.99), TFL (7.69), and PSO (5.26). When compared to beef muscles, it seems that porcine *biceps femoris* and *triceps brachii* are the most comparable to beef in collagen content but

generally much lower when compared to most beef muscles, thereby explaining why the collagen effect on meat tenderness has been relatively ignored.

Collagen in Belly Fat

As mentioned in previous sections, it is well known that dietary fats in swine diets have an enormous effect on pork fat quality. Poor pork fat quality not only affects the visual appearance but is also linked to poor slicing yields. However, there is extreme variability with correlating fat quality measurements to bacon slice yields (Seman et al., 2013). Seman et al. (2013) describes that fat measurements contribute to a range of 17 to 21% of the variation in slice yield data. This is relatively low and poses issues if applied to practical situations such as procurement specifications because it would be simple to dismiss this data and neglect this relationship. If the fat measurements only explain up to 21% of the variation it raises the question of unidentified aspects that can contribute to the slicing issues of soft bellies.

One such factor could be the collagen content of fat. It is not a stretch to theorize that collagen plays a role in soft fat due to collagen being the principle component of the connective tissue that supports and provides a measure of structure for lobules of fat cells (Enser, 1984). Furthermore, it is also known that meat from animals on high-energy diets will show greater quantities of total collagen (Torrescano et al., 2003). This is an important concept to consider for belly quality. Fat is more energy dense than protein or carbohydrates (Ewan 2001). The biggest culprit of the soft fat problem is DDGs which happens to contain close to 2 times the amount of fat than what is in corn, meaning that in addition to limiting the *de novo* fatty synthesis in the pig, the pig should have a greater amount of collagen due to the added energy in the diet. Secondly, producers want to maximize process efficiency, and the addition of fat has been shown to decrease feed intake and improve growth rate and feed efficiency. Thus, for multiple reasons, it is likely that collagen content could be a source of variation (Azain, 2001).

To date there has been very little research concerning the collagen content of pork fat. One study that analyzed the collagen content of fat was investigating how temperature stress affects growth and bacon quality (White et al., 2008). In this study, 240 gilts were selected at 88 kg of body weight and were housed at thermos-neutral temperatures at 23.9 and 32.2°C, while having two different spatial allocations (0.93 and 0.66m^2). In this study, there were no significant contribution by spatial allocation ($P = 0.74$), but there was a temperature affect.

Bellies from pigs in the 32.2°C temperature range had collagen amounts of 11.9 and 11.7 mg/g, which were higher than the collagen content from pigs in the 23.9°C (9.9 and 10.5 mg/g) temperature treatment. Building on the logic posed earlier in this section, it could be expected that the rearing conditions that contribute to soft fat would also cause a greater amount of collagen to be in that soft fat. Regardless of the amount of collagen in the fat and the effect that would have on belly firmness, it would be possible to manipulate the chemical state of the collagen through belly processing procedures. According to Purslow (2005), in a model considering intermuscular connective tissue, cooking in the range of 20-50°C (68-122°F) can increase the intermuscular connective tissue contribution to toughness. Thus, manipulating the time in the smokehouse may be a route to firm up soft fat. If too much collagen does cause soft fat, it might be possible to denature these proteins as Powell et al. (2007) claims that insoluble collagen denaturation can occur at 55°C (131°F). Though most commercial bacon processors want to avoid higher end-point temperatures in the smokehouse for fear of fat rendering, this might be a method to recoup weight losses through improving slice yields.

In conclusion, it is possible that the collagen content of bellies can change. This has been proven in environmental studies where pigs exposed to high temperatures outside of their thermos-neutral zone will contain more collagen in their bellies than pigs exposed to neutral or cold temperatures. Furthermore, in beef/pork muscle models, the collagen content has been shown to change due to rearing practices. Therefore it is possible that the collagen content in pork fat can be influenced by collagen content and in affect slicing performance of bellies.

Conclusion

As shown in this chapter, bacon production consists of a wide variability of processing methods that contribute to creating a wide range of products to meet consumer demand. Unfortunately, poor fat quality is of great concern to commercial bacon producers due to unrealized profits due to poor slicing yields. The research in this chapter has shown many research studies have investigated controlling fat quality. Despite understanding the problem, soft bellies still contribute to loss of profits. Therefore, other factors must exist, such as collagen content in bacon fat, that could contribute to poor slice yields. Furthermore, the attention fat quality has garnered has taken the emphasis away from the cooked bacon quality and how belly quality relates to cooking performance. Thus, the literature presented in this chapter will be built

upon by investigating if collagen and adipocyte characteristics contribute to belly quality, and investigating on what factors contribute to cooked bacon quality.

References

Aaslyng, M.D., C. Vestergaard, and A.G. Kock. 2014. The effect of salt reduction on sensory quality and microbial growth in hotdog sausages, bacon, ham, and salami. Meat Sci. 96: 47-55.

Abee, T., L. Krockel, and C. Hill. 1995. Bacteriocins: modes of action and potentials in food preservation and control of food poisoning. Int. J. Food Microbiology. 28: 169-185.

Aberle, Elton D., John C. Forrest, David E. Gerrard, Edward Mills. 2001. Principles of Meat Science 4th ed. Kendall/Hunt Publishing Company. Dubuque, IA.

Alcock, Joan P. 2006. Food in the Ancient World. Greenwood Publishing Group Inc, Wesport CT. pg 68-88.

AOAC. 1997. Official Methods of Analysis. 16th ed. AOAC Int., Gaithersburg, Maryland.

Apple J.K., C.V. Maxwell, J.T. Sawyer, B.R. Kutz, L.K.Rakes, M.E.Davis, Z.B. Johnson, S.N. Carr, and T.A. Armstrong. 2007. Interactive effect of ractopamine and dietary fat source on quality characteristics of fresh pork bellies. J. Anim. Sci. 85: 2682-2690.

Archile-Contreras, A.C., I.B. Mandell, and P.P. Purslow. 2010. Disparity of dietary effects on collagen characteristics and toughness between two beef muslces. Meat Sci. 86: 491-497.

Archile-Contreras, M. Cha, S. Miller, I.B. Mandell, and P.P. Purslow. 2011. Vitamins E and C may increase collagen turn-over by intramuscular fibroblasts; potential for improved meat quality. J. Agric. Food Chem. 59: 608-614

Archile-Contreras, A., I.B. Mandell, and P.P. Purslow. 2010. Disparity of dietary effects on collagen characteristics and toughness between two beef muscles. Meat Sci. 86: 491-497.

Arhchile-Contreras, A.C., and P.P. Purslow. 2011. Oxidative stress may affect meat quality by interfering with collagen turnover by muscle fibroblasts. Food Research International. 44: 582-588.

Asmus, M.D., M.A. Tavarez, M.D. Tokach, S.S. Dritz, A.L. Schroeder, J.L. Nelssen, R.D. Goodband, and J.M. DeRouchey. 2014. The effects of immunological castration and corn dried distillers grains with solubles withdrawal on growth performance, carcass characteristics, fatty acid analysis, and iodine value of pork fat depots. J. ANim. Sci. 92: 2116-2132.

Ayto, John. 1993. The Diner's Dictionary Food and Drink from A to Z. Oxford University Press, Oxford NY. p 14-15.

Azain, M.J. 2001. Fat in Swine Nutrition. In A.J. Lewis, and L.L. Southern editors, Swine Nutrition 2nd edition. Boca Raton, FL; CRC Press. p95-102.

Babatunde, G.M., W.G. Pond, E.F. Walker, Jr., and P Chapman. 1968. Effect of dietary safflower oil or hydrogenated coconut oil in hear, liver and adipose tissue fatty acid levels and physical carcass measurement of pigs fed fat-free diets. J. Anim Sci. 27:1290-1295.

Bailey A.J., and N.D. Light. 1989. Connective tissue in meat and meat products. Elsevier Science Publishing Co., New York, NY.

Bendal, J.R. 1967. The elastin content of various muscles of beef animals. Journal of Science Food Agricutlure. 18: 553-558.

Benz, J.M., S.K. Linneen, M.D. Tokach, S.S. Dritz, J.L. Nelssen, J.M. DeRouchey, R.D. Goodband, R.C. Sulabo, and K.J Prusa. 2010. Effects of dried distillers grains with solubles on carcass fat quality of finishing pigs. J. Anim. Sci. 88: 3666-3682.

Bothma, C., A. Hugo, G. Osthoff, C.C. Joubert, J.C. Swarts, H.L de Kock. 2014. Effect of dietary conjugated linoleic acid supplementation on the technological quality of backfat of pigs. Meat Sci: 97: 277-286.

Boyd, R.D., M.E. Johnston, K.Scheller, A.A. Sosnicki, and E.R. Wilson. 1997. Relationship between dietary fatty acid profile and body composition in growing pigs. PIC USA T&D Technical Memo153. Pig Improvement Company, USA, Fanklin KY.

Browne, N.A., J.K. Apple, C.V. Maxwell, J.W. Yancey, T.M. Johnson, D.L. Galloway, and B.E. Bass. 2013. Alternating dietary fat sources for growing-finishing pigs fed dried distillers grains with solubles: II. Fresh belly and bacon quality characteristics. J. Anim. Sci. 91:1509-1521.

Cameron, N.D., and M.B. Enser. 1991. Fatty acid composition of lipid in longissimus dorsi muscle of Duroc and British Landrace pigs and its relationship with eating quality. Meat Sci. 29:295-307.

Cannon, J.E., J.B. Morgan, F.K. McKeith, G.C. Smith, S. Sonka, J. Heavner, and D.L. Meeker. 1996. Pork chain quality audit survey: quantification of pork quality characteristics. J. Musc. Food. 7:29-44.

Carroll, A.L., J.M. Eggert, A.P. Schinckel, and B.T. Richert. 1999. Effects of high oil corn and duration of conjugated linoleic acid (CLA) supplementation on pig growth, pork quality and carcass composition. Purdue University Swine Day Reports. p 34-40.

Cassens, Robert. 1994. Meat Preservation Preventing Losses and Assuring Safety. Food & Nutrition Press, INC. Trumbull, CT. Pg 79-90.

Cavett, JJ. 1962. The microbiology of vacuum packed sliced bacon. J. Applied Bacteria. 25: 282-289.

Cornelia, P. C. Adriana, T. Adrian. 2009. Effect of storage condition on the chemical properties of pork bacon. Anelele Universitatii din Oradea, Fasciculua: ecotoxicology, zootennie si tehnologii de inustrie alimentara. p. 565-572.

[CDC] Center for Disease Control. Salmonella. http://www.cdc.gov/salmonella/. Accessed Jan. 23, 2014.

[CFR] Code of Federal Regulations. 1984. Title 9, part 319.107. http://www.gpo.gov/fdsys/pkg/CFR-2011-title9-vol2/pdf/CFR-2011-title9-vol2-chapIII.pdf. Accesed Aug. 13, 2014.

[CFR] Code of Federal Regulations. 1998. Title 9, part 318.7(1). http://frwebgate.access.gpo.gov/cgi-bin/get-cfr.cgi?TITLE=9&PART=318&SECTION=7&YEAR=1998&TYPE=TEXT. Accessed Dec. 10, 2009.

[CFR] Code of Federal Regulations. 2014. Title 9, part 317.8. http://www.ecfr.gov/cgi-bin/text-idx?rgn=div5&node=9:2.0.2.1.18#sp9.2.317.b. Accessed Nov. 11, 2014.

Chin, S.F., W. Liu, J.M. Storkson, Y.L. Ha, and M.W. Pariza. 1992. Dietary sources of conjugated linoleic dienoic isomers of linoleic acid, a newly recognized class of anticarcinogens. J. Food Compos. Anal. 5:185-197.

Christensen, M., P. Ertbjerg, S. Faillab, C. Sanudoc, R.I. Richardson, G.R. Nute, J.L. Olletac, B. Paneae, P. Albertie, M. Juarez, J.F. Hocquette, and J.L. Williams. 2011. Realtionship between collagen characteristics, lipid content and raw and cooked texture of meat from young bulls of fifteen European breeds. Meat Sci. 87: 61-65.

Christiansen, L.N., R.B. Tompkin, A.B. Shaparis, T.V. Kueper, R.W. Johnston, D.A. Kautter, and O.J. Kolari. 1974. Effect of sodium nitrite on toxin production by clostridium botulinum in bacon. Applied Microbiology. 27: 733-737.

Corona, E., J.V Garcia-Perez, J.V. Santacatalina, S. Ventanas, and J. Benedito. 2014. Ultrasonic characterization of pork fat crystallization during cold storage. J. Food Sci. 79: E828-E838.

Davey. C.L., A.F. Niederer, and A.E. Graafhuis. 1976. Effects of ageing and cooking on the tenderness of beef muscle. Journal of the Science of Food and Agriculture. 27: 251-256.

Davidson, Alan. 2006. The Oxford Companion to Food. 2nd ed. Oxford University Press, Oxford NY. p 49-50

Davidson, P.M., 1997. Preservatives and natural antimicrobial compounds. In: M.P. Doyle, L.R. Beuchat, and T.J. Montville Editors, Food Microbiology: Fundamentals and Frontiers. Washington, DC: American Society for Microbiology. p520-556.

Della Casa, G., D. Bochicchio, V. Faeti, G. Marchetto, E. Poletti, A. Rossi, A. Garavaldi, A. Panciroli, and N. Brogna. 2009. Use of pure glycerol in fattening heavy pigs. Meat Sci. 81:238-244.

Dempster, J.F. 1972. Some characteristics of micro-organisms isolated from vacuum packaged bacon. The Irish journal of agricultural research. 11: 351-361.

Dugan, M.E.R., J.L. Aalhus, J.K.G Kramer. 2004. Conjugated linoleic acid pork research. American Journal of Clinical Nutrition. Suppl. 79 (6): 1212S-1216S.

Dunshea, F.R., D.N. D'Souza, D.W. Pethick, G.S Harper, and R.D. Warner. 2005. Effects of dietary factors and other metabolic modifiers on quality and nutritional value of meat. Meat Sci. 71:8-38.

Duttlinger, A.W., J.M. Benz, T.A. Houser, M.D. Tokach, S.S. Dritz, J.M. DeRouchey, J.L. Nelssen, R.D. Goodband, and K.J. Prusa. 2008. Effects of increasing glycerol and dried

distillers grains with soluble on the growth performance and carcass characteristics of finishing pigs. KS Agr. Exp. Sta. Report of Prog. 1001: 175-185.

Duttlinger, A.W., T.A. Houser, J.M. DeRouchey, M.D., Tokach, S.S. Dritz, J.L., Nelssen, R.D. Goodband, K.J. Prusa, and L. Huskey. 2009. Sensory characteristics of loins from pigs fed glycerol and racopamine HCL during the last 28 days of finishing. KS Agr. Exp. Sta. Report of Prog. 1020: 274-279.

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

Engel, J.J., J.W. Smith, J.A. Unruh, R.D. Goodband, P.R. O'Quinn, M.D. Tokach, and J.L. Nelssen. 2001. Effects of choice white grease or poultry fat on growth performance, carcass leanness, and meat quality characteristics of growing-finishing pigs. J. Anim. Sci. 79: 1491-1501.

Enser, M. 1984. The relationship between the composition and consistency of pig backfat. Special Report, Meat Research Institute. 2: 53-57.

Ewan, R.C. 2001. Energy utilization in swine nutrition. In A.J. Lewis, and L.L. Southern editors, Swine Nutrition 2nd edition. Boca Raton, FL; CRC Press. p85-94.

Fang, S.H., T. Nishimura, and K. Takahashi. 1999. Relationship between development of intramuscular connective tissue and toughness of pork during growth of pigs. J. Anim. Sci. 77: 120-130.

Food Processing. 2014. Battle brewing over process for pre-cooked, sliced bacon that looks pan fried. http://www.fponthenet.net/article/88205/Battle-Brewing-Over-Process-for-Pre-Cooked--Sliced-Bacon-that-Looks-Pan-Fried.aspx. (Accessed 10 December 2014).

Gajadhar, A.A., E. Pozio, H.R. Gamble, K. Nockler, C. Maddox-Hyttel, L.B. Forbes, I. Vallee, P. Rossi, A. Marinculic, and P. Boireau. 2009. Trichinella diagnostics and control: Mandatory and best practices for ensuring food safety. Veterinary Parasitology 159: 197-205.

Gamble, H.R. 1997. Parasites associated with pork and pork products. Rev. sci. tech. Off. Int. Epiz., 16: 496-506.

Ganesan, V., K. Muthukumarappan, and K.A. Rosentrater. 2008. Effect of moisture content and soluble level on the physical, chemical, and flow properties of distillers dried grains with soluble (DDGS). Cereal Chem. 85 (4): 464-470.

Gatlin, L.A., M.T. See, D.K. Larick, X. Lin, and J. Odle. 2002. Conjugated linoleic acid in combination with supplemental dietary fat alters pork fat quality. Journal of Nutrition. 132 (10): 3105-3112.

Gatlin, L.A., M.T. See, D.K. Larick, and J. Odle. 2006. Descriptive flavor analysis of bacon and pork loin from lean-genotype gilts fed conjugated linoleic acid and supplemental fat. J. Anim. Sci. 84:3381-3386.

Gerard, D.E., A.L. Grant. 2003. Animal Growth & Development. Dubuque, IA: Kendall Hunt. p 119-131.

Gibis, M., M. Kruwinnus, J. Weiss. 2015. Impact of different pan-frying conditions on the formation of heterocyclic aromatic amines and sensory quality in fried bacon. J. Food Chemistry. 168: 383-389.

Giměnez, M.S., L. Oliveros de Furlon, and M. Carrasco de Clementi. 1985. Activity of fatty acid synthetase of rat liver after refeeding with high glycerol diet. Nutrition Reports International. 32(4): 757-763

Goehring, B.G. 2010. Influence of dietary dried distillers grains and glycerol on bacon quality. MS. Diss. Kansas State University.

Graham, A.B., R.D. Goodband, M.D. Tokach, S.S. Dritz, J.M. DeRouchey, and S. Nitikanchana. 2014. The interactive effects of high-fat, high-fiber diets and ractopamine HCL on finishing pig growth performance, carcass characteristics, and carcass fat quality. J. Anim. Sci. 92:4585-97.

Gregoire, Francine M. 2001. Adipocyte differentiation: From firbroblast to endocrine cell. Experimental Biology and Medicine 226:997-1002).

Gupta, R.C., and S. Bhargava. 1994. Determination of iodine numbers of edible oils. Biochemical Education. 22(1):47

Gunawardena, R.M., T. Gerold, and D.D. Rupp. 2014. Continuous process for cooking bacon with improved recovery. United States Patent. Patent no: US8753703 B2. June 17. 20014. http://www.google.com/patents/US20100112169 . (Accessed 2 January 2015).

Hansen, J.A. 2001 Deitary influencers of Pork Quality and practical solutions to quality problems. CFIA Swine Nutrition Conference p. 21-32.

Hanson, B. 2009. Step-by- step development of cooking processes. In Iowa State University/HansonTech Thermal Processing Workshop.

Harper, G.S., P.G. Allingham, and R.P. Le Feuvre. 1999. Changes in connective tissue of M. semitendinosus as a response to different growth paths in steers. Meat Sci. 53: 107-114.

Hartel, R.W. 2001. Crystallization in foods. Aspen Publishers Inc., Gaithersburg, MD.

Hill, F. 1966. The solubility of intramuscular collagen in meat animals of various ages. J. Food Sci. 31: 161-166.

Holly, R.A., and D. Patel. 2005. Improvement in shelf-life and safety of perishable foods by plant essential oils and smoke antimicrobials. Food Microbiology 22: 273-292.

Hugo, A., and E. Roodt. 2007. Significance of porcine fat quality in meat technology: A review. Food Reviews International 23: 175-198.

Irie. M., and M. Sakimoto. 1992. Fat characteristics of pigs fed fish oil containing eicosapentaenoic and docosaheanoic acids. J. Anim. Sci. 70:470-477.

Jabaay, R.W., J.C. Forrest, E.D. Aberle, H.V. Courtenay, and M.D. Judge. 1975. Bacon quality criteria and associated carcass traits. J. Anim. Sci. 41:431-437.

James, C., K.E. Barlow, S.J. James, M.J. Swain. 2006. The influence of processing and product factors on the quality of microwave pre-cooked bacon. J. of Food Engineering. 77:835-843.

Jay, J.M., M.J. Loessner, and D.A. Golden. 2005. Process meats and seafoods. In: Modern food microbiology. Springer Science+Business Media, LLC. p101-124.

Kellner, T.A., K.J Prusa, and J.F. Patience. 2014. Impact of dietary fat source and concentration and daily fatty acid intake on the composition of carcass fat and iodine value sampled in three regions of the pork carcass. J. Anim. Sci. 92:5485-5495.

Kemp, J.D., W.G. Moody, and J.D. Fox. 1969. Effect of fatness and fresh pork quality on yield and quality of bacon and yield of ham. J. Anim. Sci. 28: 612-614.

Kouakou, P., H. Ghalfi, J. Destain, R. Dubois-Dauphin, P. Evrard, and P. Thonart. 2009. Effects of curing sodium nitrite additive and natural meat fat on growth control of listeria monocytogenes by the bacteriocin-producing lactobacillus curvatus strain CWBI-B28. Food Microbiology. 26:623-628.

Koch, D.E., A.F. Parr, and R.A. Merkel. 1968. Fatty acid composition of the inner and outer layers of porcine backfat as affected by energy level, sex and sire. J. Food Sci. 33:176-180.

Kristensen, L., M. Therkildsen, B. Riis, M.T. Sorenson, N. Oksbjerg, P.P. Purslow, and P. Ertbjerg. 2002. Dietary-induced changes of muscle growth rate in pigs: effects on in vivo and postmortem muscle proteolysis and meat quality. J. Anim. Sci. 80: 2862-2871.

Kukay, C.C., L.H. Holcomb, J.N. Sofos, J.B. Morgan, J.D. Tatum, R.P. Clayton, and G.C. Smith. 1996. Application of HACCP by small-scale and medium-scale meat processors. Dairy, food and Environmental Sanitation 16: 74-80.

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

Larsen, S.T., B.R. Wiegand, F.C. Parrish Jr., and J.C. Sparks. Dietary conjugated linoleic acid changes belly and bacon quality from pigs fed varied lipid sources. J. Anim. Sci. 87:285-295.

Lauer, Heather. 2009. Bacon, a Love Story: A Salty Survey of Everybody's Favorite Meat. D&J Book Packaging and Media.

Lee, M, J.I. Gray, and A.M. Pearson. 1983. Effects of frying procedures and compositional factors on the temperature profile of bacon. J. of Food Sci. 48: 817-819.

Lin, M.H., D.R. Romsos, and G.A. Leveille. 1976. Effect of glycerol on lipogenic enzyme activities and on fatty acid synthesis in the rat and chicken. J. Nutrition 106(11): 1668-1677.

Lingbeck, J.M., P. Cordero, C.A O'Bryan, M.G. Johnson, S.C. Ricke, P.G. Crandall. 2014.
 Functionality of liquid smoke as an all-natural antimicrobial in food preservation. Meat
 Sci. 97:197-206.

Lo Fiego, D.P., P Santoro, P. Macchioni, and E. De Leonibus. 2005. Influence of genetic type,
 live weight at slaughter, and carcass fatness on fatty acid composition of subcuateneous
 adipose tissue of raw ham in the heavy pig. Meat Sci. 69:107-114.

MacDougall, D.B., Mottram, D.S., and D.N. Rhodes. 1975. Contribution of nitrite and nitrate to
 the colour and flavor of cured meats. J. Sci. Food Agric. 26: 1743-1754.

Mandigo, Roger. 2009. Bacon Processing Today. In Proc. 62nd Reciprocal Meat Sci. Conf.,
 Fayetteville, AR.

Mandigo, Roger. 2000. Quality lean growth modeling- bacon quality assessment.
 http://old.pork.org/filelibrary/researchdocuments/97-1999-mandigo.pdf. (Accessed 1
 December 2014.)

Mayes, P.A. 1996. Biosynthesis of Fatty Acids. Pages 216-223 in Harper's Biochemistry 24th ed.
 R.K. Murray, D.K. Granner, P.A. Mayes, and V.W. Rodwell ed. Stamford, CT.

McCormick, R.J. 1989, The influence of nutrition on collagen metabolism and stability. In Proc.
 42nd Reciprocal Meat Sci. Conf. Guelph, Canada.

McClelland, K.M., G. Rentfrow, G.L. Cromwell, M.D. Lindemann, and M.J. Azain. 2012.
 Effects of corn distillers dried grains with solubles on quality traits of pork. J. Anim. Sci.
 90:4148-4156.

Meadus, W.J., P. Duff, B. Uttaro, J.L. Aalhus, D.C. Rolland, L.L. Gibson, and M.E.R. Dugan.
 2010. Production of docosahexaenoic acid (DHA) enriched bacon. J. Agric. Food Chem.
 58:465-472.

Mersmann, H.J. and S.B. Smith. 2004. Adipose Tissue Development. Vol. 2 PP 530-538 in Encyclopedia of Meat Sciences. W.K. Jensen, C Devine, M.E. Dikeman ed. Elsevier Ltd, Oxford UK.

Miller, M.F., P.O. Ahmed, S.D. Shackelford, K.D. Haydon, and J.O Reagan. 1993. Effects of feeding diets containing different fat supplements to swine on the visual properties and storage stability of low fat sausage. Meat Sci. 33:231-244.

Milley, P.J., R.T. Toledo, and S. Ramakrishnan. 2005. Determination of minimum inhibitory concentrations of liquid smoke factions. J. Food Sci. 70:M12-M17.

Moerck, K.E. and H.R. Ball. 1973. Lipid autoxidation in mechanically deboned chicken meat. J. Food Sci. 39:876-880.

Moreno, R., P.S. Miller, T.E. Burkey, S.J. Jones, S.L. Cuppett, T.P. Carr, T.F. Jones, R.M. Diedrichsen. 2008. The Effect of Corn Distillers Dried Grain with Solubles (DDGS) on Carcass Characteristics and Pork Quality. Nebraska Swine Day Report 8-11.

Motoyama, M, K. Chikuni, T. Narita, K. Aikawa, and K. Sasaki. 2013. In situ raman spectrometric analysis of crystallinity and crystal polymorphism of fat in porcine adipose tissue. J. of Agricultural and Food Chemistry. 61: 69-75.

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

Nakamura, Y.N., H. Iwamoto, Y. Ono, N. Shiba, S. Nishimura, S. Tabata. 2003. Relationship among collagen amount, distribution and architecture in the M. longissimus thoracis and M. pectoralis profundus from pigs. Meat Sci. 64: 43-50.

Narine S.S., and A.G. Marangoni. 2002. Structure and mechanical properties of fat crystal
networks. In: A.G. Marangoni and S.S. Narine editors, Physical properties of lipids.
Marcel Dekker, Inc. New York, NY. P. 63-83.

National Pork Board. 2007. Bacon Trends.
http://www.porkretail.org/filelibrary/Retail/BaconTrends.pdf (Accessed 28 January
2015).

Nelson, R.P. 1969. Production of pre-cooked sliced bacon. Patent US3429713.
http://www.google.com/patents/US3429713 . (Accessed 28, January 2015).

Nurnberg, K., J. Wegner, and K. Ender. 1998. Factors influencing fat composition in muscle and
adipose tissue of farm animals. Livest. Prod. Sci. 56:145-156.

Ockerman, H.W., and L. Basu. 2006. Edible rendering- Rendered products for human use. In:
D.L. Meeker, editor, Essential rendering: all about the animal by-products industry. Kirby
Lithographic Company, Inc. Arlington, Va. p. 99.

O'Leary, V., and M. Solberg. 1976. Effect of sodium nitrite inhibition on intracellular thiol
groups and on the activity of certain glycolytic enzymes in clostridium perfringens.
Applied and Environmental Microbiology. 31:208-212.

Park, Y., K.J. Albright, W. Liu, J.M. Storkson, M.E. Cook, and M.W. Pariza. 1997. Effect of
conjugated linoleic acid on body composition in mice. Lipids. 32: 853-858.

Patten, L.E., J.M. Hodgen, A.M. Stelzleni, C.R. Calkins, D.D. Johnson, and B.L. Gwartney.
2008. Chemical properties of cow and beef muscles: Benchmarking the differences and
similarities. J. Anim. Sci. 86:1904-1916.

Pearson, A.M., F.W. Tauber. 1984. Processed Meats. 2nd ed. The AVI Publishing Company Inc.
Westport, CT. pg 46-68.

Pearson, A.M., T.A. Gillett. 1996. Processed Meats. 3rd ed. Chapman and Hall. Florence, KY. pg 88.

Person, R.C., D.R. McKenna, D.B. Griffin, F.K. McKeith, J.A. Scanga, K.E. Belk, G.C. Smith, J.W. Savell. 2005. Benchmarking value in the pork supply chain: Processing characteristics and consumer evaluations of pork bellies of different thicknesses when manufactured into bacon. Meat Sci. 70:121-131.

Pegg, R.B., and F. Shahidi. 2000. Nitrite Curing Of Meat: The N-Nitrosamine Problem and Nitrite Alternatives. Food & Nutrition Press, INC. Trumbull, CT pg 39-241.

Pegg, R.B., and F. Shahidi. 2006. Processing of Nitrite-Free Cured Meats. Advanced Technologies For Meat Processing. CRC Press. Boca Raton, FL. p. 309-324.

Powell, T.H., M.C. Hunt, and M.E. Dikeman. 2000. Enzymatic assay to determine collagen thermal denaturation and solubilization. Meat Sci. 54: 307-311.

Powell, T.H., M.C. Hunt, and M.E. Dikeman. 2000b. Tenderness and collagen composition of beef semitendinosus roasts cooked by conventional convective cooking and modeled, multi-stage, convective cooking. Meat Sci. 55: 421-425.

Pruess, Joanna. 2006. Seduced by Bacon: Recipes & Lore about America's Favorite Indulgence. The Lyons Press. Guilford Connecticut. p 1-3.

Purslow, P.P. 2005. Intramuscular connective tissue and its role in meat quality. Meat Sci. 70: 435-447.

Pyburn, D.G., H.R. Gamble, E.A Wagstrom, L.A. Anderson, L.E. Miller. 2005. Trichinae certification in the United States pork industry. Veterinary Parasitology 132: 179-183.

Ramsay, T.G., C.M. Evock-Clover, N.C. Steele, and M.J. Azain. 2001. Dietary conjugated
linoleic acid alters fatty acid composition of pig skeletal muscle and fat. J. Anim. Sci.
79:2152-2166.

Rangwala S.M., and M.A. Lazar. 2000.Transcriptional Control of Adipogenesis. Annual Review
of Nutrition. 20:535-539.

Rentfrow, G., T.E. Sauber, G.L. Allee, E.P. Berg. 2003. The influence of diets containing either
conventional corn, conventional corn with choice white grease, high oil corn, or high oil
high oleic corn on belly/bacon quality. Meat Sci. 64: 459-466.

Renewable Fuels Association. 2014. Pocket guide to ethanol 2014.
http://www.ethanolrfa.org/page/-/rfa-association-
site/Resource%20Center/2014%20Pocket%20Guide%20to%20Ethanol.pdf?nocdn=1.
(Accessed 30 May 2015).

Robles, C.C. 2004 The effect of fresh and frozen bellies on bacon processing characteristics and
bacon quality. MS Diss. University of Nebraska, Lincoln.

Rocourt, J., C.H. Jacquet, and A. Reilly. 2000. Epidemiology of human listeriosis and seafoods.
Int. J. Food Microbiology. 62:197-209.

Saunders, J.A., K.A. Roesentrater. 2009. Survey of US fuel ethanol plants. Bioresource
Technology. 100: 3277-3284.

Schinckel, A.P., S.E. Mills, T.E. Weber, and J.M. Eggert. 2002. A review of genetic and
nutrional factors affecting fat quality and belly firmness. Pages 89-113 in Proc. Natl.
Swine Improv. Fed. Annu. Mtg., Nashville, TN.

Scott, R.A., S.G. Cornelius, and H.J. Mersmann. 1981. Fatty acid composition of adipose tissue
from lean and obese swine. J. Anim. Sci. 53:977-981.

Sebranek, Joe. 2009. Ingredients in Meat Products. Springer Science + Media, LLC New York NY. pp 9-17.

Sebranek, J., and J. Bacus. 2007. Natural and Organic Cured Meat Products: Regulatory, Manufacturing, Marketing, Quality and Safety Issues. American Meat Science Association White Paper Series #1. http://www.meatscience.org/page.aspx?id=403. (Accessed 5 December 2014)

Sebranek, J.G., and J.B. Fox. 1985. A review of nitrite and chloride chemistry- interactions and implications for cured meats. J. Science of Food and Agriculture. 36:1169-1182.

Seman, D.L., W.N.G. Barron, M. Matzinger. 2013. Evaluating the ability to measure pork fat quality for the production of commercial bacon. J. Meat Sci. 94: 262-266.

Shackelford, S.D., M.F. Miller, K.D. Haydon, N.V. Lovegren, C.E. Lyon, and J.O Reagan. 1990. Acceptability of bacon as influenced by the feeding of elevated level of monounsaturated fats to growing-finishing swine. J. Food Science. 55: 621-624.

Shi, X., and X. Zhu. 2009. Biofilm formation and food safety in food industries. Trends in food science and Technology. 20: 407-413.

Shimokomaki, M., D.F. Elsden, and A.J. Bailey. 1972. Meat tenderness: Age related changes in bovine intramuscular collagen. J. Food Sci. 37: 892.

Smith, S,B., and D. R. Smith. 2011. Analysis of rendered fats. In: L.M.L. Nollet and F. Toldra, editors, Handbook of analysis of edible animal by-products. CRC Press Boca Raton, Fl. p. 40.

Smith G.C., R.L. West, and Z.L. Carpenter. 1975. Factors affecting desirability of bacon and commercially-processed pork bellies. J. Anim. Sci. 41:54-65.

Stein, H.H. 2008. Feed ingredient database. http://nutrition.ansci.illinois.edu/feed-ingredients. (Accessed 30 May 2015).

Stewart, C.M. 2003. Staphylococcus aureus and staphylococcal enterotoxins. In: Hocking AD, editor: Foodborne microorganisms of public health significance. 6th ed. Austrailian Institute of Food Science and Technology (NSW Branch), Sydney. P. 359-380.

Taormina, P.J., and G.W. Bartholomew. 2005. Validation of bacon processing conditions to verify control of clostridium perfringens and staphylococcus aureus. J. Food Protection. 68: 1831-1839.

Therkildsen, M., B. Riis, A. Karlsson, L. Kristensen, P. Ertbjerg, P.P. Purslow, M. Dall Aaslyng, and N. Oksbjerg. 2002. Compensatory growth response in pigs, muscle protein turn-over and meat texture: effects of restriction/realimentation period. Animal Science. 75:367-377.

Thiel-Cooper, R.L., F.C. Parrish, J.C. Sparks, B.R. Wiegand, and R.C. Ewan. 2001. Conjugated linoleic acid changes swine performance and carcass composition. J. Anim. Sci. 79:1821-1828.

Tonge, R.J., A.C. Baird-Parker, and J.J. Cavett. 1964. Chemical and microbiological changes during storage of vacuum packed sliced bacon. J. Applied Bacteriology. 27:252-264.

Torrescano, G., A. Sanches-Escalante, B. Giminez, P. Roncales, and J.A. Beltran. 2003. Shear values of raw samples of 14 bovine muscles and their relation to muscle collagen characteristics. Meat Sci. 64: 85-91.

Trager, James. 1995. The Food Chronology: A Food Lover's Compendium of Events and Anecdotes, from Prehistory to the Present. Henry Holt and Company, Inc. New York, NY p 1541, 1621, 1655.

Trayhurn P and J.H. Beattie. 2001. Physiological role of adipose tissue: white adipose tissue as an endocrine and secretory organ. Proceedings of the Nutrition Societies 60: 329-330.

Trussell, K.A., J.K. Apple, J.W. Yancey, T.M. Johnson. 2011. Compositional and instrumental firmness variations within fresh pork bellies. Meat Science 88:472-480.

USDA FSIS. US Department of Agriculture.1996. Processing Inspectors' Calculations Handbook. FSIS Directive 7620.3.

USDA FSIS. Food Standards and Labeling Policy Book. 2005. http://www.fsis.usda.gov/OPPDE/larc/Policies/Labeling_Policy_Book_082005.pdf Accessed Nov. 15, 2008.

USDA. 1972. USDA amends bacon packaging, cured meat labeling regulation. U.S.D.A. News 2717-72.

USDA. 2013. Bacon and Food Safety. http://www.fsis.usda.gov/wps/portal/fsis/topics/food-safety-education/get-answers/food-safety-fact-sheets/meat-preparation/bacon-and-food-safety/CT_Index Accessed 21 January 2015.

Vansickle, J. 2007. Does DDGS affect pork quality? National Hog Farmer. 52(3) 18-21.

Villegas, F.J., H.B. Hedrick, T.L. Veum, K.L. McFate, and M.E. Bailey. 1973. Effect of diet and breed on fatty acid composition of porcine adipose tissue. J. Anim. Sci. 36:663-668.

Wang, H., X. Zhang, Q. Zhang, K. Ye, X. Xu, and G. Zhou. 2015. Comparison of microbial transfer rates from Salmonella spp. biofilm growth on stainless steel to selected processed and raw meat. Food Control. 50:574-580.

Walstra, P. 2003. Crystallization. In Physical chemistry of foods. Marcel Dekker, Inc. New York, NY. p. 583-649.

Warris, P.D., S.N. Brown, J.G. Franklin, and S.C. Kestin. 1990. The thickness and quality of backfat in various pig breeds and their relationship to intramuscular fat and the setting of joints from the carcasses. Meat Sci. 28:21-29.

Warnants, N., M.J. Van Oeckel, and C.V. Boneque. 1999. Incorporation of dietary polyunsaturated fatty acids into pork fatty tissues. J. Anim. Sci. 77:2478-2490.

Weber, T.E., K. Enright, B.T. Richert and A.P. Schinckel. 2001. Evaluation of the effects of dietary fat, conjugated linoleic acid, and ractopamine on growth performance and carcass quality in genetically lean gilts. Purdue University Swine Research Reports. pp 60-71.

Weston, A.R., R.W. Rogers, PAS, and T.G. Althen. 2002. Review: The role of collagen in meat tenderness. The Professional Animal Scientist. 18: 107-111.

Wheeler, T.L., S.D. Shackelford, and M. Koohmaraie. 2000. Variation in proteolysis, sarcomere length, collagen content, and tenderness among major pork muscles. J. Anim. Sci. 78: 958- 965.

White, H.M., B.T. Richert, A.P. Schinckel, J.R. Burgess, S.S. Donkin, and M.A. Latour. 2008. Effects of temperature stress on growth performance and bacon quality in grow-finish pigs housed at two densities. J. Anim. Sci. 86: 1789-1798.

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

Widmer, M.R., L.M. McGinnis, D.M. Wulf, and H.H. Stein. 2008. Effects of feeding distillers dried grains with solubles, high-protein distillers dried grains, and corn germ to growing-finishing pigs on pig performance, carcass quality, and the palatability of pork. J. Anim. Sci. 86:1819-1831.

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

Wiegand, B.R., J.C. Sparks, F.C. Parrish, Jr. and D.R. Zimmerman. 2002. Duration of feeding conjugated linoleic acid influences growth performance, carcass traits, and meat quality of finishing barrows. J. Anim. Sci. 80:637-643.

Wiseman, J., and J.A. Agunbiade. 1998. The influence of changes in dietary fat and oils on fatty acid profiles of carcass fat in finishing pigs. Livestock Production Science 54:217-222.

Wood, J.D. Fat deposition and the quality of fat tissue in meat animals. Pages 407-435 in Fats in Animal Nutrition. J. Wiesman, ed.; Butterworths London, 1984.

Xu, G., S.K. Baidoo, L.J. Johnston, D. Bilbus, J.E. Cannon, and G.C. Shurson. 2010. The effects of feeding diets containing corn distillers dried grains with solubles, and withdrawal period of distillers dried grains with solubles, on growth performance and pork quality in grower-finisher pigs. Journal of Animal Science. 88:1388-1397.

Chapter 3 - INVESTIGATING COLLAGEN AND ADIPOCYTE CHARACTERISTICS OF BACON FAT FROM BELLIES WITH DIFFERENT IODINE VALUES

B.L. Goehring, J.A. Unruh, J.M. DeRouchey, S.S. Dritz, B.M. Gerlach, A.M. Tapian, G.D. McCoy, M.A. Vaughn, S.M. Ebarb, J.M. Gonzalez, R.C. Johnson, D.A. Mohrhauser, and T.A. Houser

Abstract

The objective of this study was to examine the collagen and adipocyte characteristics in bacon fat with different iodine values (IV). Seventy-two pigs were selected using Near-Infrared Transmission (NitFom™ Instrument) from a commercial swine harvest facility and organized into three IV categories: High, 76.5 g/100g; Intermediate, 70.5 g/100g; and Low, 64.9 g/100g. Belly dimensions and firmness were measured at the plant. Bellies were processed into bacon according to plant protocols and transported to the Kansas State University Meat Laboratory. Three sequential bacon slices were selected at a point 24 cm from the shoulder end for histochemistry and collagen analysis. No statistical differences were observed for belly dimensions among IV categories. Belly firmness increased as IV decreased. Adipocyte size and number did not change between IV categories. High IV bellies showed larger amounts of soluble, insoluble and total collagen when compared to low IV bellies. In conclusion, the increased collagen content in High IV bellies may contribute to decreased belly firmness.

Introduction

      The bacon industry is a major component of the pork industry and has experienced massive changes during the last half decade. The pursuit of efficient pork production has driven the average market hog to be leaner, resulting in a 29% reduction of fat in current bellies compared to what was observed 40 years ago compared to 2005 (Gatlin et al., 2002; Person et al., 2005; See et al., 2002). Maximizing bacon slicing profits are further challenged with the occurrence of soft fat. Soft fat has become an increasing concern such that bacon quality research during the last decade has been primarily focused on improving fat quality via diet manipulation (Benz et al., 2010; Leick et al., 2010; Whitney et al., 2006; Widmer et al., 2008; Xu et al., 2010). Fat quality is typically expressed in terms of iodine value (IV), which is a reflection of the fat saturation with a high IV number indicating fat that is more unsaturated while a low IV number indicates fat that is more saturated (Benz et al., 2010; Leick et al., 2010; Xu et al., 2010).

      Seman et al. (2013) proposed a model to illustrate the variability contributing to slice yields and commented that manufacturing processes such as workmanship (slicer and bacon press settings), belly grading, and slicing parameters are several factors independent of fat quality that play a role in slice yield. Furthermore, these authors described the fat component of bellies as only contributing to 17 to 21% of the variability in slice yields, therefore other unidentified aspects of the bacon process may be contributing to slicing issues of soft bellies. One factor that could play a role in belly firmness and subsequently the soft fat slicing issue is the collagen content of fat. Collagen is a key component of connective tissue that provides support of fat depots (Enser, 1984). The biological factors that contribute to soft fat (diet, heat stress, or disease conditions) can also contribute to changes in collagen. Torrescano et al. (2003) stated that muscle from animals fed high energy diets showed increased quantities of total collagen. High energy diets are associated with the addition of fat into pig diets (Ewan, 2001). There is limited information on the collagen content in pork bellies. However in a temperature stress trial, White et al. (2008) showed that bellies from pigs raised at 32.2°C had more collagen than pigs raised in a 23.9°C environment. If collagen content changes in a similar fashion as fat saturation with different animal management practices, it would merit investigating how collagen

in pork fat relates to belly firmness. It is commonly understood that collagen contributes to instrumental toughness of meat (Torrescano et al., 2003), so it possible that this effect could be experienced by bellies during slicing.

Finally, another factor that could influence firmness is the actual size of the fat cells within the fat depots. Using a porcine model to describe biological obesity, Pawar et al. (2015) fed pigs a high-fat/high-fructose diet (listed as 16.1% crude protein, 43.0% ether extract, and 40.8% carbohydrates) versus a control diet (listed as 13% crude protein, 2% fat, and 6% fiber) for six weeks. This study showed that the faster growing pigs on the high-fat diet increased body weight faster with a greater percentage of subcutaneous fat and significantly larger adipocyte size than pigs on the control diet. As previously mentioned, todays modern pigs are leaner genetically than pigs produced 40 years ago (Gatlin et al., 2002; Person et al., 2005). Thus, the adipocyte size could be a factor in addition to fatty acid composition that could explain softer fat. Since collagen content and adipocyte size can be changed through production processes, (Archile-Contreras et al. 2010), the objective of this study was to determine how collagen and adipocyte characteristics of belly fat change in relation to belly fat IV and how these factors contribute to belly firmness.

Materials and Methods

Fresh pork bellies were acquired from a commercial swine harvest facility (Farmland Foods, Milan, MO) over the course of three sampling dates. As carcasses exited the blast freezer and entered the carcass cooler, IV was measured on the left side of the pork carcass above the scapula (clear plate) and two inches from the mid line using a NitFom™ (Near-Infrared transmission) sensor unit (Carometec A/S, Herlev, Denmark). The IV of at least 200 carcasses was measured during each sampling date. NitFom™ IV measurements were validated by taking core samples from the same location on the carcass where the NitFom™ measurement was taken. Cores were taken using a 2.5 mm core bit attached to a drill. The diameter of the core attachment was wide enough to completely surround the sampling site of the NitFom™. Core IV were verified using a Bruker-NIR (Near-Infrared-Transmission spectroscopy) bench top device. Pork carcasses were stored overnight in carcass coolers which allowed time to identify the pork carcasses that fit three IV category parameters (Low, Intermediate and High). Bellies assigned to the Low IV category had an average IV of 64.9 g/100g with a standard deviation of

1.5. Bellies assigned to the Intermediate IV category had an average IV of 70.5 g/100g with a standard deviation of 1.3. High IV bellies were classified with an average IV of 76.5 g/100g and standard deviation of 2.0 (Table 1).

Fresh Belly Analysis

After carcass fabrication, bellies from both the right and left sides were collected from each selected carcass (n = 72). As pork carcasses exited the carcass cooler identification numbers were drawn on the skin surface of the belly with a wax crayon so that bellies could be collected from the belly line. Belly length was measured by positioning the ruler down the middle of the belly starting from the ham end. Three belly thickness measurements were taken on the dorsal edge throughout the length of the belly with measurements taken 5 cm from the ham edge, 5 cm from the shoulder edge, and in the middle of the belly. Belly width was measured by placing the ruler 1/3rd the belly length from the ham edge and 1/3rd the belly length from the shoulder edge. Belly weight was measured using an electronic scale.

Belly firmness was measured by centering the belly perpendicular to the belly length over a round metal bar. Bellies were placed skin side down and firmness was measured on the dorsal side of the belly. Firmness was quantified by measuring the distance between the bottom of the ham and shoulder edges. After fresh belly measurements were taken, bellies were stacked in cardboard combos and sent for further processing to Farmland Foods Inc. (Denison, IA).

Bacon Processing

Fresh bellies were commercially processed into bacon using proprietary curing and smoking procedures. Before slicing, the IV results from the Bruker-NIR were analyzed and bellies from carcasses that showed IV discrepancies between the NitFom™ and the Bruker-NIR were excluded from the study. At this point, the 24 paired bellies (right and left sides) intended for this study were identified. A total of 48 bellies were acquired from each replication, resulting in 144 bellies for the experiment. Bellies were sliced using a high speed slicer set to a slice thickness of 4 mm in continuous order from the shoulder end to the ham end. Bacon slices were bulk boxed so that there was only one belly per box and that the ends of the belly were clearly marked so that researchers could identify the anatomical origins of each slice in each belly. After packaging, bacon slices were transported back to the Kansas State University Meat Science Laboratory (Manhattan, KS, USA) for analysis.

Slice Selection for Analysis

To maintain continuity in slice sampling, a standard was created measuring 60 cm in length with five 12 cm long zones marked on it similar to the method described by Trussell et al. (2011). The standards were aligned with every belly during sampling so that the center most 60 cm were sampled. Zone 1 started on the shoulder end and zone 5 was on the ham end. The slices that were outside of the middle 60 cm were not utilized. One bacon slice from each of the five zones was collected and pulverized as a composite sample (fatty acid data not shown). Bacon IV was 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).

Histochemistry

One 0.5 cm thick bacon slice was used for histochemistry. This sample profile included an *Abdominus* muscle, a fat layer, the *Cutaneous Trunci*, and the bottom fat layer. The *Abdominus* muscle was included in the sample so that it was possible to identify the location (above or below the *Cutaneous Trunci*) of each photomicrograph collected. Samples were preserved in 10% formaldehyde and sent to the Kansas State University Veterinary Histopathology Laboratory to be paraffin embedded. Sections were cut using a Leitz 1512 microtome (Ramsey, Minnesota) with disposable microtome blades (818). Two 10-μm thick sections were collected on positively charged slides (Fisher Scientific, Pittsburgh, PA) for each sample.

To remove the paraffin wax, slides were heated in an incubator at 55°C for 20 min and positioned to allow drainage of the melting paraffin. Slides were immersed in xylene twice for 10 min and were then submerged in 100, 95, 70, 50, and 30% ethanol solutions for one min each, with the exception of the 100% ethanol (2 min). To finish the deparaffinization process, slides were submerged in a 0.85% NaCl solution and 1× phosphate buffered saline (PBS) for 2 min each.

Samples were stained with Harris Hematoxylin and Eosin-Y (Fisher Scientific). Slides were submerged in Harris Hematoxylin for 1 min and then removed and rinsed with water until the runoff water was clear. Then slides were submerged in Eosin-Y for 2 minutes and then rinsed as previously stated. The staining protocol was concluded by dehydrating the sections in ascending alcohol solutions (50, 70, 80, 95, and 100%) for 1 min each and submerging the

sections in Xylene for 2 min. After staining, samples on the slides were covered with 10 µL of 9:1 glycerol in PBS and were cover-slipped for imaging. Sections were imaged using a Nikon Eclipse TI-U inverted microscope equipped with a Nikon DS-QiMc digital camera at a 10× working distance magnification (Nikon Insturments Inc., Melville NY). For each slide, 4 representative photomicrographs were taken in each fat layer of each section.

Collagen Measurement

Collagen content was analyzed by using a methodology modified from Hill (1966). Fat from two bacon slices was separated from the lean, frozen in liquid nitrogen, and pulverized in a blender (Model 33Bl79, Waring Products, New Hartford, CT). Samples were lyophilized and 3 g of tissue was solubilized by incubation in 12 mL of 1/4 strength Ringer's solution at 77°C for 80 min with gentle shaking every 10 min. Samples were centrifuged at $2,250 \times g$ for 12 min at 20°C. The soluble (supernatant and insoluble) fractions were separated. Three mL of Ringer's Solution was added to the insoluble pellet centrifuged as described previously. After centrifugation, the 3 mL of Ringer's solution was transferred to the soluble fraction test tube. Three mL of concentrated H_2SO_4 were added to the soluble fraction test tubes, and 30 mL of 3.5 molar H_2SO_4 were added to the insoluble fraction for hydrolysis of the samples. All test tubes were incubated at 105°C for 16 h.

The insoluble hydrolysate was transferred to a 500 mL volumetric flask and brought to volume with $1M\Omega$ H_2O. The soluble hydrolysate was transferred to a 250 mL volumetric flask and brought to volume with $1M\Omega$ H_2O. After mixing, samples were gravity filtered through Whatman 541 filter paper (125 mm diameter) and immediately analyzed using a hydroxyproline assay. Hydroxyproline determination was carried out using procedures outlined by Bergman and Loxley (1963) using a BioTek Eon spectrophotometer (Winooski, VT) reading at an absorbance of 558 nm. Total and fractional collagen content was determined by multiplying the hydroxyproline content of the soluble fraction by 7.25 and the insoluble fraction by 7.52 (Cross et al., 1973).

Statistical Analysis

The data were analyzed as a generalized randomized block design with subsampling using the MIXED Procedure of SAS (SAS Institute, Inc., Cary, NC). Each pig served as the experimental unit. Sampling date was included as a random effect. Belly thickness and weight

were used as covariate factors in treatment analysis of belly firmness. Belly thickness was used as a covariate factor in treatment analysis of belly collagen content. An α-level of 0.05 was used to assess significance among means. The Proc CORR function of SAS was used to analyze the relationships of the data. The Proc REG function of SAS was used to investigate possible predictive equations for belly firmness. Prediction equations were determined using backwards elimination. The accuracy of each predictive equation was evaluated using r^2 values. Variance of each equation was expressed as the residual standard deviation (RSD).

Results and Discussion

Fresh Belly Characteristics

Belly IV in the High IV category was greater than the Intermediate ($P < 0.05$) and Low ($P < 0.05$) IV category, and bellies in the Intermediate IV category tended to have greater ($P = 0.09$) IV than the Low IV bellies (Table 3-2). Belly IV category did not impact belly weight ($P = 0.26$), length ($P = 0.87$), width ($P = 0.62$) or thickness ($P = 0.14$); however, High IV bellies tended to have thinner ($P = 0.06$) bellies than Low IV bellies. Belly firmness decreased as the bellies increased in IV ($P < 0.05$).

It is well established in literature that there is a gradient in IV units throughout fat depots and even within fat depots such as in the belly (Trussell et al. 2011; Duttlinger et al., 2012; Asmus et al., 2014). Sampling from five different locations within the belly could explain some of the variation in IV when compared to the NitFom™ because only a small area is utilized for analysis.

No significant difference in belly dimensions between IV categories is a result that has occurred in many previous publications. Dahlen et al. (2011) found that there was no difference in belly thickness between bellies that had IV values of 57.8, 63.1, or 64.9 g/100g when feeding dried distillers grains with solubles (DDGs) at dietary levels up to 20%. Leick et al. (2010) observed no differences in belly thickness with belly IV of 61.5, 65.4, 69.3, and 72.3 g/100g while feeding 10, 20, and 30% DDGs. Similarly, when including ractopamine in pig diets, Apple et al. (2007), was unable to observe differences in belly thickness with belly IVs of 65.3, 68.5, 69.5, and 72.7 g/100g. Browne et al. (2013) observed no differences in belly width or length during phase feeding yellow grease or beef tallow, or by changing the duration of those fat sources. Boler et al. (2012) investigated the effect of gonadotropin-releasing factor

immunological castration on belly quality and observed that bellies did not increase in length, but pigs that were immunologically castrated had wider bellies. Belly weight results agree with Larsen et al. (2008) who found no differences in belly weight while supplementing normal corn diets with conjugated linoleic acid and choice white grease. Similarly, McLelland et al. (2012) observed no difference in belly green weights when feeding 15 to 30% DDGs to pigs. Boler et al. (2012) observed belly weights increase with increasing time between administration of gonadotropin-releasing factor and slaughter. It seems that when swine diets are balanced and meet the nutritional needs, there is very little difference in belly dimensions. However, if growth rate is impacted which leads to differences in final carcass weight, belly dimensions can be impacted. When selecting the pigs for this current study, a narrow range of carcass weights were specifically selected (90.26 to 106.12 kg) in an attempt to limit the variation in belly dimensions, therefore it is likely this explains the consistency observed in this study.

Histology Characteristics

No statistical differences were observed in the size of the fat cells ($P = 0.32$) between IV treatments (Table 3-3). In disagreement with the current study, Barnes et al. (2012) fed diets that produced low (55.9 g/100g) and high (59.2 g/100g) IV intramuscular fat and found that the adipocytes of the low IV intramuscular fat were bigger. Similar to the current study, the authors observed no differences in adipocyte number. It is possible that the selection method of bellies in this study limited our ability to detect differences in adipocyte characteristics because we cannot account for the management practices that would contribute to adipocyte modification (Nakajima et al., 2011). Sorensen et al. (1996) demonstrated the effect growth rate has on adipocyte size by measuring the adipocyte volume of pigs treated with porcine growth hormone. Sorensen et al. (1996) observed a 9% improvement in feed intake, and an 8% improvement in the feed to gain ratio; resulting in an increase in muscle deposition (5%) and a decrease in fat deposition (43%). This change in tissue accretion resulted in a 54% decrease in adipocyte cell volume. In addition to growth rate, Smith et al. (1999) observed that diet, genetics, and age all contributed to influencing the expression of Stearoyl-coenzyme A desaturase mRNA, which is a marker of terminal differentiation of preadipocytes. In terms of pig production, this mechanism is especially important because fat saturation can influence how Stearoyl-Coenzyme A desaturase is regulated, thus influencing adipocyte size.

Collagen Characteristics

There was a greater amount of soluble, insoluble and total collagen in the High IV bellies versus Low IV bellies ($P < 0.05$). There was no change in the percent soluble collagen between the IV categories ($P = 0.18$). Results from the current study show that bellies with greater IV values have greater amounts of collagen in the fat depots compared to lower IV values ($P < 0.05$). Although this was only observed between the High and Low IV categories, there was a trend of the High IV category being greater than the Intermediate category. In one of the few studies to measure the collagen content in bacon, White et al. (2008) quantified collagen of pigs raised in different temperature (23.9 vs 32.2°C) environments. In this study, bacon from pigs raised in a 32°C, which also had the greatest IV, had 13.6% more total collagen when compared to the 23.9°C treatment group. The authors attributed the lower collagen content in pigs from the 23.9°C temperature treatment to larger adipocyte size. This logic, however, does not explain the results in this study as there were no significant differences in adipocyte size or amount. In the present study set there was evidence for a marginally significant effect ($P = 0.07$) for bellies in the High IV group to contain 12.87% less fat than in the Low IV category which would provide a dilution effect to the total collagen content (data not shown). Previous research with collagen in pork demonstrates that the total amount of collagen, specifically the insoluble collagen portion, is relatively resistant to manipulation. Kristensen et al. (2002) observed that muscle total collagen content did not change, but the soluble collagen content increased 12% when pigs were fed *ad libitum* diets compared to pigs fed restricted diets. Similarly, Therkildsen et al. (2002) investigated protein turnover and observed that total concentration of collagen did not change between control and restricted dietary treatments, and that the days of restricted feeding did not change the solubility of collagen. However, the collagen solubility did increase 11.6% between the control feeding regimen and the restricted feeding treatments. The collagen component could be important to palatability characteristics of bacon as Carpenter et al. (1963) reported bacon tenderness scores were negatively related to bacon weight. Since increased collagen content is attributed to a dilution effect because of the trend of thinner bellies, and knowing that main component responsible for adding weight to bellies is fat (Freeden and Martin, 1975; Freeden, 1980), it is probable that Carpenter et al. (1963) was observing the collagen effect in their sensory panels.

The soluble component of collagen can be manipulated through management practices than stimulate collagen turnover (Purslow, 2014). Matrix metalloproteinases (MMPs) are a class of proteases that breakdown connective tissues that is secreted from cells when activated extracellularly. Tissue inhibitors of matrix metalloproteases (TIMPs) regulate the expression of MMPs by limiting the access of proteolytic enzymes to the active site on the MMPs (Purslow et al., 2012). The inhibition of MMPs allows for collagen fibrillogenesis. The studies mentioned previously (Kristensen et al., 2002; Therkildsen et al., 2002; White et al., 2008) all featured dietary challenges to the pig which could explain the mechanism for stimulating protein turnover, as these dietary challenges provided stress which would be expressed with the hormone epinephrine (Cha and Purlsow, 2011). Epinephrine increases the extracullular activity of MMPs from fibroblasts and myoblasts, thus stimulating more collagen degradation. It is probable that animal physiological processes adapt to the environment (diet) and essentially enter an accelerated growth phase after overcoming the lag caused by the "environmental challenge", thereby increasing the concentration of TIMPs which would allow for new synthesis of heat soluble collagen.

The soluble collagen component of belly fat could possibly have an impact on belly slicing because several studies show that heat treatment can change the strength of collagen. Lewis et al. (1991) showed that the tensile strength of isolated perimysia cooked at 50°C decreased by 34%. Purslow (2014) reports that the triple-helical structure of collagen can be denatured in solution at 38°C and that fibrous collagen can be denatured between 60 and 68.5°C. As there is no standardized thermal treatment protocol for bellies, it is possible that the thermal processing temperatures reached a temperature and time point that changes the tensile properties of thermally processed bellies and affect bacon slicing yields.

Statistical Correlations and Regression

Correlations discussed in this study were analyzed to determine the relationship with belly firmness and bacon IV (Table 3-4). The strongest correlation was between carcass IV and belly firmness (r = -0.59), followed by the relationship between belly firmness and bacon IV (r = -0.52). Correlation results are similar to the study conducted by Trussell et al. (2011), who analyzed correlations between the belly flop test and belly IV across 15 different zones in the belly with a range of correlations (r = -0.46 to -0.87) demonstrating the variability of firmness

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within the belly. Thus, the negative relationships between IV depots and belly firmness in the current study meet expectations. Overall, these correlation results still support the thought that IV is a major contributor to soft fat (Apple et al., 2007; Larsen et al., 2009; & Duttlinger et al., 2012).

Between the adipocyte characteristics, adipocyte size had the stronger correlations with belly firmness ($r = 0.35$, $P < 0.05$) and Bacon IV ($r = -0.29$, $P < 0.05$). The number of adipocytes were negatively correlated with belly firmness ($r = -0.31$, $P < 0.05$) and positively related with bacon IV ($r = 0.25$, $P < 0.05$). Between the adipocyte and collagen components, total collagen was shown to have the strongest relationship in the study with a negative correlation with belly firmness ($r = -0.39$, $P < 0.05$), and positive relationship with bacon IV ($r = 0.33$, $P < 0.05$). Insoluble collagen was negatively related to belly firmness ($r = -0.36$, $P < 0.05$), and positively related to bacon IV ($r = 0.33$, $P < 0.05$). Soluble collagen had the weakest correlation to belly firmness ($r = 0.16$, $P < 0.05$) and no significant relation with bacon IV.

Though the fat components (adipocyte and collagen characteristics) did not have strong correlations with belly firmness and IV, there were still statistically significant relationships demonstrated. It is important to consider adipocyte and collagen components because these characteristics are physically and structurally part of bellies. Therefore, it would be expected that these components contribute a small contribution to belly firmness.

Predictive equations predicting belly firmness are displayed in Table 3-5. All predictive equations for this data set were moderately inaccurate (adjusted $r^2 < 0.50$), thus only the strongest equations, which happened to be for belly firmness are displayed. Equation 1 uses carcass IV, bacon IV, belly weight, belly length, soluble collagen, insoluble collagen, and total collagen as predictor terms. Equation 2 uses carcass IV, bacon IV, belly weight, and belly length as predictors. Equation 3 contains carcass IV, bacon IV, belly weight, and belly length. Equation 4 included carcass IV, belly weight, and belly length as prediction terms. When considering the terms, equation 1 was the most accurate with the highest adjusted r^2 value (0.45), however not all of the terms were significant at the $P \leq 0.05$ level (Bacon IV $P = 0.08$). The most useful of the four predictors would be equation 4 due to the possibility of measuring carcass IV, belly weight, and length and sorting bellies by firmness prior to bacon processing.

Conclusions

Results of this study show that it is possible to observe greater quantities of collagen in the belly fat of pigs that have a high iodine value when compared to pigs with a low iodine value. This was observed between bellies with an average IV difference of 9.41. Minimal differences were observed in adipocyte characteristics between IV categories. Response variables correlated poorly with objective belly firmness and belly IV. Of the adipocyte and collagen characteristics, the strongest correlation was with total collagen and belly firmness ($r = -0.39$). The question of how adipocyte characteristic and collagen content relate to fat quality would benefit from a diet manipulation study because the animals sampled in this study were raised in different environments, and the variation in management practices could influence adipocyte and collagen characteristics of pigs.

In addition, this is one of the first studies to attempt to describe how large the differences between belly iodine values have to be to detect differences in belly firmness. This study suggests that a minimum difference of 3 IV units is enough to detect differences in belly firmness. The NitFom technology provides the opportunity to sort carcasses based on fat quality, but the question then becomes how to define the criteria for sorting on fat quality. Many sources say a single IV point (70 or 74) should be the cut off for belly quality but it is not apparent in literature if there is an equivalent decrease in belly firmness or cutting yields between bellies with an IV of 60 and 70 or between 70 and 80. This study shows that bellies with high IV will have higher collagen content, which could be important to improving slice yields because it is possible to manage collagen properties during processing. This provides exciting opportunities for future research in bacon processing.

References

AOCS (1998). Official Methods and Recommended Practices of the AOCS 5th ed. Am Oil Chem. Soc., Champaign IL.

Apple, J.K., C.V. Maxwell, J.T. Sawyer, B.R. Kutz, L.K. Rakes, M.E. Davis, Z.B. Johnson, S.N. Carr, and T.A. Armstrong. 2007. Interactive effect of ractopamine and dietary fat source on quality characteristics of fresh pork bellies. J. Anim. Sci. 85: 2682-2690.

Archile-Contreras, A.C., I.B. Mandell, and P.P. Purslow 2010. Disparity of dietary effects on collagen characteristics and toughness between two beef muscles. Meat Science. 86: 491-497.

Archile-Contreras, A.C., and P.P. Pursllow. 2011. Oxidative stress may affect meat quality by interfering with collagen turnover by muscle fibroblasts. Food Research International. 44: 582-588.

Asmus, M.D., M.A. Tavarez, M.D. Tokach, S.S. Dritz, A.L. Schroeder, J.L. Nelssen, R.D. Goodband, and J.M. DeRouchey. 2014. The effects of immunological castration and corn dried distillers grains with solubles withdrwawal on growth performance, carcass characteristics, fatty acid analysis, and iodine value of pork fat depots. J. Anim. Sci. 92: 2116-2132.

Benz, J.M., S.K. Linneen, M.D. Tokach, S.S. Dritz, J.L. Nelssen, J.M. DeRouchey, R.D. Goodband, R.C. Sulabo, and K.J. Prusa, 2010. Effects of dried distillers grains with solubles on carcass fat quality of finishing pigs. Journal of Animal Science. 88: 3666-3682.

Boler, D.D., J. Killefer, D.M. Meeuwse, V.L. King, F.K. McKeith, and A.C. Dilger. 2012. Effects of slaughter time post-second injection on carcass cutting yields and bacon characteristics of immunologically castrated male pigs. J. Anim. Sci. 90: 334-344.

Browne, N.A., J.K. Apple, C.V. Maxwell, J.W. Yancey, T.M. Johnson, D.L. Galloway, and B.E. Bass. 2013. Alternating dietary fat sources for growing-finishing pigs fed dried distillers grains with solubles: II. Fresh belly and bacon quality characteristics. J. Anim. Sci. 91:1509-1521.

Carpenter, Z.L., R.G. Kauffman, R.W. Bray, and K.G. Weckel 1963. Factors influencing quality in pork. B. Commercially cured bacon. Journal of Food Science. 28:578-583.

Cha, M.C. and P.P. Purslow 2011. Epinephrine-induced MMP expression is different between fibroblasts and myoblasts. Cell Biochemistry and Function. 29: 603-609.

Dahlen, R.B.A., S.K. Baidoo, G.C. Shurson, J.E. Anderson, C.R. Dahlen, and L.J. Johnston. 2011. Assessment of energy content of low-solubles corn distillers dried grains and effects on growth performance, carcass characteristics, and pork fat quality in growing-finishing pigs. J. Anim. Sci. 89: 3140-3152.

Duttlinger, A.J., J.M. DeRouchey, M.D. Tokach, S.S. Dritz, R.D. Goodband, J.L. Nelssen, T.A. Houser, and R.C. Sulabo. 2012. Effects of increasing crude glycerol and dried distillers grains with solubles on growth performance, carcass characteristics, and carcass fat quality of finishing pigs. J. Anim. Sci. 90: 840-852.

Enser, M. 1984. The relationship between the composition and consistency of pig backfat. Special Report, Meat Research Institute. 2: 53-57.

Ewan, R.C. 2001. Energy utilization in swine nutrition. In A.J. Lewis, and L.L. Southern editors, Swine Nutrition 2nd edition. Boca Raton, FL; CRC Press. p85-94.

Fredeen, H.T. 1980. Yields and dimensions of pork bellies in relation to carcass measurements. Journal of Animal Science. 51: 59-68.

Freeden, H.T., and A.H. Martin. 1975. Criteria of belly bacon desirability. II. Visual appraisal and physical measurements of the belly. Canadian Journal of Animal Science. 55: 649-659.

Gatlin, L.A., M.T. See, J.A. Hansen, D. Sutton, and J. Odle. 2002. The effects of dietary fat sources, levels, and feeding intervals on pork fatty acid composition. Journal of Animal Science. 80: 1606-1615.

Kristensen, L., M. Therkildsen, B. Riis, M.T. Sorensen, N. Oksbjerg, P.P. Purslow, and P. Ertbjerg. 2002. Dietary-induced changes of muscle growth rate in pigs: Effects on in vivo and postmortem muscle proteolysis and meat quality. Journal of Animal Science. 80: 2862-2871.

Larsen, S.T., B.R. Wiegand, F.C. Parrish, Jr., J.E. Swan, and J.C. Sparks. 2009. Dietary conjugated linoleic acid changes belly and bacon quality from pigs fed varied lipid sources. Journal of Animal Science. 87: 285-295.

Leick, C.M., C.L. Puls, M. Ellis, J. Killefer, T.R. Carr, S.M. Scramlin, M.B. England, A.M. Gaines, B.F. Wolter, S.N. Carr, and F.K. McKeith. 2010. Effect of distillers dried grains with solubles and ractopamine (Paylean) on quality and shelf-life of fresh pork and bacon. Journal of Animal Science. 88: 2751-2766.

Lewis, G.J., P.P. Purslow, and A.E Rice. 1991. The effect of conditioning on the strength of perimysial connective tissue dissected from cooked meat. Meat Science. 30: 1-12.

McClelland, K.M., G. Rentfrow, G.L. Cromwell, M.D. Lindemann, and M.J. Azain. 2012. Effects of corn distillers dried grains with solubles on quality traits of pork. J. Anim. Sci. 90: 4148-4156.

Nakajima, I., O.E. Mika, O. Koichi, S. Muroya, M. Shibata, and K. Chikuni. 2011. Cellularity of developing subcutaneous adipose tissue in landrace and meishan pigs: Adipocyte size differences between two breeds. Animal Science Journal: 82: 144-149.

Pawar, A.S., X. Zhu, A. Eirin, H. Tang, K.L. Jordan, John R. Woolard, A. Lerman, and L.O. Lerman. 2015. Adipose tissue remodeling in a novel domestic porcine model of diet-induced obesity. Obesity 23(2): 399-407.

Person, R.C., D.R. McKenna, D.B. Griffen, F.K. McKeith, J.A. Scanga, K.E. Belk, G.C. Smith, and J.W. Savell. 2005. Benchmarking value in the pork supply chain: Processing characteristics and consumer evaluations of pork bellies of different thicknesses when manufactured into bacon. Meat Science. 70: 121-131.

Purslow, P.P. (2014). New developments on the role of intramuscular connective tissue in meat toughness. Th Annual Review of Food Science and Technology. 5: 133-153.

Purslow, P.P., A.C. Archile-Contreras, M.C. Cha. 2012. Meat Science and Muscle Biology Symposium: Manipulating tenderness by increasing the turnover of intramuscular connective tissue. Journal of Animal Science. 90: 950-959.

Seman, D.L., W.N.G. Barron, M. Matzinger. 2013. Evaluating the ability to measure pork fat quality for the production of commercial bacon. J. Meat Sci. 94: 262-266.

Smith, S.B., H.J. Mersmann, E.O. Smith, and K.G. Britain. 1999. Steoryl-coenzyme A desaturase gene expression during growth in adipose tissue from obese and crossbred pigs. Journal of Animal Science. 77: 1710-1716.

Sorensen, M.T., N. Oksbjerg, N. Agergaard, and J.S. Petersen. 1996. Tissue deposition rates in relation to muscle fibre and fat cell characteristics in lean female pigs (Sus scrofa) following treatment with porcine growth hormone (pGH). Comparative biochemistry and physiology. 113A(2):91-96.

Shackelford, S.D., M.F. Miller, K.D. Haydon, N.V. Lovegren, C.E. Lyon, and J.O Reagan. 1990. Acceptability of bacon as influenced by the feeding of elevated level of monounsaturated fats to growing-finishing swine. J. Food Science. 55: 621-624.

Sorensen, K.M., H. Petersen, S.B. Engelsen. 2012. An on-line near-infrared (NIR) transmission method for determining depth profiles of fatty acid composition and iodine value in porcine adipose fat tissue. Applied Spectroscopy. 66(2): 218-226.

Therkildsen, M., B. Riis, A. Karlsson, L. Kristensen, P. Ertbjerg, P.P. Purslow, M.D. Aaslyng and N. Oksbjerg. 2002. Compensatory growth response in pigs, muscle protein turn-over and meat texture: effects of restriction/realimentation period. Animal Science. 75: 367-377.

Torrescano, G., A. Sanches-Escalante, B. Gininez, P. Roncales, and J.A. Beltran. 2003. Shear values of raw samples of 14 bovine muscles and their relation to muscle collagen characteristics. Meat Science. 64: 85-91.

Trussell, K.A., J.K. Apple, J.W. Yancey, T.M. Johnson. 2011. Compositional and instrumental firmness variations within fresh pork bellies. Meat Sci. 88: 472-480.

White, H.M., B.T. Richert, A.P. Schinckel, J.R. Burgess, S.S. Donkin, and M.A. Latour. 2008. Effects of temperature stress on growth performance and bacon quality in grow-finish pigs housed at two densities. J. Anim. Sci. 86: 1789-1798.

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

Widmer, M.R., L.M. McGinnis, D.M. Wulf, and H.H. Stein. 2008. Effects of feeding distillers dried grains with solubles, high-protein distillers dried grains, and corn germ to growing-finishing pigs on pig performance, carcass quality, and the palatability of pork. J. Anim. Sci. 86:1819-1831.

Xu, G.., S.K. Baidoo, L.J. Johnston, D. Bibus, J.E. Cannon, and G.C. Shurson. 2010. Effects of feeding diets containing increasing content of corn distillers dried grains with solubles to grower-finisher pigs on growth performance, carcass composition, and pork fat quality. J. Anim. Sci. 88: 1398-1410.

Table 3-1 Pork carcass descriptive statistics

IV Category[A]	n	Average HCW (kg)	HCW SD	Average IV[B]	IV SD
Low	24	98.1	9.5	64.9	1.5
Intermediate	24	97.2	8.1	70.5	1.3
High	24	98.3	10.9	76.5	2.0
Total	72	97.9	9.6	70.7	5.0

[A]IV = Iodine value. High IV group was defined at an average IV of 76.50 with a standard deviation of 2.0. Intermediate IV was defined at an average IV of 70.50 with a standard deviation of 1.3. Low IV was defined at an average IV of 64.90 with a standard deviation of 1.5.

[B]Iodine values were predicted using Near-Infrared Transmission (NitFom™)

Data were collected by B.L. Goehring, J.A. Unruh, J.M. DeRouchey, S.S. Dritz, B.M. Gerlach, A.M. Tapian, G.D. McCoy, M.A. Vaughn, S.M. Ebarb, J.M. Gonzalez, R.C. Johnson, and T.A. Houser.

Table 3-2 Least squares means of fresh belly characteristics from bellies classified into three iodine (IV) categories

| Characteristic | Iodine Value Category[A] | | | | P- value |
	High	Intermediate	Low	SE[B]	Model
Belly Fat IV[C]	76.9[a]	70.9[b]	67.7[b]	1.50	<0.05
Belly Weight, kg	7.8	7.8	8.4	0.37	0.26
Belly Length, cm	74.8	75.2	75.5	1.24	0.87
Belly Width, cm	32.6	32.5	32.1	0.50	0.62
Belly Thickness, cm	3.5	3.6	3.7	0.08	0.14
Belly Firmness[D], cm	5.7[c]	7.9[b]	11.4[a]	0.74	<0.05

[A]Treatment means with different superscripts are different ($P < 0.05$).

[B]Standard error of the means.

[C]High IV group was defined at an average IV of 76.50 g/100g with a standard deviation of 2.0. Intermediate IV was defined at an average of 70.50 g/100g with a standard deviation of 1.3. Low IV was defined at an average IV of 64.90 g/100g with a standards deviation of 1.5. Fat IV was 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).

[D]Belly firmness measured by centering bellies perpendicular to the belly length skin side down over a round metal bar. Measurements were quantified by measuring the distance between the bottom of the ham and shoulder edges.

Data were collected by B.L. Goehring, J.A. Unruh, J.M. DeRouchey, S.S. Dritz, B.M. Gerlach, A.M. Tapian, G.D. McCoy, M.A. Vaughn, S.M. Ebarb, J.M. Gonzalez, R.C. Johnson, and T.A. Houser.

Table 3-3 Least squares means of collagen and histology characteristics of bacon fat from bellies classified into three iodine values (IV) categories

Characteristic	Iodine Value Category[A,B]			SE[C]	*P- value* Model
	High	Intermediate	Low		
Adipocyte Size, μm^2	4,016	4,223	4,369	204	0.32
Adipocyte Number, per mm^2	246	233	223	8.1	0.11
Soluble Collagen, mg/g	13.4[a]	12.0[ab]	11.2[b]	0.74	<0.05
Insoluble Collagen, mg/g	35.5[a]	30.2[ab]	25.2[b]	2.73	<0.05
Total Collagen, mg/g	48.4[a]	42.2[ab]	36.7[b]	3.20	<0.05
% Soluble Collagen	29.5	29.5	33.3	1.46	0.18

[A]Treatment means with different superscripts are different ($P < 0.05$).

[B]High IV group was defined at an average IV of 76.50 g/100g with a standard deviation of 2.0. Intermediate IV was defined at an average of 70.50 g/100g with a standard deviation of 1.3. Low IV was defined at an average IV of 64.90 g/100g with a standards deviation of 1.5. Fat IV was 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).

[C]Standard error of the means.

Data were collected by B.L. Goehring, J.A. Unruh, J.M. DeRouchey, S.S. Dritz, B.M. Gerlach, A.M. Tapian, G.D. McCoy, M.A. Vaughn, S.M. Ebarb, J.M. Gonzalez, R.C. Johnson, and T.A. Houser.

Table 3-4 Association between fat components and belly flop measurements and bacon iodine value (BIV)

Fat Component	Belly Flop[A]	BIV[B]
Adipocyte Size, μm	0.35*	-0.29*
Adipocyte Number, per mm^2	-0.31*	0.25*
Soluble Collagen, mg/g	-0.28*	0.27*
Insoluble Collagen, mg/g	-0.36*	0.29*
Total Collagen, mg/g	-0.39*	0.33*
% Soluble Collagen	0.16*	--
Belly Flop	--	-0.52*
Carcass IV	-0.59*	--

[A]Bacon Iodine Value. BIV was measured 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).

[B]Belly flop was measured by centering a belly perpendicularly over a bar and measuring the distanced between the ends.

*$P < 0.05$.

Data were collected by B.L. Goehring, J.A. Unruh, J.M. DeRouchey, S.S. Dritz, B.M. Gerlach, A.M. Tapian, G.D. McCoy, M.A. Vaughn, S.M. Ebarb, J.M. Gonzalez, R.C. Johnson, and T.A. Houser.

Table 3-5 Regression equations generated for prediction of belly firmness

Equation	Models[A]	Adjusted R^2	RSD[B]
1	$= 46.78 - (0.24^T \times CIV) - (0.12^* \times BIV) + (1.14^T \times BW) - (0.25^T \times BL) + (79.02^* \times SC) + (79.11^* \times IC) - (79.14^* \times TC)$	0.45	2.79
2	$= 46.78 - (0.27^T \times CIV) - (0.14^T \times BIV) + (1.21^T \times BW) - (0.25^T \times BL)$	0.43	2.86
3	$= 41.62 - (0.25^T \times CIV) - (0.13^* \times BIV) + (1.14^T \times BW) - (0.25^T \times BL) + (0.0009^T \times AS)$	0.44	2.81
4	$= 43.78 - (0.38^T \times CIV) + (1.19^T \times BW) - (0.24^T \times BL)$	0.41	2.90

[*]Probabilities for Regression coefficients at $P \leq 0.10$.

[T]Probabilities for Regression coefficients at $P \leq 0.05$.

[A]CIV = carcass fat IV; BIV = belly fat IV; BW = belly weight; BL = belly length; SC = soluble collagen; IC = insoluble collagen; TC = total collagen; AS = adipocyte size.

[B]Residual Standard Deviation.

Data were collected by B.L. Goehring, J.A. Unruh, J.M. DeRouchey, S.S. Dritz, B.M. Gerlach, A.M. Tapian, G.D. McCoy, M.A. Vaughn, S.M. Ebarb, J.M. Gonzalez, R.C. Johnson, and T.A. Houser.

Chapter 4 - DEVOLOPING AN OBJECTIVE METHOD TO EVALUATE COOKED BACON SLICE DISTORTION

B.L. Goehring, J.A. Unruh, J.M. DeRouchey, S.S. Dritz, A.M. Tapian, and T.A. Houser

Abstract

The objectives of this study were to develop objective methodologies to score and quantify distortion experienced by bacon during cooking. Subjective bacon distortion was scored using a 1 to 5 scale and a 1 to 3 scale. New methodologies to describe bacon distortion were created by measuring the number of crests per bacon slice and the average distance between crests (Crest Frequency and Bacon Distortion Index). Bacon dimensions, weights, and cook yields were measured to determine if there was a location effect within the belly and to generate regression equations to predict visual distortion scores. Regression equations generated from this data did not accurately predict bacon distortion. Bacon cooking performance did vary between locations within the belly due to differences in proximate composition within the belly. It was possible to detect differences in the Crest Frequency and Bacon Distortion Index response of bacon from different locations within the belly.

Introduction

It is common in bacon literature to discuss how bacon sales and bacon markets always seem to be improving. This is still the case, as Meatpoultry.com reports that bacon usage in food service sectors has increased by 102 million pounds from 2011 to 2013 and that sales in the retail segment have grown 11% in 2013 and 2014. Without a doubt, pre-cooked bacon products hold a significant amount of market demand. The most distinguishing characteristic of retail pre-cooked bacon is that the slices are very thin and flat, and are visibly different from pan-fried slices. Despite limited consumer information on the desirability of commercial pre-cooked bacon in literature, the Hormel Company is marketing a cooked bacon product with the appearance similar to pan-fried slices currently called, "Hormel Bacon 1, Perfectly Cooked Bacon" (http://www.hormelfoodservice.com/brands/bacon1.aspx). When bacon is cooked, regardless of the cookery method, the slices tend to curl, shrink, and become "wavy," in appearance to some degree. This is what is referred to in literature as bacon distortion. When considering the marketing of the Hormel Bacon 1 product, it is inferred that consumers desire a certain cooked appearance.

In 2007, the National Pork Board reported that 45% of bacon preparations were done with a stove top frying pan. Fifteen percent of bacon preparations used the microwave while three percent used the oven. The cookery method could play a role in consumer preferences in selecting retail pre-cooked bacon as well as how consumers perceive the quality of bacon brands by the distortion reflective of the cookery method. The challenge of evaluating bacon distortion is that investigative tests are limited to a subjective (1-5) scoring system. This subjective scoring system originally was developed during the Quality Lean Growth Modeling-Bacon Quality Assessment project conducted by the University of Nebraska on a grant funded by the National Pork Board (Mandigo, 2000). Findings from this study (Mandigo, 2000; Robles, 2004) insinuate that the fat component plays a role in bacon distortion as they found differences in distortion between belly location, gender and fat composition. However it is obvious that subjective scales are not consistent between studies as observed when comparing the scales used by Robles (2004) and Rentfrow et al. (2003). Therefore, the objective of this study was to create an objectively

quantifiable scoring system using either a predictive equation that can be accurately reproduced to evaluate bacon distortion.

Materials and Methods

Bacon Processing and Selection

Pork bellies were obtained from a commercial swine harvest facility (Farmland Foods, Milan, MO) and processed into bacon using commercial bacon processing methods (Farmland Foods, Denison, IA). Iodine values for bacon slices selected ranged from 67 to 85 g/100g. Bacon slices originated from multiple locations within the belly. In order to describe the general location of slice origin within the belly, a numerical picture scale was created (Figure 4-1). This scale was on a 1 to 6 scale, with 1 originating from the shoulder end of the belly, and 6 originating from the ham end. For each number there was a corresponding image that portrays the general muscle alignment of bacon slices from each area. Since the bacon slices originated from different areas of the belly, the number of muscles in each slice was quantified. The collagen content and proximate composition and fatty acid composition of this bacon population was analyzed in a previous study and the data was used in statistical analysis.

Bacon Cookery

Three different cooking appliances were used in this study. A Blodgett dual-air-flow oven (DFD-201, G.S. Blodgett Co., Inc., Burlington, VT), a microwave oven with convection (AMC7159TAB, Amana, Benton Harbor, MI) (13.0 amp single phase, 1000 watt, output frequency 2450 MHz), and a Oster ceramic electric griddle (CKSTGRFM18XX-ECO Series_14EM1, Jarden Products, Inc, Boca Raton, FL). Between the three appliances 19 different cooking protocols were used in an effort to identify cooking protocols for subsequent studies. Response variables by cooking method are not displayed in this study due to uneven replication for each protocol. When a cooking protocol was shown to produce bacon that was raw or severely burnt, it was discarded in favor of protocols that produced a golden brown color and had a minimum cook loss of 60% of the raw weight. Furthermore, it was also expected that cooking time might influence distortion and the multiple cooking methods were used to attempt to force a wide range of distortions scores. The oven protocol used temperatures set at 177°C with cook times of 10 and 14 min, 204°C with cook times of 6, 10, and 12 min and 232°C with

cook times of 6 and 10 minutes. Bacon slices were placed on cooking racks on aluminum trays.
Trays were placed in the middle racks of the oven. At the halfway point of the cooking time,
trays were removed and the bacon flipped, and then the trays were rotated in the oven to reduce
front to back cooking variation in the oven. Five bacon slices were cooked on a tray and only a
single tray was placed in the oven at a time. After cooking, bacon slices were blotted with paper
towels to remove grease.

The griddle temperatures utilized were 177 and 191°C with a 10 min cook time, 204°C
with a 8 and 10 min cook time, and 216°C with 8, 10, and 12 min cook times. At the halfway
point during cooking, slices were flipped. During the protocol trial stage, it was discovered that
there was extreme variation in visual doneness of bacon, which corresponded to areas of the
griddle that were directly over the heating coil. To reduce cooking variation, only two bacon
slices were cooked per cooking session, placed within the diameter of the heating coil. Between
each cooking session the surface of the grill was cleaned to eliminate oil accumulation, fat
burning, and to prevent bacon from sticking to the griddle. While cooking, surface temperatures
did not exceed the set temperatures by more than 15°C. After cooking, bacon slices were blotted
with paper towels to remove grease.

The microwave cooking protocols selected were set at a power level of 10 (100% power)
with a 1 min cook time, power level 9 (90% power) with a 1 and 2 min cook time, a power level
8 (80% power) with a 3 min cook time, and a power level of 7 (70% power) with a cook time of
3 minutes. This particular microwave is a 1000 watt microwave, which means that a power level
setting of 10 the microwave is operating at full power, while a power level 9 sets the power level
at 900 watts. One bacon slice was cooked at a time in a ridged bacon grill with vented cover (US
Patent no: D471, 397, Progressive International, Kent, Washington). Between each cooking
session, the bacon tray was drained of grease and cleaned. After cooking, bacon slices were
blotted with paper towels to remove grease.

Bacon Measurements

Prior to cooking, a photo (Nikon Coolpix P90, 6MM68411-01, Nikon Corp, Tokyo,
Japan) was taken with all raw bacon slices alongside a ruler so that raw length, raw bacon
surface area, total lean area, and total fat area could be measured using NIS-Elements Imaging
Software (Basic Research, 3.3; Nikon Instruments, INC) similar to Scramlin et al., (2008). After

cooking, another photo was taken of each bacon slice so that cooked length and cooked surface area could be measured. Raw and cooked bacon slices were weighed using an Explorer Pro scale (EP2102C, Ohaus Corporation, Pine Brook, NJ,). After image analysis, length shrink (raw length-cooked length/raw length × 100), area shrink (raw area-cooked area/ raw area × 100), and a lean:fat ratio (lean area/fat area) were calculated. Bacon dimensions were quantified using the photo imaging software in an attempt to limit handling of bacon to prevent slice stretching and to ensure all bacon slices were the same temperature before cooking.

Bacon Distortion Measurements

Bacon distortion was evaluated by using 2 subjective scales. Subjective scale 1 was a numerical scale with a 1 representing a flat piece of bacon, and a 5 representing a high distortion of a bacon slice (Figure 4-2). This system is similar to the numerical score published by Rentfrow et al. (2003) and designed by Mandigo (2000). Subjective scale 2 was a simplified version of the Mandigo scale using a 1 to 3 scale with 1 being a flat piece of bacon, 2 intermediate distortion score, and 3 as an extreme distortion score. Subjective scale 2 combines distortion scores of 1 and 2 from subjective scale 1 into a score of 1, and scores of 4 and 5 as a 3. Subjective scale 2 was created in an attempt to create an easier scoring system with less variation.

Cooked Bacon Measurements

The current study is attempting to create objective means to quantify bacon distortion. To meet this goal, this study used concepts found in physics that describe frequency, wavelength, amplitude and velocity of a wave. The term Crest number was used to describe the number of waves/crests on each cooked bacon slice. The term Average Crest Distance (ACD) was used to describe the average distance between the midpoints of each crest. This measurement was taken in sequential order between each crest. Cooked Bacon Frequency (CBF) is a term repurposing the frequency equation ($f=1/T$), defined as cooked length/ crest number and provides a measure of the number of crests per bacon slice (http://physics.info/sound/). Cooked Bacon Distortion Index (CBDI) is a term that uses the concept of wave velocity (frequency × wavelength) and applied to distortion as CBF × ACD. The final two terms Raw Bacon Frequency (RBF) and Raw Bacon Distortion Index (RBDI) are similar to CBF and CBDI with the exception that raw length was substituted in place of cooked length. The raw length terms were added because it

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was unknown if the length of the raw slice influences the response in crests. A larger RBDI or CBDI number would indicate a flatter piece of bacon.

Statistical Analysis

Descriptive statistics describing raw and cooked bacon variables were evaluated using the PROC MEANS procedure of SAS (SAS Inst., Inc., Cary, NC). The PROC GLM function of SAS was used to evaluate differences caused by slice origin within the belly. All response variables were then evaluated for correlation using the PROC CORR procedure of SAS to evaluate the relationship between variables and to prevent multicolinearity. The PROC REG function of SAS was used to develop regression equations using the quantitative response variables. Strength of the equations was evaluated using backward elimination and r^2 values (Weisberg, 2005). Variables qualified for inclusion into models if the statistical significance was $P < 0.05$. Once significant terms were identified, further model discrimination was done using the Bayesian information criterion (BIC).   When comparing models, if the BIC was reduced by more than 2 units, the model was considered improved (Kass and Raftery, 1995; Paulk et al., 2015). Bacon slice was the observational unit (n = 585).

Results and Discussion

Descriptive Statistics and Relationships

Descriptive statistics are displayed in Table 4-1. These values describe the raw and cooked characteristics, the collagen content, proximate composition and distortion measurements of the bacon measured in this study. Select correlations ($P < 0.05$) are displayed in Table 4-2. The average distance between crests was inversely related to the number of crests (r = -0.58), and the percent surface area (r = -0.41) and length shrink (r = -0.46). This relationship suggests that a bacon slice that experiences less shrink during cooking will have a longer distance between crests and a longer distance between crests will result in a smaller number of crests. Cooked bacon weight was also inversely related to percent surface area (r = -0.49) and length shrink (r = -0.45), thus implying that bacon with heavier cooked weights would experience less shrink during cooking. The strongest relationship in this study was between length shrink and the Subjective scale 1 distortion measurement (r = 0.60).

Bacon Characteristics of Bacon Slices Originating From Different Locations of the Belly

Raw and cooked bacon length is displayed in Figure 4-3. Raw bacon length did not change between bacon locations ($P > 0.05$). Cooked bacon slices from location 6 were shown to be the shortest slices, while slices from zone 3-5 were the longest ($P < 0.05$). Bacon from zone 6 showed the highest percent length shrink after cooking followed by zones 1 and 2 and zones 3-5 showed the lowest percent shrink compared to the other zones ($P < 0.05$; Figure 4-4).

Raw and cooked bacon weights are displayed in Figure 4-5. The lightest raw bacon slices originated from zone 6 ($P < 0.05$). Bacon from zones 4, and 5 were the heaviest cooked bacon slices, while bacon slices from zone 2 and 3 were intermediate in weight ($P < 0.05$). Cooked bacon from zone 6 was the lightest ($P < 0.05$). Figure 6 shows the total surface area of raw and cooked bacon slices. Bacon from zones 1, 5, and 6 showed the greatest total raw surface area compared to zone 3 which exhibited the lowest surface area ($P < 0.05$). Location 4 showed bacon that had the largest cooked area compared to the other locations ($P < 0.05$).

The lean to fat ratio calculated from the surface area of the fat and lean components of the raw bacon is displayed in Figure 4-7. Bacon from location 5 possessed the highest lean to fat ratio, while location 6 possessed the lowest lean to fat ratio ($P < 0.05$). The area shrink experienced by bacon slices was significantly different between every zone with the exception of zones 1 and 6 (Figure 4-8). Bacon originating from locations 1 and 6 displayed the highest area shrink followed by bacon from locations 2, 4, and 3 with zone 5 bacon showing the lowest amount of area shrink after cooking ($P < 0.05$). Bacon from zone 5 showed the highest cook yield (Figure 4-9) compared to the other zones ($P < 0.05$). There was no difference in bacon cook yields between zones 2, 4, and 6 ($P > 0.05$). Additionally, zones 2, 4, and 6 produced bacon with the lowest cook yields.

It is reasonable to expect that there would be minimal differences in slice length within a belly due to commercial processes using bacon presses to shape bellies into uniform rectangles (Person et al., 2005). The differences seen in cooked length, length shrink, slice weight (raw and cooked), surface area (cooked and raw), surface area lean to fat ratio, area shrink, and cook yields can be explained by the proximate composition of each location within the belly. Jabaay et al. (1975) investigated bacon quality characteristics of bacon from different areas of the belly. Jabaay et al. (1975) also reported that bacon from areas of the belly that had the highest cook

yields (positions equivalent to zones 1, 5, and 6 in this study) also had the lowest fat content. Variability of proximate composition within the belly was also observed by Trussell et al. (2011), who also reported that the middle of the belly (equivalent to zones 2-4 in this study) was the fattest area of the belly. This disagrees slightly with observations in the current study because zone 4 and 6 had the lowest lean to fat ratio as measured by the surface area of the lean and fat portions. Diet formulations play an important role in changing the belly composition as shown by Scramlin et al. (2008) who reported an increase in the total lean area and the area of the *cutaneious trunci* muscle in bacon slices by adding 5 ppm of ractopamine to pig diets. Therefore it can be expected that there will be inconsistent cooking performance within every belly. This concept is indirectly supported by numerous studies investigating bacon cooking because studies that report no difference between belly dimensions also observe no differences in cooking performance of bacon slices (Brown et al., 2013; McClelland et al., 2012; Rentfrow et al., 2003; Widmer et al., 2008). In contrast, Carpenter et al. (1963) reported that bacon from lean bellies shrank less compared to fatter bellies. Very little literature has been published looking at how fat composition affects bacon yields; however, in ground buffalo models formulated with 5 and 15% fat resulted in a 4 % increase in cook yields with leaner patties as well as a difference in dimensional shrinkage of 76% between the patty formulations (Nisar et al., 2010).

Subjective Distortion Scores

Subjective distortion scores for each belly location are displayed in Figure 4-10. Using Subjective scale 1 (1-5 scale), bacon slices from zone 6 had the highest distortion scores ($P <$ 0.05). Zones 1 and 5 showed intermediate distortion scores when compared to zone 6 and zones 2-4 ($P < 0.05$). Subjective scale 2 (1-3 scale) showed a similar pattern to the first subjective scale but doesn't portray the magnitude of distortion that was observed with Subjective scale 1. With Subjective scale 2, zone 6 had the numerically highest distortion score ($P < 0.05$). With the reduced scale, there was no differentiation between zone 6 and 5 ($P > 0.05$) nor between zone 5 and zone 1($P < 0.05$). Similar to Subjective scale 1, zones 2-4 did not differentiate in distortion scores ($P > 0.05$).

Presently, there have been few studies investigating cooked bacon distortion. Robles, 2004 documented differences in distortion between 5 different locations within the belly. In agreement with the current study, Robles reported that the middle section of the belly displayed

the lower distortion scores when compared to bacon slices originating from the anterior and posterior ends of the belly. Distortion results in the Robles study also corresponded with differences in fat composition between the belly locations, with the anterior and posterior ends containing the highest percentage of fat. Other studies that measure the bacon distortion response from pigs fed different diets were unable to detect differences in distortion slices (McClelland et al., 2012; Rentfrow et al., 2003; Widmer et al., 2008). It is most likely that no differentiation in distortion scores was observed because there were no differences in belly dimensions, nor differences in sampling location, thus implying that there were no differences in belly composition that would cause differences in distortion. Changes in dimensions such as belly thickness, would correspond to an increase in fat composition (Fredeen and Martin, 1975; Freeden, 1980).

Objective Distortion Measurements

Figure 4-11 shows the Crest frequency (CF) and Bacon Distortion Index score (BDI) using the cooked length in the calculation equations. Zone 5 displayed the highest numerical BDI score while zone 3 showed the lowest BDI score ($P < 0.05$). Similar to the subjective scoring systems, there were no difference between zones 3 and 4 ($P > 0.05$). Bacon from zones 1 and 5 showed the highest numerical CF scores while zones 2 and 6 showed the lowest numerical scores ($P < 0.05$). Like with the BDI scores, there were no differences in CF scores between zones 3 and 4. Graphically, the CF and BDI scores follow a similar pattern.

Figure 4-12 displays the CF and BDI using the raw slice length in the calculation equations. Similar to the cooked length BDI, zone 5 had the highest numerical BDI score followed by zone 1 while zone 2 showed the lowest score ($P < 0.05$). Bacon from zones 3 and 4 showed similar BDI scores. Bacon from zones 2-4 showed numerically lower CF scores compared to zones 1 and 5 ($P < 0.05$). There was no difference in CF between zones 3 and 4 ($P > 0.05$).

Overall, the graphical patterns displayed in Figure 4-11 matches the data pattern described in Figure 4-12. This suggests that the length measurement (raw or cooked) doesn't contribute as much to the CF and BDI values as the crest quantification does. Since there was no difference in raw bacon length, using the cooked length in the equations would be more descriptive of the bacon slice because the cooked length was shown to change between locations

while the raw length stayed constant. Graphically, the CF and BDI scores follow a similar pattern, but the average crest distance shows a huge impact on the scale of the BDI, thus suggesting that the BDI is the more practical measurement to describe the bacon slice. This scoring system was designed with the expectation that the pattern of CBF and BDI scores when graphed would be the inverse of the distortion by location graphs, which was not the case in this study. However, it may be that the results of these scores are confounded by the numerous cooking methods used to prepare the bacon in this study due to the different rate of heating and heating delivery mechanics. It is established in this study that there is a variation in composition within the belly, which means that bacon from the various belly locations will have different heating properties, thus causing different rates of moisture and fat loss (James et al., 2006). Furthermore, the different cooking appliances and different temperatures and cook times would have very different heat transfer mechanics due to the oven being dependent on air velocity to transfer heat and the microwave dependent on energy wave-molecule interactions (Meda and Raghaven, 2005; Sing and Heldman, 2001).

Bacon slices from belly location 2 had the highest number of bacon crests after cooking ($P < 0.05$; Table 4-3). Crest numbers of bacon from locations 3 and 4 showed numerically lower numbers compared to bacon from location 2 but were higher when compared to locations 1, 5, and 6 ($P < 0.05$). Bacon from location 5 showed the largest distance between crests when compared to the bacon from the other zones ($P < 0.05$). Bacon from zones 3 and 4 averaged a 22% larger distance between crests when compared to bacon slices from zone 2, which showed the smallest distance between crests.

The bacon slices in this study that had the lowest distortion score (zones 2-4), also had the greatest number of crests in the study. Prior to this study, the authors believed that higher distortion scores would be caused by greater crest numbers. However, it seems that the crest number only describes part of the phenomenon of distortion and isn't a direct reflection on the magnitude of the curling observed during cooking. It was also expected that bacon with low distortion scales would have longer distances between crests, and high distortion scores would have smaller distances between crests. This also was not the case as bacon from zone 6 had the highest distortion score with the second lowest distance between crests, while zones 3 and 4 which produced the lowest distortion scores displayed intermediate distances between crests compared to the other zones.

Bacon Distortion Predictive Equations

Predictive equations generated using linear regression equations are displayed in Table 4-4. Equation 1 lists the equation with the highest r^2 (0.46) generated from this study for Subjective Scale 1. Equations 2 and 3 describe the equations predicting Subjective Scale 2 with the highest R^2 values of this study. Equation 3 had had the highest r^2 (0.42) value between the models predicting Subjective Scale 2. Due to the weak predictive ability of these equations, no evaluations were done between predicted and observed responses.

Conclusions

Results of this study show that there is variability in cooking performance and cooked bacon characteristics within the belly due to variation in composition. Bacon from the middle section of the belly experiences smaller dimensional shrink and flatter bacon while bacon slices from the anterior and posterior ends show higher distortion scores with greater dimensional shrink and lower cooked weights. This suggests that bacon processors can control weight variation and cooking performance in ready to eat bacon packages and HRI packaged bacon by processing the middle 40 cm of the belly. Furthermore, these results report that the proximate composition of the bacon slice plays a role in bacon distortion thereby creating opportunities to create markets for bacon with specific cooking performances. This study shows that it is possible to reduce the variation in subjective score response by reducing the scale from 1 through 5 to 1 to 3, but is not as effective at describing the magnitude of distortion that can be shown within a belly. Finally, the response variables collected in this study were unable to help develop reliable predictive equations that would accurately predict bacon distortion.

References

Agresti, A. 1996.. An introduction to categorical data analysis. John Wiley & Sons, Inc, New York, NY.

AOCS (1998). Official Methods and Recommended Practices of the AOCS 5th ed. Am Oil Chem. Soc., Champaign IL.

Browne, N.A., J.K. Apple, C.V. Maxwell, J.W. Yancey, T.M. Johnson, D.L. Galloway, and B.E. Bass. 2013. Alternating dietary fat sources for growing-finishing pigs fed distillers grains with solubles: II. Fresh belly and bacon quality characteristics. Journal of Animal Science. 91: 1509-1521.

Carpenter, Z.L., R.G. Kauffman, R.W. Bray, and K.G. Weckel. 1963. Factors influencing quality in pork. B. Commercially cured bacon. Journal of Food Science. 28: 578-583.

Fredeen, H.T. (1980). Yields and dimensions of pork bellies in relation to carcass measurements. Journal of Animal Science. 51: 59-68.

Freeden, H.T., and A.H. Martin. 1975. Criteria of belly bacon desirability. II. Visual appraisal and physical measurements of the belly. Canadian Journal of Animal Science. 55: 649-659.

Jabaay, R.W., J.C. Forrest, E.D. Aberle, H.V. Courtenay, and M.D. Judge. 1975. Bacon quality criteria and associated carcass traits. Journal of Food Science. 41: 431-437.

James, C., K.E. Barlow, S.J. James, M.J. Sawin. 2006. The influence of processing and product factors on the quality of microwave pre-cooked bacon. Journal of Food Engineering. 77: 835-843.

Kass, R.E., and A.E. Raftery. 1995. Bayes factors. Journal of the American Statistical Association. 90:773-795.

Mandigo, R.W. (Unpublished results). Quality lean growth modeling-bacon quality assessment. National Pork board. Retrieved March 15, 2015, from http://research.pork.org/FileLibrary/ResearchDocuments/97-1999-Mandigo.pdf.

McClelland, K.M., G. Rentfrow, G.L. Cromwell, M.D. Lindemann, and M.J. Azain. 2012. Effects of corn distillers dried grains with solubles on quality traits of pork. Journal of Animal Science. 90. 4148-4156.

Meda, V., and V. Raghavan. 2005. Microwave heating and the dielectric properties of foods. In :H. Schubert and M. Regier editors, The microwave processing of foods. CRC Press, Boca Raton, FlL

Meat+Poultry. 2014. Precooked potential. Retrieved April 15, 2015, from http://www.meatpoultry.com/Writers/Other%20Contributors/Precooked%20Potential.aspx?cck=1.

National Pork Board. 2007. Bacon trends. Retrieved April 15, 2015, from, http://www.porkretail.org/filelibrary/Retail/BaconTrends.pdf.

Nisar, M.P.U., M.K. Chatli, D.K. Sharma, and J. Sahoo. 2010. Effect of cooking methods and fat levels on the physico-chemical processing, sensory and microbial quality of buffalo meat patties. Asian-Australian Journal of Animal Science. 23: 1380-1385.

Paulk, C.B., J.R. Bergstrom, M.D. Tokach, S.S. Dritz, D.D. Burnett, E.W. Stephenson, M.A. Vaughn, J.M. DeRouchey, R.D. Goodband, J.L. Nelssen, and J.M. Gonzalez. 2015. Equations generated to predict iodine value of pork carcass back, belly, and jowl fat. Journal of Animal Science. 93: 1666-1678,

Platter, W.J., J.D. Tatum, K.E. Belk, P.L. Chapman, J.A. Scanga, and G.C. Smith. 2003. Relationships of consumer sensory ratings, marbling score, and shear force value to consumer acceptance of beef strip loin steaks. Journal of Animal Science. 81: 2741-2750.

Person, R.C., D.R. McKenna, D.B. Griffin, F.K. McKeith, J.A. Scange, K.E. Belk, G.C. Smith, and J.W. Savell. 2005. Benchmarking value in the pork supply chain: processing characteristics and consumer evaluations of pork bellies of different thicknesses when manufactured into bacon. Meat Science. 70: 121-131.

Rentfrow, G., T.E. Sauber, G.L. Allee, and E.P. Berg. 2003. The influence of diets containing either conventional corn, conventional corn with choice white grease, high oil corn, or high oil high oleic corn on belly/bacon quality. Meat Science. 64: 459-466.

Robles, C.C. (2004). The effect of fresh and frozen bellies on bacon processing characteristics and bacon quality. Master's Thesis. University of Nebraska, Linoln, NE.

Scramlin, S.M., S.N. Carr, C.W. Parks, D.M. Fernandez-Duenas, C.M. Leick, F.K. McKeith, J. Killefer. 2008. Effect of ractopamine level, gender, and duration of ractopamine on belly and bacon quality traits. Meat Science. 80: 1218-1221.

Singh, R.P, and D.R. Heldman. 2001. Introduction to food engineering. Academic Press, CA.

Trussell, K.A., J.K. Apple, J.W. Yancey, T.M. Johnson. 2011. Compositional and instrumental firmness variations within fresh pork bellies. Meat Science. 88: 472-480.

Weisberg, S. (2005). Applied linear regression, 3rd ed. John Wiley & Sons, Hoboken, NJ.

Widmer, M.R., L.M. McGinnis, D.M. Wulf, and H.H. Stein. 2008. Effects of feeding distillers dried grains with soluble, high-protein distillers dried grains, and corn germ to growing-finishing pigs on pig performance, carcass quality, and the palatability of pork. Journal of Animal Science. 86: 1819-1831.
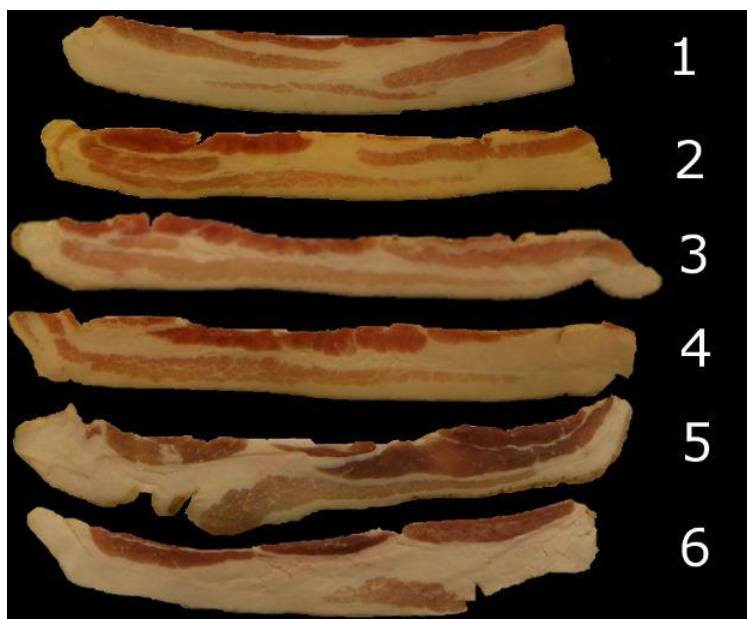
Figure 4-1. Numerical score for origin of bacon within the belly.
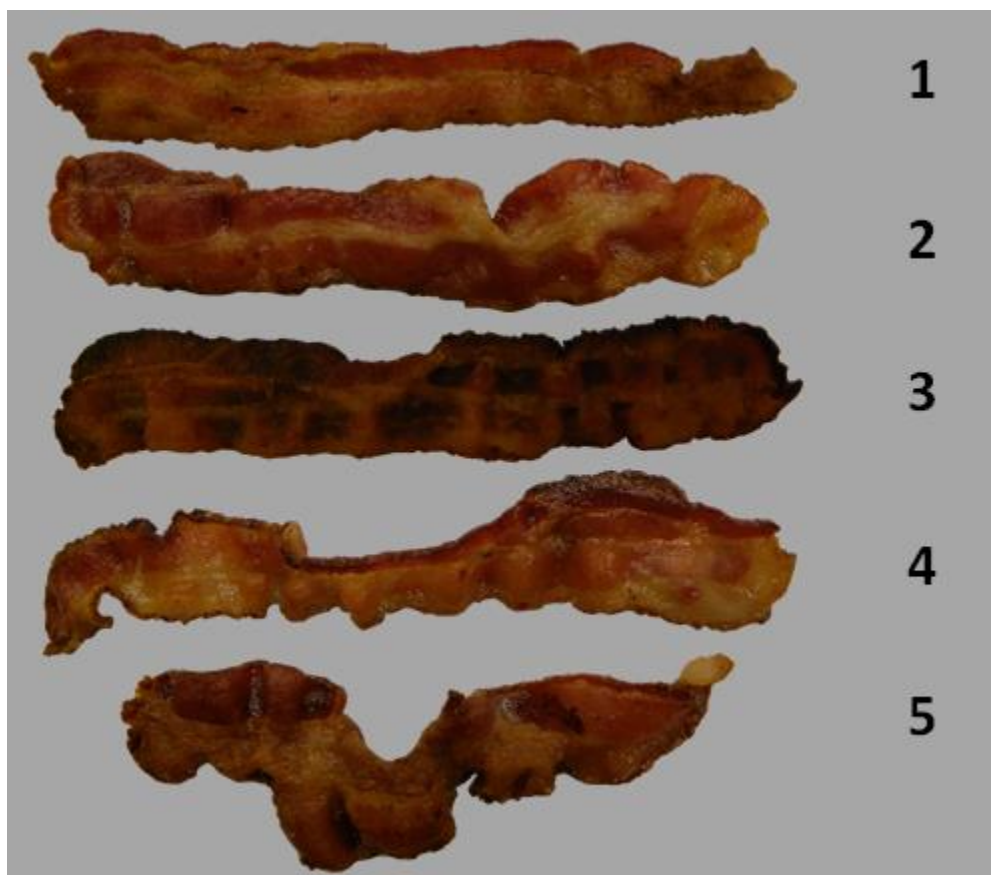
Figure 4-2. Cooked bacon distortion scale.

Figure 4-3. Least squares means of bacon length of bacon slices originating from different locations within the belly.
Different superscripts are significantly different ($P < 0.05$). Data were collected by B.L. Goehring, J.A. Unruh, J.M. DeRouchey, S.S. Dritz, A.M. Tapian, and T.A. Houser
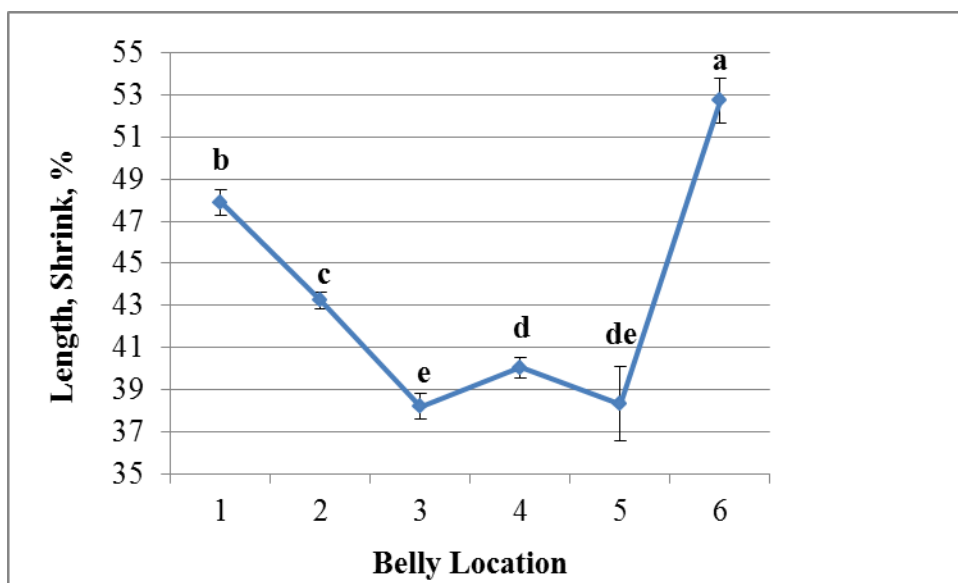
Figure 4-4. Least squares means of length shrink of bacon slices originating from different locations within the belly.

Different superscripts are significantly different ($P < 0.05$). Data were collected by B.L. Goehring, J.A. Unruh, J.M. DeRouchey, S.S. Dritz, A.M. Tapian, and T.A. Houser

Figure 4-5. Least squares means of bacon weight of bacon slices originating from different locations within the belly.
Different superscripts are significantly different ($P < 0.05$). Data were collected by B.L. Goehring, J.A. Unruh, J.M. DeRouchey, S.S. Dritz, A.M. Tapian, and T.A. Houser
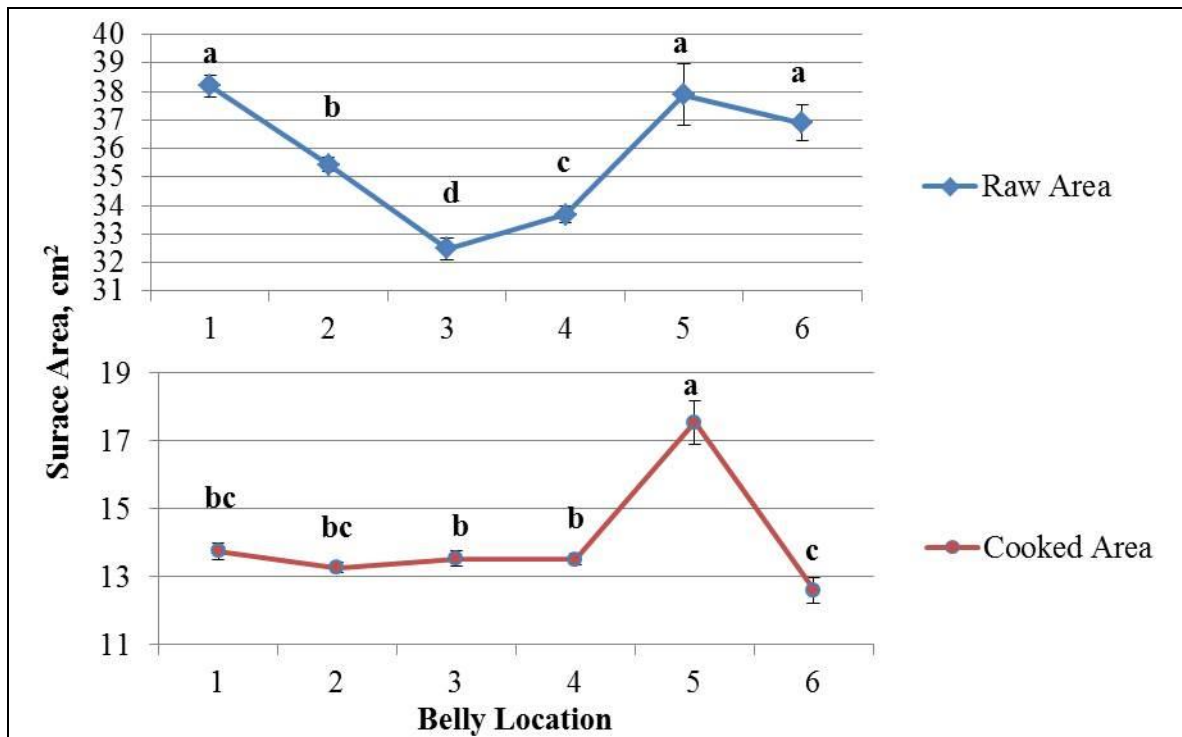
Figure 4-6. Least squares means of bacon surface area from bacon slices originating from different locations within the belly.
Different superscripts are significantly different ($P < 0.05$). Data were collected by B.L. Goehring, J.A. Unruh, J.M. DeRouchey, S.S. Dritz, A.M. Tapian, and T.A. Houser
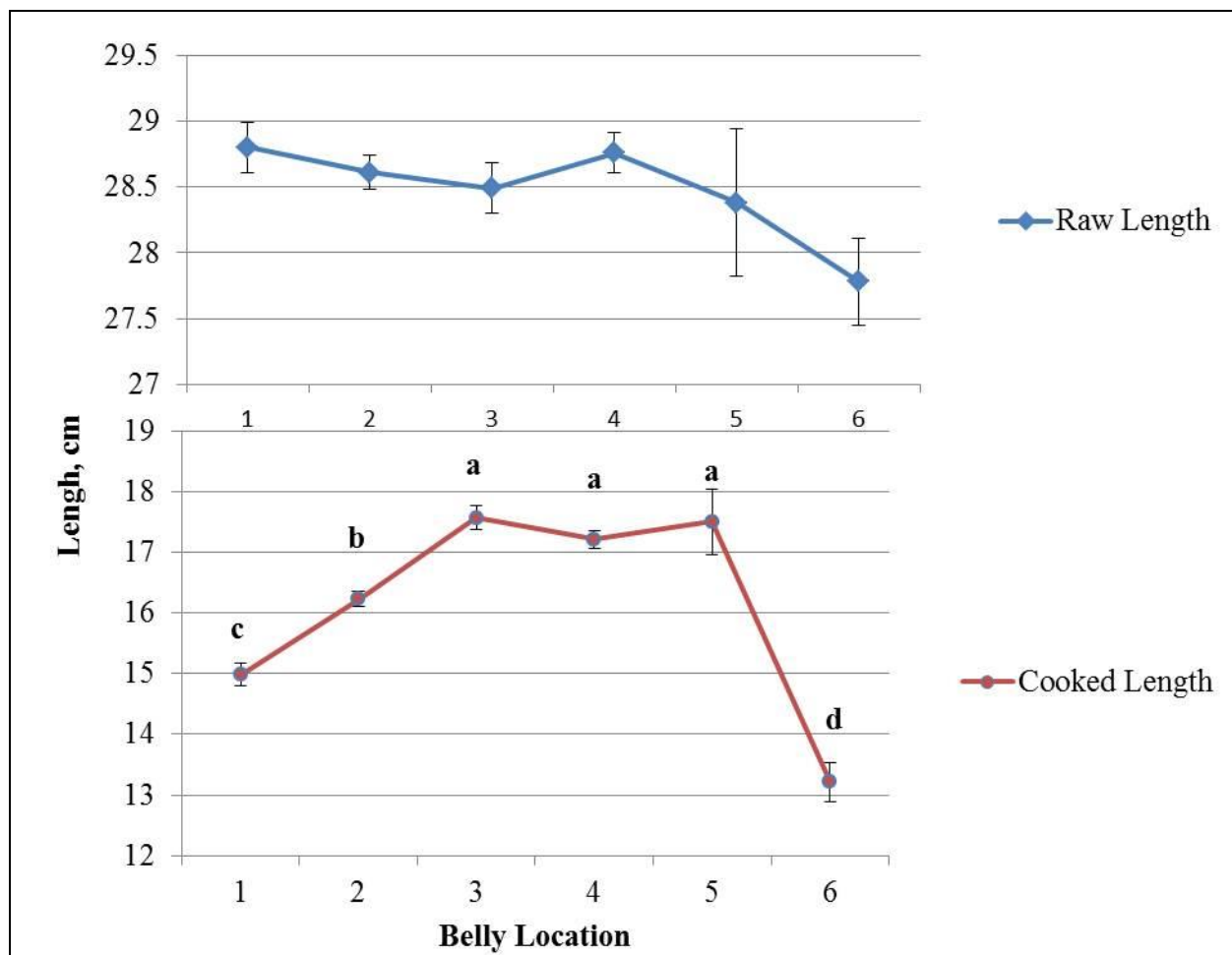
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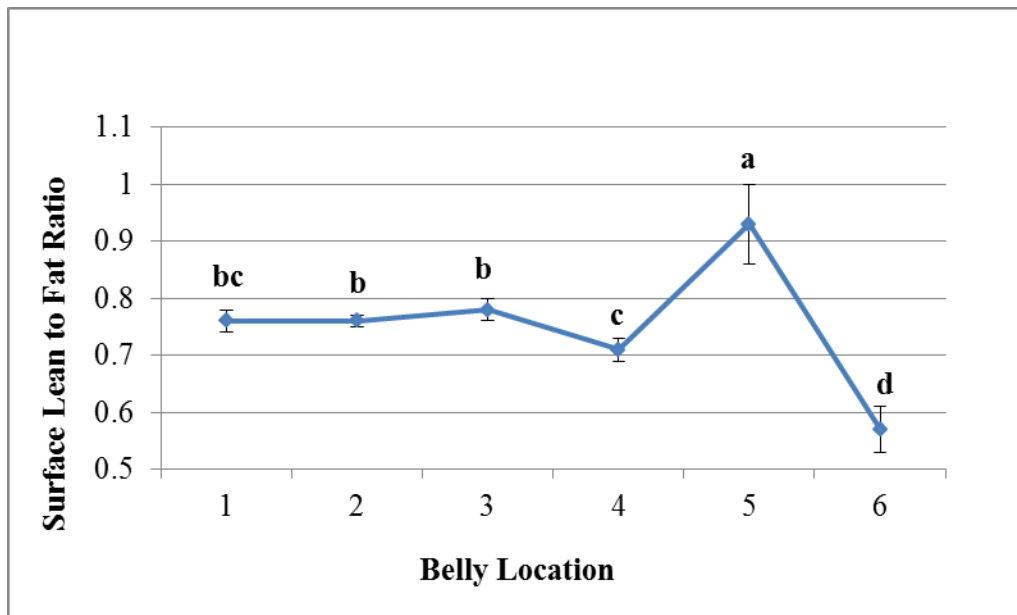
Figure 4-7. Least squares means of the lean to fat ratio of bacon slices originating from different locations within the belly
Different superscripts are significantly different ($P < 0.05$). Data were collected by B.L. Goehring, J.A. Unruh, J.M. DeRouchey, S.S. Dritz, A.M. Tapian, and T.A. Houser
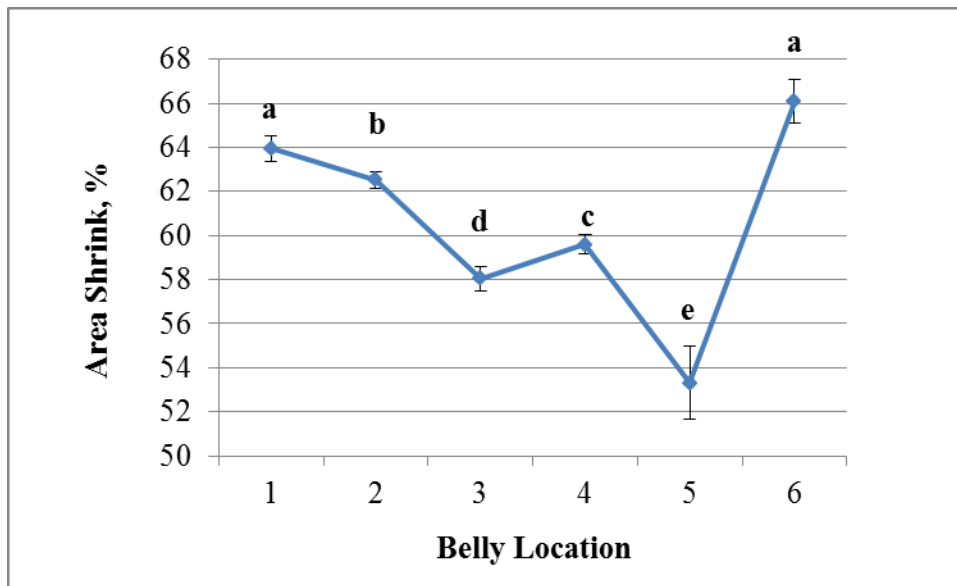
Figure 4-8. Least squares means of surface area shrink exhibited by bacon from different locations within the belly.
Different superscripts are significantly different ($P < 0.05$). Data were collected by B.L. Goehring, J.A. Unruh, J.M. DeRouchey, S.S. Dritz, A.M. Tapian, and T.A. Houser
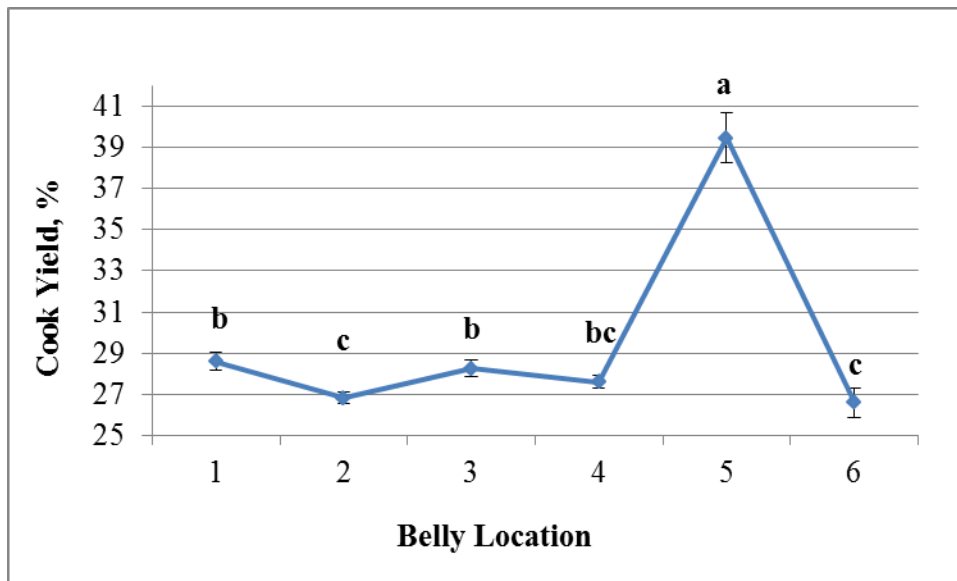
Figure 4-9. Least squares means of cook yields from bacon originating from different locations within the belly.
Different superscripts are significantly different ($P < 0.05$). Data were collected by B.L. Goehring, J.A. Unruh, J.M. DeRouchey, S.S. Dritz, A.M. Tapian, and T.A. Houser
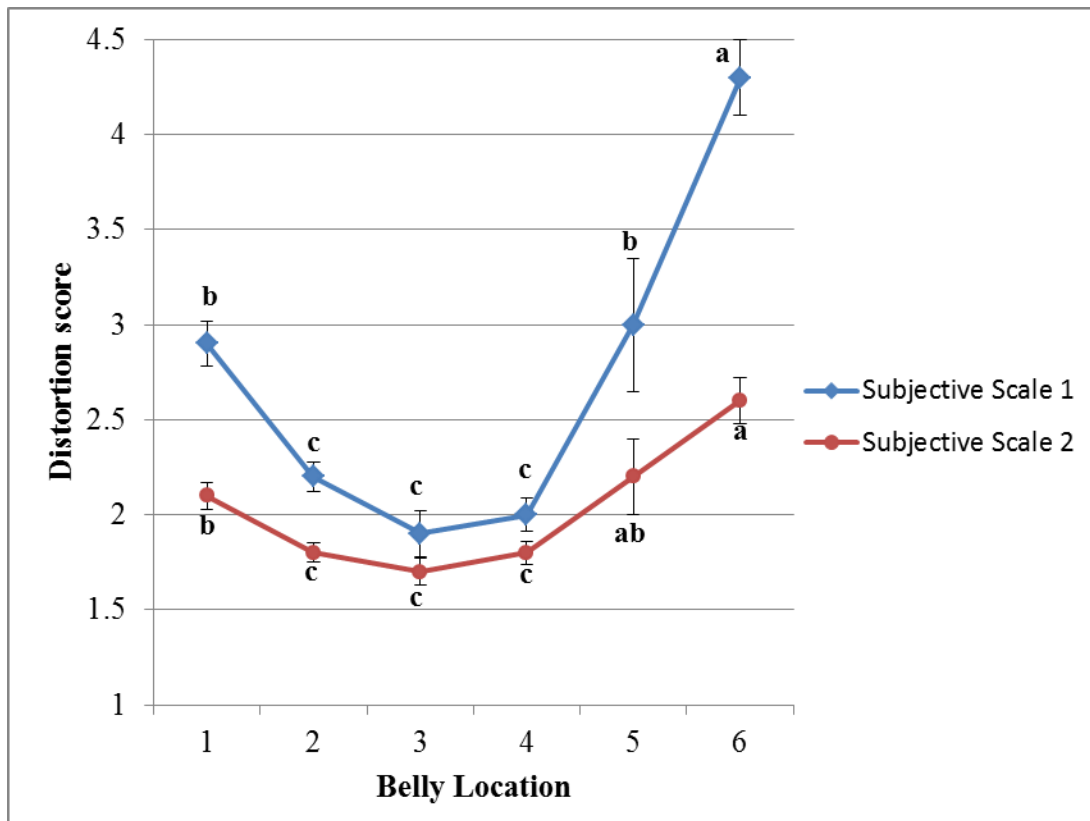
Figure 4-10. Least squares means of subjective bacon scores of bacon originating from different locations within the belly.

Belly location 1 = Shoulder end of belly; belly location 6 = ham end of belly. Subjective scale 1: 1 = a flat piece of bacon; 5 = extremely distorted bacon. Subjective scale 2: 1 = a flat piece of bacon; 3 = extremely distorted bacon. Different superscripts are significantly different ($P < 0.05$).Data were collected by B.L. Goehring, J.A. Unruh, J.M. DeRouchey, S.S. Dritz, A.M. Tapian, and T.A. Houser
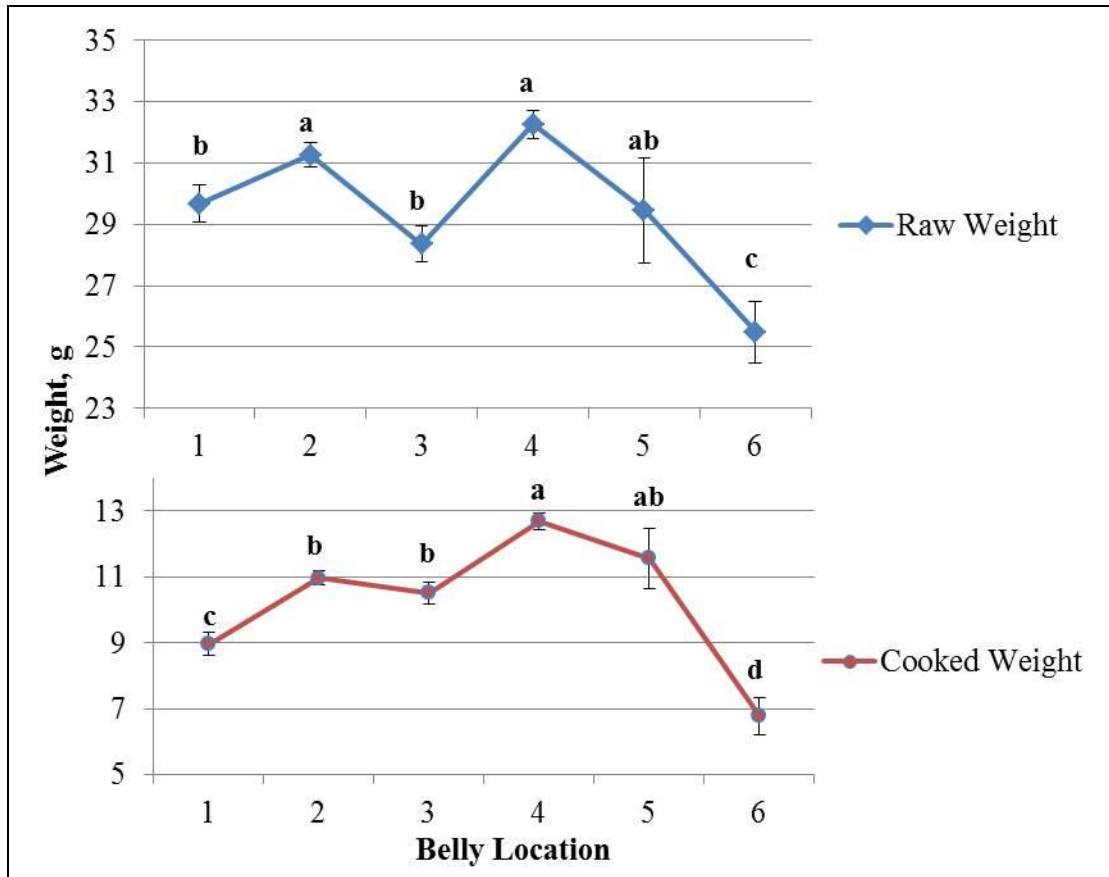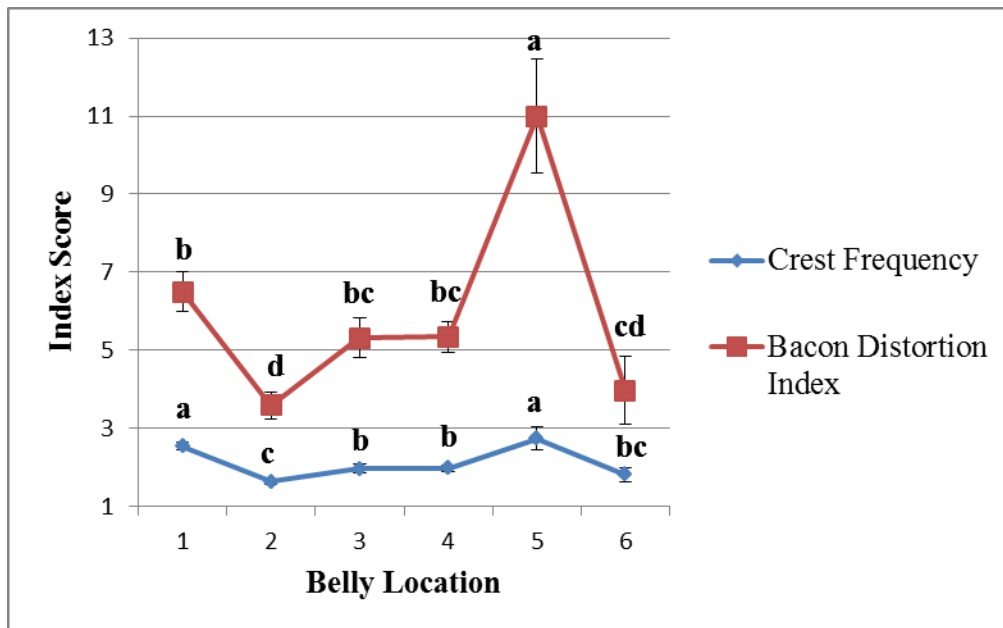
Figure 4-11. Least squares means of cooked bacon distortion index scores by belly location. Different superscripts are significantly different (*P* < 0.05). Data were collected by B.L. Goehring, J.A. Unruh, J.M. DeRouchey, S.S. Dritz, A.M. Tapian, and T.A. Houser
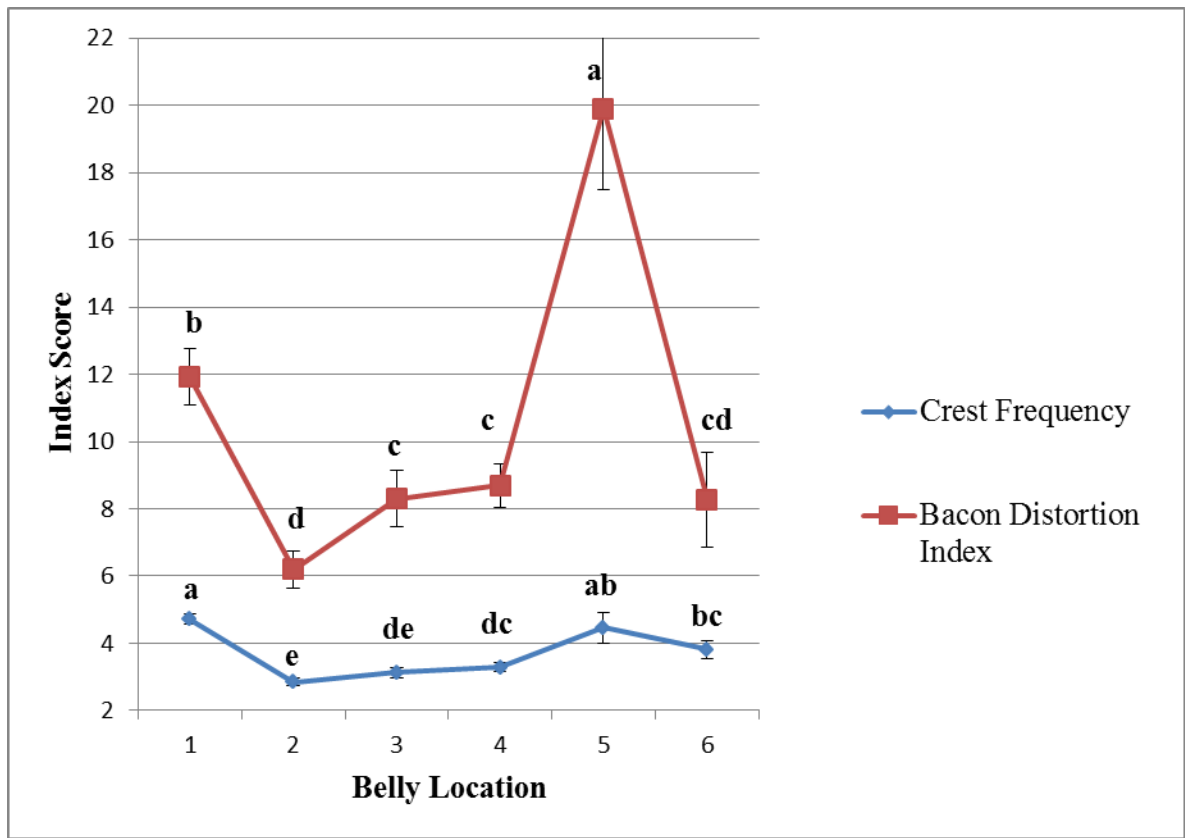
Figure 4-12. Least squares means of raw bacon distortion index scores by belly location.
Crest frequency defined as raw length/crest number. Bacon distortion index defined as crest frequency × average distance between crests. Different superscripts are significantly different ($P < 0.05$). Data were collected by B.L. Goehring, J.A. Unruh, J.M. DeRouchey, S.S. Dritz, A.M. Tapian, and T.A. Houser.

Table 4-1. Descriptive statistics for bacon response variables

Item	Mean	SD[A]	Minimum	Maximum
Raw bacon description				
Belly IV[B], g/100g	72.8	8.0	61.5	85.3
Raw slice weight, g	31.1	5.9	13.9	43.4
Raw length, cm	28.6	1.9	22.3	33.1
Raw surface area, cm^2	34.6	3.8	25.0	43.4
Lean surface area, cm^2	14.5	2.6	8.1	21.9
Fat surface area, cm^2	20.1	3.7	8.1	29.9
Lean: fat	0.8	0.2	0.03	2.5
Number of muscles	4.5	1.0	2.0	7.0
Collagen content				
Total collagen, mg/g	42.9	17.3	18.3	90.5
Insoluble collagen, mg/g	29.7	15.1	7.4	76.0
Soluble collagen, mg/g	13.1	4.4	7.2	23.4
Proximate composition[C]				
Moisture, %	42.6	5.4	29.4	51.4
Fat, %	39.3	7.1	26.7	56.0
Protein, %	12.6	2.2	8.4	16.7
Cooked bacon description				
Cooked weight, g	11.4	3.4	3.6	19.6
Cooked yield, %	27.5	3.8	19.1	49.9
Cooked length, cm	16.1	2.0	9.0	21.3
Length shrink. %	45.6	6.8	25.9	61.1
Cooked surface area, cm^2	13.3	1.8	7.2	22.1
Area shrink,	61.4	5.4	42.1	80.3
Distortion measurements				
Number of crests	10.4	3.8	2.0	30.0
Average crest distance. cm	2.3	0.8	1.0	5.6
Subjective scale 1 (1-5)	2.3	1.3	1.0	5.0
Subjective scale 2 (1-3)	1.9	0.7	1.0	3.0

[A]Standard Deviation

[B] Calculated as (C16:1 × 0.95) + (C18:1 × 0.86) + (C18:2 × 1.732) + (C18:3 × 2.616) + (C20:1 × 0.785) + (C22:1 × 0.723), AOCS 1998.

[C]AOAC 990.02 (1994), AOAC PVM-1 (2003)

Data were collected by B.L. Goehring, J.A. Unruh, J.M. DeRouchey, S.S. Dritz, A.M. Tapian, and T.A. Houser.

Table 4-2. Selected bacon correlations[A]

Cooked response variable	Average crest distance[B]	Cooked weight	Length Shrink,%
Surface area shrink, %	-0.41	-0.49	-
Length shrink, %	-0.46	-0.45	-
Crest number[C]	-0.58	-	-
Subjective scale 1[D]	-	-	0.60

[A]Listed correlations are significant $P < 0.05$

[B]Average distance between bacon crests

[C]Number of crests in a bacon slice

[D]Bacon distortion scale 1: 1= flat piece of bacon; 5 = highly distorted bacon

Data were collected by B.L. Goehring, J.A. Unruh, J.M. DeRouchey, S.S. Dritz, A.M. Tapian, and T.A. Houser.

Table 4-3. Least squares means of cooked bacon characteristics by belly location

Item	Belly Location						SE[A]	P – value[B]
	1	2	3	4	5	6		
Crest number[C]	7.2[c]	11.5[a]	10.5[b]	10.0[b]	8.4[bc]	8.3[bc]	1.9	<0.05
Average crest distance[D], cm	2.3[bc]	2.0[d]	2.5[b]	2.5[b]	3.0[a]	2.1[cd]	0.4	<0.05

[A] Standard error of the mean.

[B] Different superscripts in a row differ ($P < 0.05$).

[C] The number of crests on an individual bacon slice.

[D] The average distance between crests on a bacon slice.

Data were collected by B.L. Goehring, J.A. Unruh, J.M. DeRouchey, S.S. Dritz, A.M. Tapian, and T.A. Houser.

Table 4-4. Regression equations generated for prediction of bacon distortion

Equation	Models[A,B]	Adjusted R^2	RMSE[C]
1. Subjective scale 1	$= 0.34 + (0.06 \times RWT) + (0.10 \times YD) + (0.34 \times RAE) - (1.01 \times CAE) - (0.27 \times AS) - (0.68 \times RL) + (1.10 \times CL) + (0.40 \times LS) + (0.04 \times CREST) - (0.17 \times ACREST)$	0.46	0.96
2. Subjective scale 2	$= 3.04 + (0.007 \times BIV) - (0.08 \times Nmus) + (0.03 \times CWT) + (0.05 \times YD) - (0.12 \times CAE) - (0.41 \times ACREST) - (0.44 \times CBF) + (0.09 \times CBDI)$	0.34	0.59
3. Subjective scale 2	$= -1.34 + (0.05^T \times CWT) + (0.06^* \times YD) - (0.06^T \times CAE) + (0.03^T \times AS) + (0.03^T \times LS) - (0.28^* \times ACREST) - (0.36^T \times CBF) + (0.07^T \times CBDI)$	0.42	0.55

[A]Probabilities for Regression coefficients at $P \leq 0.05$

[B]RWT = Raw bacon weight; YD = cook yield; RAE = Raw surface area; CAE = cooked surface area; AS = surface area shrink; RL = Raw length; CL = cooked length; LS = Length shrink; CREST = Average number of crests per bacon slice; ACREST = Average distance between crests on a bacon slice; BIV = Bacon iodine value; CBF = Cooked bacon frequency; CBDI = Cooked bacon distortion index.

[C]Root mean square error.

[D]Bayesian information criterion values can evaluate the precision of the model. Models that minimize BIC indicate a more precise model.

Data were collected by B.L. Goehring, J.A. Unruh, J.M. DeRouchey, S.S. Dritz, A.M. Tapian, and T.A. Houser.

Chapter 5 - QUANTIFYING THE INFLUENCE OF BACON IODINE VALUE ON COOK YIELDS AND DISTORTION USING THREE DIFFERENT COOKING APPLIANCES

B.L. Goehring, J.A. Unruh, J.M. DeRouchey, S.S. Dritz, A.M. Tapian, M.A. Vaughn, K.J. Phelps, A.M. Collins, and T.A. Houser

Abstract

The objective of this study was to examine how iodine value (IV) interacts with cooking methodology to influence cooking characteristics, fat quality, and distortion of bacon. Three hundred bacon slices were selected from two IV categories, Low (61.5 to 65.5 g/100g) and High (78.8 to 85.3 g/100g) and cooked using three different appliances (oven, microwave, and griddle). Cooking bacon on a griddle showed the greatest distortion scores, while the oven produced bacon with the lowest distortion scores. Bacon with higher IV produced bacon with increased distortion scores. Bacon from the High IV group showed smaller cooked dimensions, a lower cooked weight but a higher cook yield than Low IV bacon. Cooking bacon with the oven produced bacon with the largest dimensions. Cooked bacon originating from the High IV group produced bacon with a lower fat content and higher protein content. Bacon cooked on the griddle contained more fat than bacon cooked on other appliances.

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Introduction

Modern pork production practices place a premium on efficient and cost effective production strategies. A byproduct of these processes is the occurrence of soft bellies which has generally been acknowledged as a contributing factor to low slicing yields (Seman et al., 2013). The component identified as a major contributor to soft bellies is the ratio of unsaturated to saturated fatty acids in belly fat commonly expressed in terms of Iodine Value (IV) (Engel et al., 2001). Previous literature suggests that IV increases through the addition of ingredients to swine diets that contain a high proportion of unsaturated fatty acids (Shackelford et al., 1990; Apple et al., 2007). The increase in unsaturated fatty acids could be important for cooking performance because this would alter the melting point of fat depots. Fat depots within the pork carcass are known to have different IV level which was illustrated by Graham et al. (2009) who observed that the IV of leaf fat was 52 g/100g, while the IV of bellies ranged from 59 to 61 g/100g, and back fat between 64 and 67 g/100g. The relationship between melting points and fat depots illustrate the variability of fat saturation within pork carcasses and is important because it shows it is possible to produce bellies with a wide range of IV resulting in a broad range of melting points.

Differences in melting point could play a significant role in influencing variation in commercial pre-cooked bacon as well as bacon cooking performance within consumers' homes. Another factor affecting how fat cooks is low water content and low specific heat, which will cause fat to heat more rapidly causing conditions likely to increase fat melting. This becomes more important when considering that the total amount of fat also influences cook yield. This was illustrated by Jabaay et al. (1975), who observed that bacon from the areas of the belly that contained the most fat (middle of the belly) also had the lowest cook yield. Differences in cook yields have not been unanimous in the literature due to different sampling methods that do not account for fat composition, different belly processing, and different cooking methodologies. A similar situation occurs when evaluating bacon distortion due to different sampling methods and cooking processes that hide the fat effect on distortion. Therefore, the objective of this study was to describe the differences in cook yields and bacon distortion of bacon slices with different IV values using three different cooking methods.

Materials and Methods

Bacon Selection

Pork Pork bellies were obtained from a commercial swine harvest facility (Farmland Foods, Milan, MO) and processed into bacon using commercial bacon processing methods (Farmland Foods, Denison, IA). Bacon slices originated from the middle third of the belly. Bacon slices were sorted into two IV categories (Low and High). Bacon in the Low IV category had an IV range of 61.5 to 65.6 g/100g and the High IV category ranged from 78.8 to 85.3 g/100g. A total of 60 bellies were selected for this study.

Bacon Cookery

Three different cooking appliances were used in this study. Prior to this study, multiple cooking protocols were tested on bacon slices to identify the cooking protocol for each appliance. Selection criteria included producing bacon slices with similar cook yields, and similar degree of doneness (dark brown color). For each belly used in this trial, 5 bacon slices were cooked with each appliance.

A Blodgett dual-air-flow oven (DFD-201, G.S. Blodgett Co., Inc., Burlington, VT), a microwave oven with convection (AMC7159TAB, Amana, Benton Harbor, MI) (13.0 amp single phase, 1000 watt, output frequency 2450 MHz), and a Oster ceramic electric griddle (CKSTGRFM18XX-ECO Series_14EM1, Jarden Products, Inc, Boca Raton, FL) were used to cook bacon in this study. The oven protocol was 204°C with a 10 min cook time. Bacon slices were placed atop wire cooling racks setting in aluminum trays. Trays were placed in the middle racks of the oven. At the halfway point of the cooking time, trays were removed and the bacon flipped, and then the trays were rotated in the oven to reduce front to back cooking variation in the oven. Five bacon slices were cooked on a tray and only a single tray was placed in the oven at a time. After cooking, bacon slices were blotted with paper towels to remove grease.

The griddle cooking protocol had the temperature set the same as the oven at 204°C with a 10 min cook time. At the halfway point during cooking, slices were flipped. To reduce cooking variation, only two bacon slices were cooked per cooking session and placed within the diameter of the heating coil so that no part of the slice lay directly on top of the heating coils. Between each cooking session the surface of the grill was cleaned to eliminate oil accumulation, burning, and bacon sticking to the griddle. Griddle temperature was monitored using a laser

thermometer. While cooking, surface temperatures did not exceed the set temperatures by more than 15°C. After cooking, bacon slices were blotted with paper towels to remove grease.

Bacon slices cooked in the microwave were cooked at power level 9 (90% power) for 2 min. A power level 9 indicates that the oven is producing 900 watts out of a possible 1000. One bacon slice was cooked at a time in a ridged bacon grill with vented cover (US Patent no: D471, 397, Progressive International, Kent, Washington). Between each cooking session, the bacon tray was drained of grease and cleaned. After cooking, bacon slices were blotted with paper towels to remove grease.

Bacon Measurements

Prior to cooking, a photo (Nikon Coolpix P90, 6MM68411-01, Nikon Corp, Tokyo, Japan) was taken with all raw bacon slices alongside a ruler so that raw length, raw bacon surface area, total lean surface area, and total fat surface area could be measured using NIS-Elements Imaging Software (Basic Research, 3.3; Nikon Instruments, INC). After cooking, a photo was taken of each cooked bacon slice so that cooked length and cooked surface area could be measured. Raw and cooked bacon slices were weighed using an Explorer Pro scale (EP2102C, Ohaus Corporation, Pine Brook, NJ). After image analysis, length shrink (raw length-cooked length/raw length × 100), area shrink (raw area-cooked area/ raw area × 100), and a lean to fat ratio (lean area/fat area) were calculated. Bacon dimensions were quantified using the photo imaging software in an attempt to limit handling of bacon in order to prevent slice stretching and to ensure all bacon slices were the same temperature before cooking to increase precision of the photo measurements.

Bacon Distortion Measurements

Bacon distortion was evaluated by using a numerical subjective scale with 1 representing a flat piece of bacon, and 5 equal to highly distorted bacon (Figure 5-1). This system is similar to the numerical score published by Rentfrow et al. (2003), and designed by Mandigo (2000).

Cooked Bacon Measurements

To quantify bacon distortion, this study uses physics concepts (wavelength, amplitude and velocity of a wave) and applies it to bacon. The term Crest number was used to describe the number of waves/crests on each cooked bacon slice. This measurement was taken in sequential

order between each crest. Crest Frequency (CF) is a term repurposing the frequency equation (f=1/T), redefined in this study as cooked length/crest number and provides a measure of the number of crests per bacon slice. Bacon Distortion Index (BDI) is a term that uses the concept of wave velocity (frequency $\times$ wavelength) and applied to distortion as CF $\times$ average distance between crests. Using the BDI and CF numbers, higher numbers would indicate flatter bacon.

Chemical Analysis of Cooked Bacon

The 5 cooked bacon slices representing each belly were frozen in liquid nitrogen, pulverized in a blender (Model 33B179, Waring Products, New Harford, CT), and stored in whirlpak bags. Samples analyzed for proximate analysis and fatty acid composition were taken out of a composite sample. Protein composition was analyzed using the AOAC 990.02 (1994) protocol, and moisture and fat with the AOAC PVM-1 (2003) protocol. Pulverized bacon was weighed into screw-cap tubes with Teflon-lined caps for fatty acid analysis. Samples were then mixed with 3 mL of methanolic-HCL and 2 mL of an internal standard consisting of 2 mg/mL of methyl tridecanoic acid in benzene and heated in a water bath for 120 min at 70°C for transmethylation. During heating, tubes were vortexed at 45 and 90 min. After heating, 2 mL of benzene and 3 mL of K_2CO_3 were added to extract the methyl esters. Methylated fatty acids were analyzed by gas chromatography (Palmquist and Jenkins, 2003). Iodine values were calculated from the fatty acid composition using the AOCS (1998) protocol: (C16:1 $\times$ 0.95) + (C18:1 $\times$ 0.86) + (C18:2 $\times$ 1.732) + (C18:3 $\times$ 2.616) + (C20:1 $\times$ 0.785) + (C22:1 $\times$ 0.723).

Statistical Analysis

A 2 $\times$ 3 factorial design was used to investigate interactions between cooking appliance and IV with main effects of two IV categories Low (61.5 - 65.6 g/100g) and High (78.8 to 85.3 g/100g) with three cooking appliances (oven, microwave, and griddle). Each belly was defined as the experimental unit. Five bacon slices were selected per belly for cooking. Data were analyzed using the PROC GLM procedure of SAS (SAS Institute, Inc., Cary, NC). An α-level of 0.05 was used to assess significance among means.

Results and Discussion

Raw Bacon Population Description

Raw dimensional measurements for the sampled bacon population are displayed in Table 5-1 and dimensional data of the bellies sampled in this study are in Table 5-2. The average raw weight of bacon from the High iodine group was lighter and longer than bacon from the Low iodine group ($P < 0.05$). High IV bacon showed greater lean surface area compared to bacon from the Low IV group ($P < 0.05$). Low IV bacon showed a greater amount of total surface area and fat surface area when compared to High IV bacon ($P < 0.05$). There was no difference in the lean to fat surface area ratio of the bacon between the IV categories ($P < 0.05$). In this sample population, High IV bacon contained a higher percentage of moisture and protein, but a lower percentage of fat when compared to Low IV bacon ($P < 0.05$). There were no belly width or thickness differences between IV categories ($P > 0.24$). However there was a trend for the Low IV bellies to be heavier than the High IV bellies ($P > 0.08$). Sampled bellies did show differences in belly length with the Low IV bellies being 3% longer ($P < 0.05$).

The differences observed in raw weight between the Low and High IV bacon slices can be explained by the physical and chemical nature of the whole belly. It has been established that belly weight is negatively correlated with belly lean content (Fredeen and Martin, 1975; Freeden 1980), thus the addition of fat content to the belly is the expected way that a pig would biologically add weight to the belly. This is further substantiated by the Low IV bacon having a greater fat surface area, and the High IV bacon having a greater lean surface area. Bacon length is equivalent to belly width in bacon literature, and the literature has shown mixed results when reporting belly width. Browne et al. (2013) reported no differences in belly width when feeding pigs different levels of yellow grease and beef tallow that resulted in an IV range of 4.5 g/100g. In a study by Boler et al. (2012), investigating how immunological castration affects belly characteristics, it was reported that immunological castrated pigs had a wider belly with a higher IV (77.9- 79.8 g/100g) than physically castrated pigs that had an IV of range of 77.7 to 77.2 g/100g. Furthermore, a study looking at environmental stress on growth performance of pigs reported no difference in raw bacon length despite observing different bodyweights and IV levels (White et. al., 2008). A study by Leick et al. (2010) contradicts these findings by reporting a linear decrease in belly width as IV increased. However, this was seen by feeding dried distillers

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grains (DDGs) above 30%, which is generally not the standard for practical application of a high fat feed ingredient. Logically it would be predicted that bacon with a higher IV would have a lower melting point (Cornelia et al. 2009; Smith and Smith 2011) and would be less likely to hold its shape, thus it is possible that the differences observed in the current study while handling the bacon.

The higher moisture and lower fat content in the High IV bacon slices can also be explained by the trend observed that the Low IV bellies had a heavier belly ($P = 0.08$; Table 2). This increase in weight due to increasing quantities of fat thereby lowers the percentage of lean content in bacon slices. Since one of the major constituents of lean is water, the reduction of that lean component in relation to the fat content would cause a decrease in moisture content in Low IV bellies. Observing greater amounts of moisture and a smaller percentage of fat was also observed by Boler et al. (2012) between physically castrated pigs (lower IV) and immunologically castrated pigs (higher IV). This is corroborated by Clark et al. (2014) who reported that gilts with higher IV (65.94 g/100g) contained greater concentrations of moisture and less concentrations of fat than barrows with Low IV (62.8 g/100g).

Cooked Bacon Dimensional Response to Iodine Value

Bacon dimensional response to IV is listed in Table 5-3. Bacon slices with Low IV averaged a longer cooked length, a heavier cooked weight, and a greater cooked surface area ($P < 0.05$). Bacon slices in the High IV group displayed a greater cook yield and a greater amount of length shrink ($P < 0.05$). There were no statistical differences in cooked surface area shrink between the IV categories ($P = 0.43$).

There was a 5% difference in cooked length between High and Low IV bacon slices observed in this study with Low IV slices showing a longer cooked slice. This occurred despite the High IV bacon averaging a 3.8% longer raw bacon slice. Results of this study agree with White et al. (2008) who studied the influence of environmental temperature on pigs and the resulting bacon characteristics. White et al. (2008) observed an average IV difference of 1.6 g/100g between temperature treatments which resulted in the higher IV group possessing shorter cooked lengths. The smaller cooked length coincides with an increased length shrink (Table 3) and a smaller percentage of fat in the cooked bacon (Table 8) from the High IV group, which

could mean that the lower melting point of High IV bacon (Smith and Smith, 2011) is the reason for this observation.

The 9% difference in cooked bacon weight can be attributed to the raw bacon weight, as Low IV bacon was 12.8% heavier than bacon from the High IV group. Thus, cooked weight is not an accurate indication of IV influence on cooked weight. A 4% difference in cook yields was observed between the IV groups. The difference in cook yield is most likely not due to IV alone, but rather the amount of fat in the raw bacon slices because raw bacon from the Low IV group contained more fat. Previous literature has established that bacon cook yields are related to fat content. Increasing fat content will result in lower bacon yields during cooking (Carpenter et al., 1963; Jabaay et al., 1975). Previous literature investigating fat quality disagrees with the results of the current study. Widmer et al. (2008) observed a trend with a linear increase in bacon cook yields as belly IV increased 3 g/100g between control and a 20% inclusion of DDGs. Furthermore, Rentfrow et al. (2003) and McClelland et al. (2012) also observed no differences in cooking loss despite feeding pigs diets that resulted in differences in fat IV. It should be noted that the authors of the McClelland and Rentfrow studies sampled bacon from 5 points across the length of the belly whereas the current study sampled bacon from the middle of the belly. Trussell et al. (2011) illustrated that belly thickness and proximate composition changes throughout the length of the belly, thus it is important to consider proximate composition when investigating bacon cook yields.

Cooked Bacon Dimensional Response to Cooking Method

Between the three cooking appliances, bacon cooked in the oven resulted in a longer cooked length, a smaller area shrink, and less length shrink ($P < 0.05$, Table 5-4). Bacon cooked on the griddle displayed a heavier cooked weight when compared to the microwave ($P < 0.05$), but was not different from the oven ($P > 0.05$). Bacon cook yields were the greatest using the griddle, and lowest with the microwave ($P < 0.05$). Bacon cook yields from the oven were intermediate between the griddle and the microwave ($P < 0.05$).

The oven producing longer bacon with less dimensional shrink is likely due to the oven producing lower distortion scores. Also, an explanation can be formed by the heating mechanics of the appliances themselves. The oven transmits heat via forced air convection, which means that the scale of heat transfer is dependent on the air velocity past the bacon (Singh and

Heldman, 2001). Therefore, bacon prepared in the oven experienced more evenly distributed heat transfer compared to the other two methods because the bacon was cooked on cooling racks, ultimately allowing more surface contact between the heated air and the bacon slices. Whereas the griddle uses conductive heat transfer and the heat was only applied to one side at a time. Also observed with the griddle, was initial shrinkage during cooking, which caused crest formation. The crests formed in the bacon end up cooking differently because not all of the bacon surface area is in contact with the heat source. The microwave would also show variation in heating within a bacon slice. Microwave energy causes heating through interactions between the energy waves and the molecules of a dielectric material (a material that resists the flow of electric charges) (Meda and Raghaven, 2005; Sing & Heldman, 2001). Bacon consists of fat and lean, which have vastly different dielectric properties due to the lean containing more moisture than the fat, which then would cause localized differences in rate of heating. These cooking mechanics might also explain the differences observed in cook yields. The griddle would produce greater cook yields because of the higher occurrence of non-contact points between the bacon and the grill. The microwave would produce the lowest cook yields. Despite bacon fat having a low dielectric loss (a materials ability to dissipate heat), once the heat has been absorbed, heat transfer mechanisms apply, allowing the fat to reach very high temperatures (above 100°C), thereby heating faster in a microwave than in the other appliances, thus causing smaller yields (Lyng et al., 2005; James et al., 2006).

Bacon Distortion Response

There was an IV and cooking appliance interaction on bacon distortion scores and crest number (Table 5-5) but not for CF or BDI. Iodine value fixed effects for distortion measurements are displayed in Table 5-6. Cooking appliance fixed effects for distortion measurements are displayed in Table 5-7. High IV bacon cooked with the griddle produced the highest distortion score ($P < 0.05$). In contrast, Low IV bacon cooked by the microwave and the oven produced the lowest distortion scores ($P < 0.05$). High IV bacon produced bacon with more subjective distortion and a higher number of crests in the bacon slice when compared to Low IV slices ($P < 0.05$). In contrast, Low IV bacon produced a higher crest frequency and bacon distortion index ($P < 0.05$). When cooking bacon, the griddle produces bacon with the highest distortion scores, with the microwave creating intermediate distortion scores, and the

oven forming the lowest distortion scores ($P < 0.05$). The microwave showed higher crest numbers than the griddle, which produced higher crest numbers than the oven ($P < 0.05$). The oven caused the highest CF and BDI of the cooking methods ($P < 0.05$). The microwave displayed the lowest bacon frequency and distortion index compared to the other cooking appliances ($P < 0.05$).

There is a limited amount of literature investigating bacon distortion. Results reported generally disagreed with distortion results of the current study. While feeding pigs different levels of DDGs that resulted in differences in belly IV (64.7 to 75.3 g/100g), Widmer et al. (2008) reported no differences in distortion scores. Similar to Widmer, McClelland et al. (2012) fed pigs various levels of DDGs (0, 15, 30, and 45%) that resulted in bacon from bellies with different IV (65.4, 69.7, 75.8 and 79.5 g/100g) and was also unable to observe differences in distortion. Contradiction to this current study was also found by Rentfrow et al. (2003) who reported no differences in distortion scores, even though feeding pigs with different fat sources (choice white grease, high oil corn, high oleic oil corn) produced fat with different IV levels. When considering the proximate composition of both the raw and cooked bacon in this study and the previously discussed papers concerning bacon distortion, it is most likely that IV has little to do with explaining bacon distortion, but rather the proximate composition of the slice that is the major contributor.

In the current study, differences between distortion scores between High and Low IV bacon can be contributed to the moisture content. Since the Low IV bacon had less moisture, low IV bacon will have a lower specific heat value (James et al., 2006; Lyng et al., 2005; Meda & Raghaven, 2005). A lower specific heat value means it will take less heat to cause a temperature change, thus the Low IV will heat up faster, and therefore be cooked faster. Fats can reach temperatures above 100°C, and once heated can transfer that heat to the rest of the bacon (James et al., 2006). Since there is less moisture as a whole, the bacon surface dehydrates faster, thereby losing its viscous and elastic properties due to faster crust formation (Portanguen, Ikonic, Clerjon, & Kondjoyan, 2014). Bacon placed on the griddle will experience more moisture evaporation in areas in contact with the griddle, leading to uneven moisture migration and crest development. Ultimately this allows more lean shrinkage which leads to more pronounced crest formation due to the slower development of the crust. The heating method for the oven causes surface dehydration and crust development more efficiently and consistently than the other

methods thereby allowing little muscle fiber shrinkage because of low muscle pliability and crust formation. The microwave would also cause inconsistent moisture loss in bacon for several reasons. The difference in dielectric properties in the fat and lean phases of bacon would cause differences in heating. Furthermore, it is generally understood that the heat transfer within food via conduction is influenced by geometry, homogeneity, and composition which can be highly variable in bacon (Brewer, 2005). A final hurdle to efficient microwave heating is the fact that high moisture and high salt content will inhibit microwave penetration (Brewer 2005).

Proximate Analysis Response to Iodine Value and Cooking Method

Proximate analysis results from IV treatments are displayed in Table 5-8. Cooked bacon with High IV contained a greater amount of protein and a smaller amount of fat compared to Low IV bacon ($P < 0.05$). The 14% difference in fat content between the two IV categories after cooking can be explained by the fact that there was a 21% difference in fat content, and since the Low IV bacon had more fat, it is likely that less total fat was being cooked off. This same logic applies to the protein content in cooked bacon because the reduction of fat through cooking will concentrate the protein component.

Proximate analysis results from cooking appliance are listed in Table 5-9. Moisture and protein content of cooked bacon was not different between IV groups ($P > 0.05$). However, bacon cooked with a griddle contained a higher amount of fat than bacon cooked with the microwave and oven ($P < 0.05$). The results of the current study disagree with Larsen et al. (2009), who measured the proximate composition of cooked bacon while investigating how the addition of dietary conjugated linoleic acid to diets with different types of fat impact bacon quality. Larson reported that bacon with different IV (57 to 65 g/100g) did not change in fat, protein or moisture content by cooking with different appliances (microwave vs. electric skillet). Therefore, the differences between cooking method observed in this study might be explained by the cooking methodology. Samples cooked in the oven were placed on a wire cooling rack during the cooking process and the microwave tray for the bacon contained ridges which allowed fat to drain away while cooking. The griddle cooking process allowed no means for the fat to drain away, and despite blotting all bacon slices with paper toweling, excess fat was still absorbed.

Cooked Bacon Fatty Acid Composition Response to Iodine Value and Cooking
Appliance

There was no cooking appliance interaction with IV treatment on fatty acid composition. Fatty acid composition of cooked bacon with different iodine values is displayed in Table 5-10. Cooked bacon from the Low IV bacon contained 14% more Myristic acid, 16% greater Palmitic acid, 12% more Margaric acid, and 29% greater Stearic acid content ($P < 0.05$). Furthermore the Low IV bacon contained 20% greater Palmitoleic acid, 10% more Oleic acid, 15% greater Vaccenic acid, and 18% more Gondoic acid, which resulted in 20% more total saturated fatty acids, and 11% more total mono-unsaturated fatty acids compared to High IV bacon ($P < 0.05$). The High IV bacon contained 65% more Linoleic acid, 60% greater α-Linolenic acid, and 52% more Eicosadienoic acid which caused 65% more total poly-unsaturated fat and a 24% greater IV ($P < 0.05$). Fatty acid composition response to different cooking appliances is listed in Table 11. Cooking bacon with different cooking appliances resulted in no differences in fatty acid composition ($P > 0.05$).

Since fat with high unsaturation have lower melting points (Smith and Smith, 2011) it could be expected that there would be an equalization in fat saturation due to fatty acids with lower melting points melting off during the cooking process, however, this was not the case. Prior to cooking there was a 24% difference between the average IV value of each group, and this did not change after cooking, thus there is not a possibility of decreasing lipid oxidation potential by cooking off the unsaturated fats. Furthermore, it was not possible to change the fatty acid composition by using different cooking appliances, but this study does not eliminate the possibility that different cooking temperatures/times could produce bacon with different fat saturations.

Conclusions

Results of this study show that High IV bacon had bacon with less fat, greater cooked yield and higher distortion scores when compared to Low IV bacon. Furthermore, it was observed that there were clear differences in cook yields between the griddle, microwave and oven, with the griddle producing cooked bacon with a higher fat composition. The response of High IV bacon to cooking could be important to commercial bacon operations. It is well established in literature that High IV bellies can be expected to produce lower slicing yields.

Results of this study suggest that slice yield loss of poor quality bellies can be recouped by segregating High IV bellies into pre-cooked bacon applications and Low IV bellies into retail sectors. Furthermore, this study illustrates the possibility to influence the visual appearance of cooked bacon through IV and cooking method selection, which could lead to the development of new marketing concepts for consumers. It is also viable to make recommendations to consumers on ways to reduce fat via cookery method. Finally, it is not possible to manipulate the fatty acid composition of cooked bacon by using the cooking appliances evaluated in this study.

References

AOAC. (1994). Protein (crude) in animal feed. Official Methods of Analysis (16th ed.). Gaithersburg, Maryland. Association of Official Analytical Chemists.

AOAC. (2003). Rapid determination of fat and moisture in meats by microwave and nuclear magnetic resonance analysis. Official method PVM-1. Official Methods of Analysis (16th ed.). Gaithersburg, Maryland. Association of Official Analytical Chemists.

AOCS (1998). Official Methods and Recommended Practices of the AOCS 5th ed. Am Oil Chem. Soc., Champaign IL.

Apple, J.K., C.V. Maxwell, J.T. Sawyer, B.R. Kutz, L.K. Rakes, M.E. Davis, Z.B. Johnson, S.N. Carr, and T.A. Armstrong. 2007. Interactive effect of ractopamine and dietary fat source on quality characteristics of fresh pork bellies. J. Anim. Sci. 85: 2682-2690.

Brewer, M. (2005). Microwave processing, nutritional and sensory quality. In :H. Schubert and M. Regier editors, The microwave processing of foods. CRC Press, Boca Raton, FlL

Boler, D.D., J. Killefer, D.M. Meeuwse, V.L. King, F.K. McKeith, and A.C. Dilger. 2012. Effects of slaughter time post-second injection on carcass cutting yields and bacon characteristics of immunologically castrated male pigs. J. Anim. Sci. 90: 334-344.

Browne, N.A., J.K. Apple, C.V. Maxwell, J.W. Yancey, T.M. Johnson, D.L. Galloway, and B.E. Bass. 2013. Alternating dietary fat sources for growing-finishing pigs fed dried distillers grains with solubles: II. Fresh belly and bacon quality characteristics. J. Anim. Sci. 91:1509-1521.

Carpenter, Z.L., R.G. Kauffman, R.W. Bray, and K.G. Weckel 1963. Factors influencing quality in pork. B. Commercially cured bacon. Journal of Food Science. 28:578-583.

Clark, D.L., B.M. Bohrer, M.A. Taverez, D.D. Boler, J.E. Beever, A.C. Dilger. 2014. Effects of the porcine IGF2 intron 3-G3072A mutation on carcass cutability, meat quality, and bacon processing. Journal of Animal Science. 92: 5778-5788.

Cornelia, P. C. Adriana, and T. Adrian. 2009. Effect of storage condition on the chemical properties of pork bacon. Anelele Universitatii din Oradea, Fasciculua: ecotoxicology, zootennie si technologii de inustrie alimentara. 565-572.

Engel, J.J., J.W. Smith, J.A. Unruh, R.D. Goodband, P.R. O'Quinn, M.D. Tokach, and J.L. Nelssen. 2001. Effects of choice white grease or poultry fat on growth performance, carcass leanness, and meat quality characteristics of growing-finishing pigs. Journal of Animal Science. 79: 1491-1501.

Fredeen, H.T. 1980. Yields and dimensions of pork bellies in relation to carcass measurements. Journal of Animal Science. 51: 59-68.

Freeden, H.T., and A.H. Martin. 1975. Criteria of belly bacon desirability. II. Visual appraisal and physical measurements of the belly. Canadian Journal of Animal Science. 55: 649-659.

Graham, A.B., R.D. Goodband, M.D. Tokach, S.S. Dritz, J.M. DeRouchey, and S. Nitikanchana. 2014. The interactive effects of high-fat, high-fiber diets and ractopamine HCL on finishing pig growth performance, carcass characteristics, and carcass fat quality. Journal of Animal Science. 92: 4585-4597.

Jabaay, R.W., J.C. Forrest, E.D. Aberle, H.V. Courtenay, and M.D. Judge. 1975. Bacon quality criteria and associated carcass traits. Journal of Food Science 41: 431-437.

James, C., K.E. Barlow, S.J. James, and M.J. Sawin. 2006. The influence of processing and product factors on the quality of microwave pre-cooked bacon. Journal of Food Engineering: 77: 835-843.

Larsen, S.T., B.R. Wiegand, F.C. Parrish, Jr., J.E. Swan, and J.C. Sparks. 2009. Dietary
conjugated linoleic acid changes belly and bacon quality from pigs fed varied lipid
sources. Journal of Animal Science. 87: 285-295.

Leick, C.M., C.L. Puls, M. Ellis, J. Killefer, T.R. Carr, S.M. Scramlin, M.B. England, A.M.
Gaines, B.F. Wolter, S.N. Carr, and F.K. McKeith. 2010. Effect of distillers dried grains
with solubles and ractopamine (Paylean) on quality and shelf-life of fresh pork and
bacon. Journal of Animal Science. 88: 2751-2766.

Lyng, J.G., L. Zhang, and N.P. Brunton. 2005. A survey of the dielectric properties of meats and
ingredients used in meat product manufacture. Meat Science. 69: 589-602.

Meda, V., and V. Raghavan. 2005. Microwave heating and the dielectric properties of foods. In
:H. Schubert and M. Regier editors, The microwave processing of foods. CRC Press,
Boca Raton, FlL

McClelland, K.M., G. Rentfrow, G.L. Cromwell, M.D. Lindemann, and M.J. Azain. 2012.
Effects of corn distillers dried grains with solubles on quality traits of pork. J. Anim. Sci.
90: 4148-4156.

Palmquist, D.L., and T.C. Jenkins. 2003. Challgenges with fats and fatty acid methods. Journal
of Animal Science, 81, 3250-3254.

Portanguen, S., P. Ikonic, S. Clerjon, and A. Kondjoyan. 2014. Mechanisms of crust
development at the surface of beef meat subjected to hot air: an experimental study. Foo
Bioprocess Technology. 7: 3308-3318.

Rentfrow, G., T.E. Sauber, G.L. Allee, and E.P. Berg. 2003. The influence of diets containing
either conventional corn, conventional corn with choice white grease, high oil corn, or
high oil high oleic corn on belly/bacon quality. Meat Science. 64: 459-466.

Seman, D.L., W.N.G. Barron, M. Matzinger. 2013. Evaluating the ability to measure pork fat
quality for the production of commercial bacon. J. Meat Sci. 94: 262-266.

Shackelford, S.D., M.F. Miller, K.D. Haydon, N.V. Lovegren, C.E. Lyon, and J.O Reagan. 1990. Acceptability of bacon as influenced by the feeding of elevated level of monounsaturated fats to growing-finishing swine. J. Food Science. 55: 621-624.

Singh, R.P, and D.R. Heldman. 2001. Introduction to food engineering. Academic Press, CA.

Smith, S.B., and D.R. Smith. 2011. Analysis of rendered fats. In : L.M.L. Nollet and F. Toldra editors, Handbook of analysis of edible animal by-products. CRC Press, Boca Raton, FL p. 40.

Trussell, K.A., J.K. Apple, J.W. Yancey, T.M. Johnson. 2011. Compositional and instrumental firmness variations within fresh pork bellies. Meat Sci. 88: 472-480.

White, H.M., B.T. Richert, A.P. Schinckel, J.R. Burgess, S.S. Donkin, and M.A. Latour. 2008. Effects of temperature stress on growth performance and bacon quality in grow-finish pigs housed at two densities. J. Anim. Sci. 86: 1789-1798.

Widmer, M.R., L.M. McGinnis, D.M. Wulf, and H.H. Stein. 2008. Effects of feeding distillers dried grains with solubles, high-protein distillers dried grains, and corn germ to growing-finishing pigs on pig performance, carcass quality, and the palatability of pork. J. Anim. Sci. 86:1819-1831.
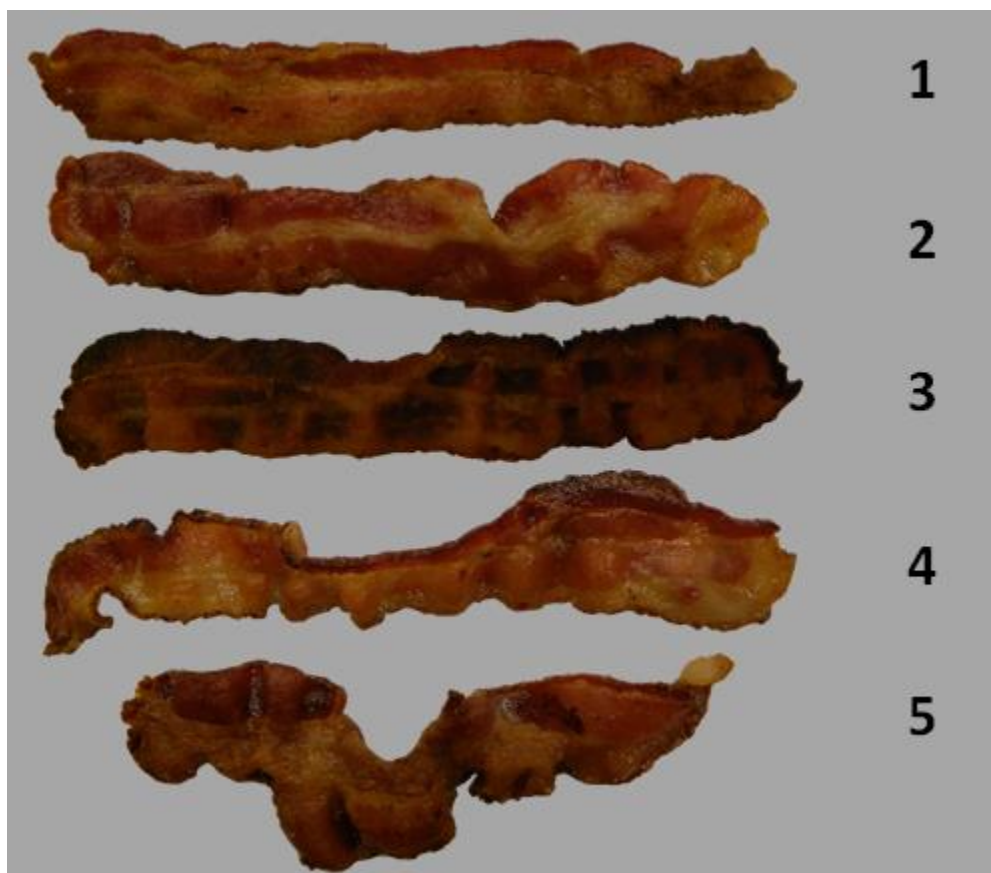
Figure 5-1. Cooked bacon distortion scale.

Table 5-1. Least squares means of raw bacon characteristics

	Iodine Value			
Item	High[A]	Low[B]	SEM[C]	*P*- value
Raw weight, g	22.8	26.2	0.29	<0.05
Total surface area[D], cm^2	33.4	34.4	0.30	<0.05
Lean surface area[E], cm^2	15.5	13.6	0.18	0.05
Fat surface area[F], cm^2	17.9	20.7	0.25	<0.05
Lean:Fat surface area[G]	0.9	0.7	0.01	0.43
Raw length, cm	29.4	28.3	0.14	<0.05
Raw moisture, %	46.4	40.6	0.84	<0.05
Raw fat, %	34.0	42.1	0.80	<0.05
Raw protein, %	13.9	12.1	0.32	<0.05

[A]High iodine value (78.8 to 85.3 g/100g).

[B]Low iodine value (61.5 to 65.5 g/100g).

[C]Standard error of the mean.

[D]Total surface area of the bacon slice.

[E]Surface area of the lean portion in a bacon slice.

[F]Surface area of the fat portion in a bacon slice.

[G]Leat to fat ratio of the surface area in a bacon slice.

Data were collected by B.L. Goehring, J.A. Unruh, J.M. DeRouchey, S.S. Dritz, A.M. Tapian, M.A. Vaughn, K.J. Phelps, and T.A. Houser.

Table 5-2. Least square means of belly dimensions of sample population

| | Iodine Value | | | |
Item	High[A]	Low[B]	SEM[C]	*P*- value
Belly weight, kg	7.5	7.9	0.18	0.08
Belly length, cm	74.4	80.0	0.45	<0.05
Belly width, cm	31.8	32.5	0.42	0.24
Belly thickness, cm	3.4	3.4	0.05	0.36

[A]High iodine value (78.8 to 85.3 g/100g).

[B]Low iodine value (61.5 to 65.5 g/100g).

[C]Standard error of the mean, n = 20 bellies.

Data were collected by B.L. Goehring, J.A. Unruh, J.M. DeRouchey, S.S. Dritz, A.M. Tapian, M.A. Vaughn, K.J. Phelps, and T.A. Houser.

Table 5-3. Least squares means of cooked bacon dimensional response to cooking method

| Item | Iodine Value | | SEM[C] | *P*- value |
	High[A]	Low[B]		
Cooked length, cm	16.4	17.2	0.15	<0.05
Cooked weight, g	6.3	7.00	0.09	<0.05
Cooked surface area[D], cm^2	13.0	13.6	0.12	<0.05
Cooked yield, %	27.7	26.6	0.20	<0.05
Surface area shrink, %	60.6	60.2	0.38	0.43
Length shrink, %	44.4	39.2	0.54	<0.05

[A]High iodine value (78.8 to 85.3 g/100g).

[B]Low iodine value (61.5 to 65.5 g/100g).

[C]Standard error of the mean.

[D]Cooked surface area.

Data were collected by B.L. Goehring, J.A. Unruh, J.M. DeRouchey, S.S. Dritz, A.M. Tapian, M.A. Vaughn, K.J. Phelps, and T.A. Houser.

Table 5-4. Least squares means of cooked bacon dimensional response to cooking method

Item	Cooking Appliance[A]			SEM[B]	*P*- value
	Griddle	Microwave	Oven		
Cooked length, cm	16.4[b]	16.5[b]	17.3[a]	0.18	<0.05
Cooked weight, g	6.9[a]	6.4[b]	6.6[ab]	0.11	<0.05
Cooked area, cm^2	13.0[b]	13.1[b]	13.8[a]	0.15	<0.05
Cooked yield, %	28.0[a]	26.0[c]	27.3[b]	0.24	<0.05
Surface area shrink, %	61.3[a]	61.1[a]	59.0[b]	0.45	<0.05
Length shrink,%	43.4[a]	42.4[a]	39.5[b]	0.65	<0.05

[A]Values within a row with different letters are significantly different ($P < 0.05$).

[B]Standard error of the mean.

Data were collected by B.L. Goehring, J.A. Unruh, J.M. DeRouchey, S.S. Dritz, A.M. Tapian, M.A. Vaughn, K.J. Phelps, and T.A. Houser.

Table 5-5. Iodine value and cooking method interactions on bacon distortion

Item	Griddle High[B]	Griddle Low[C]	Microwave High	Microwave Low	Oven High	Oven Low	SEM[D]	P- value[A] APP[E] × IV
Distortion score[F]	3.5[a]	2.8[b]	3.0[b]	1.7[c]	1.6[c]	1.3[d]	0.11	<0.05
Crest number[G]	11.2[b]	10.9[b]	14.6[a]	12.0[b]	8.8[c]	7.7[c]	0.47	<0.05

[A]Values within a row with different letters are significantly different ($P < 0.05$).

[B]High iodine value (78.8 to 85.3 g/100g).

[C]Low iodine value (61.5 to 65.5 g/100g).

[D]Standard error of the mean.

[E]Cooking appliance.

[F]Distortion score 1= Flat slice of bacon; 5 = extreme curling of bacon slice.

[G]The number of crests in a cooked bacon slice.

Data were collected by B.L. Goehring, J.A. Unruh, J.M. DeRouchey, S.S. Dritz, A.M. Tapian, M.A. Vaughn, K.J. Phelps, and T.A. Houser.

Table 5-6. Least squares means of distortion measurements for iodine value

Item	Iodine Value			
	High[A]	Low[B]	SEM[C]	*P*- value
Distortion Score[D]	2.8	1.9	0.06	<0.05
Crest Number[E]	11.5	10.2	0.27	<0.05
Crest Frequency[F]	1.6	2.0	0.06	<0.05
Bacon Distortion Index[G]	1.5	2.2	0.12	<0.05

[A]High iodine value (78.8 to 85.3 g/100g).

[B]Low iodine value (61.5 to 65.5 g/100g).

[C]Standard error of the mean.

[D]Distortion score 1= Flat slice of bacon; 5 = extreme curling of bacon slice.

[E]The number of crests in a cooked bacon slice.

[F]Crest frequency defined as cooked length/crest number.

[G]Cooked bacon distortion index defined as cooked bacon frequency × average crest distance.

Table 5-7. Least squares means of distortion values for cooking appliance

Item	Cooking Appliance[A]			SEM[B]	P- value
	Griddle	Microwave	Oven		
Distortion Score[C]	3.2[a]	2.4[b]	1.5[c]	0.08	<0.05
Crest Number[D]	11.1[b]	13.3[a]	8.2[c]	0.32	<0.05
Crest Frequency[E]	1.7[b]	1.4[c]	2.4[a]	0.07	<0.05
Bacon Distortion Index[F]	1.5[b]	1.2[c]	2.8[a]	0.14	<0.05

[A]Values within a row with different letters are significantly different ($P < 0.05$).

[B]Standard error of the mean.

[C]Distortion score 1= Flat slice of bacon; 5 = extreme curling of bacon slice.

[D]The number of crests in a cooked bacon slice.

[E]Crest frequency defined as cooked length/crest number.

[F]Cooked bacon distortion index defined as cooked bacon frequency × average crest distance.

Data were collected by B.L. Goehring, J.A. Unruh, J.M. DeRouchey, S.S. Dritz, A.M. Tapian, M.A. Vaughn, K.J. Phelps, and T.A. Houser.

Table 5-8. Least squares means of proximate analysis of cooked bacon with different iodine values.

Item	Iodine Value High[A]	Low[B]	SEM[C]	P- value
Moisture, %	6.2	6.1	0.68	0.90
Fat, %	32.6	37.6	0.80	<0.05
Protein, %	52.4	49.3	0.74	<0.05

[A]High iodine value (78.8 to 85.3 g/100g).

[B]Low iodine value (61.5 to 65.5 g/100g).

[C]Standard error of the mean.

Data were collected by B.L. Goehring, J.A. Unruh, J.M. DeRouchey, S.S. Dritz, A.M. Tapian, M.A. Vaughn, K.J. Phelps, and T.A. Houser.

Table 5-9. Least squares means of proximate analysis of cooked bacon cooked with different cooking appliances

Item	Cooking Appliance[A] Griddle	Microwave	Oven	SEM[B]	P- value
Moisture, %	5.0	7.4	6.1	0.81	0.13
Fat, %	37.8[a]	33.4[b]	34.1[b]	0.95	<0.05
Protein, %	49.6	51.2	51.4	0.89	0.43

[A]Values within a row with different letters are significantly different ($P < 0.05$).

[B]Standard error of the mean.

Data were collected by B.L. Goehring, J.A. Unruh, J.M. DeRouchey, S.S. Dritz, A.M. Tapian, M.A. Vaughn, K.J. Phelps, and T.A. Houser.

Table 5-10. Least squares means of fatty acid composition of cooked bacon, cooked with different iodine values

Item	Iodine Value High[A]	Low[B]	SEM[C]	P- value[D]
Myristic acid (C14:0), %	1.5	1.7	0.03	<0.05
Palmitic acid (C16:0), %	22.2	26.1	0.25	<0.05
Palmitoleic acid (C16:1), %	2.4	2.9	0.08	<0.05
Margaric acid (C17:0), %	0.4	0.4	0.01	<0.05
Stearic acid (C18:0), %	8.4	11.3	0.33	<0.05
Oleic acid (C18:1n9c), %	35.2	38.9	0.50	<0.05
Vaccenic acid (C18:1n7), %	3.1	3.6	0.19	0.06
Linoleic acid (C18:2n6t), %	22.8	11.6	0.42	<0.05
α-Linolenic acid (C18:3n3), %	0.8	0.4	0.02	<0.05
Gondoic acid (C20:1),%	0.6	0.8	0.03	<0.05
Eicosadienoic acid (C20:2), %	0.8	0.5	0.02	<0.05
Total SFA[E], %	32.7	39.9	0.36	<0.05
Total MUFA[F], %	41.9	46.8	0.38	<0.05
Total PUFA[G], %	24.7	12.7	0.45	<0.05
Iodine value[H], g/100g	77.9	61.5	0.62	<0.05

[A]High iodine value (78.8 to 85.3 g/100g).

[B]Low iodine value (61.5 to 65.5 g/100g).

[C]Standard error of the mean.

[D]Values within a row with different letters are significantly different ($P < 0.05$).

[E]Total saturated fatty acids, expressed as percentage of total fatty acids present.

[F]Total monounsaturated fatty acids, expressed as a percentage of total fatty acids present.

[G]Total polyunsaturated fatty acids, expressed as a percentage of total fatty acids present.

[H]Calculated from fatty acid analysis using AOCS (1998) protocol: (C16:1 × 0.95) + (C18:1 × 0.86) + (C18:2 × 1.732) + (C18:3 × 2.616) + (C20:1 × 0.785) + (C22:1 × 0.723).

Data were collected by B.L. Goehring, J.A. Unruh, J.M. DeRouchey, S.S. Dritz, A.M. Tapian, M.A. Vaughn, K.J. Phelps, and T.A. Houser.

Table 5-11. Least squares means of fatty acid composition of cooked bacon cooked with different cooking appliances

Item	Cooking Appliance[A]			SEM[B]	*P*- value
	Griddle	Microwave	Oven		
Myristic acid (C14:0), %	1.6	1.6	1.6	0.03	0.61
Palmitic acid (C16:0), %	23.9	23.7	24.8	0.30	0.06
Palmitoleic acid (C16:1), %	2.6	2.7	2.7	0.11	0.78
Margaric acid (C17:0), %	0.4	0.4	0.4	0.01	0.83
Stearic acid (C18:0), %	9.8	10.0	9.9	0.39	0.96
Oleic acid (C18:1n9c), %	37.2	37.2	36.9	0.60	0.91
Vaccenic acid (C18:1n7), %	3.1	3.3	3.7	0.23	0.22
Linoleic acid (C18:2n6t), %	17.6	17.5	16.4	0.50	0.13
α-Linolenic acid (C18:3n3), %	0.6	0.6	0.6	0.03	0.06
Gondoic acid (C20:1),%	0.7	0.7	0.7	0.03	0.73
Eicosadienoic acid (C20:2), %	0.7	0.7	0.6	0.02	0.22
Total SF[C], %	36.1	35.7	37.1	0.43	0.06
Total MUFA[D], %	44.2	44.4	44.5	0.45	0.91
Total PUFA[E], %	19.1	19.2	17.8	0.54	0.13
Iodine value[F], g/100g	70.2	70.6	68.2	0.74	0.06

[A]Values within a row with different letters are significantly different ($P < 0.05$).

[B]Standard error of the mean.

[C]Total saturated fatty acids, expressed as percentage of total fatty acids present.

[D]Total monounsaturated fatty acids, expressed as a percentage of total fatty acids present.

[E]Total polyunsaturated fatty acids, expressed as a percentage of total fatty acids present.

[F]Calculated from fatty acid analysis using AOCS (1998) protocol: (C16:1 × 0.95) + (C18:1 × 0.86) + (C18:2 × 1.732) + (C18:3 × 2.616) + (C20:1 × 0.785) + (C22:1 × 0.723).

Data were collected by B.L. Goehring, J.A. Unruh, J.M. DeRouchey, S.S. Dritz, A.M. Tapian, M.A. Vaughn, K.J. Phelps, and T.A. Houser.

Chapter 6 - Future Research

Results from Chapter 3 show that fat from high IV bellies contain a greater amount of collagen when compared to low IV bellies. This is significant information to consider for bacon slicing. In beef research it is commonly understood that increasing the collagen content of beef increases the force required to shear through it. It is possible that the increased collagen content in the fat causes increased stress on the seam between the fat and the lean layers causing slicing breaking to occur. The next step in this area of research would be to statistically relate the collagen to slicing yields and to investigate animal production practices that can influence collagen content in the fat. This chapter also showed a statistical relation between belly firmness and adipocyte characteristics. This area of query would be better answered utilizing diet manipulation studies as opposed to collecting bellies that originate from various farms with various genetics and management practices.

Chapters 4 and 5 show factors that contribute to bacon distortion. Proximate composition of a bacon slice is a factor in influencing distortion. Though these studies quantified the entire lean and fat portions, it seems that the area of the cutaneous trunci might be an important area to quantify because bacon slices that had the smallest area of cutaneous trunci appeared to have the highest distortion score, while bacon slices with the largest cutaneous trunci appeared to produce bacon slices with the most crests. As the crest frequency and bacon distortion index scores weren't an exact replication of subjective distortion scores, it is worth using the cutaneous trunci length or surface area in the crest frequency and bacon distortion index scores. Knowing that proximate composition and cooking appliance contribute to distortion scores; it is now possible to create bacon with a spread of distortion scores with relative ease. Thus we have the ability to create bacon for consumer panels to evaluate the consumer perception of cooked bacon and determine if a new quality attribute to cooked bacon exists. Since cooking protocols exist for various cooking appliances it would also be beneficial to use these in sensory panels in order to make cooking recommendations to maximize the sensory properties of bacon.