RESEARCHREPORT

PORK QUALITY

Title: Quality Lean Growth Modeling-Bacon Quality Assessment – **NPB #97-1999**

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INTRODUCTION

The belly, one of the primal cuts of pork, represents about 12-15% of the carcass weight, and when cured, contributes substantially to the total value of the pork carcass. Bacon commands a premium price despite low muscle content because pork processors manufacture an extremely palatable product and marketing strategies have created a very favorable cooked product image. In 1995, consumers bought 725 million pounds of retail bacon (deli and prepackaged) for $1.2 billion (Salvage, 1997). The average household purchased more than 7 pounds of bacon per year, spending about $12 for this product. Pork bacon was reported to comprise 85% of the total amount of bacon sold (Salvage, 1997).

This study was designed to increase the research data base for bacon as a part of the NPPC project titled ***"Quality Lean Growth Modeling".*** Major goals included the determination of quantitative and qualitative differences in sliced bacon from those pigs. Ingredients and processing procedures continue to change as well as the introduction of pre-cooking technologies.

There were two major thrusts of the project. The first thrust targets the base data to be obtained from all the pigs in the ***"Quality Lean Growth Modeling Project"***. This phase of the overall project was designed to address the qualitative and quantitative criteria of bacon in pigs outlined in the stratification of that project. The second thrust of the project is to expand the information base to focus directly on the commercial bacon industry. Since bacon is viewed as a potential growth area for the pork industry by many people, specific questions to increase understanding and assistance to the bacon industry was important. Specific questions in include the anticipated differences in lean and fat content in pigs, major reduction in the total fat of the pig, introduction of microwave cookery, pre-cooked bacon for food service uses. These changes in bacon use as an accompaniment to other foods, particularly salads and sandwiches is a growth area. This second thrust expands the research findings and new data will supplement early bacon work, much of the work done prior to the 1980's.

Quality Lean Growth Modeling Project

The Quality Lean Growth Modeling (QLGM) project was funded and launched by the National Pork Board in 1996. The goal of this project was to improve the efficiency of production and quality of pork. The QLGM project was comprised of 1,588 pigs in three test groups. The design of the project included genetic line, diet, sex, and end-point slaughter weight and a seasonal replication.. This project also provided the chance to explore lean growth models that surpass the current models. These models have been explored up to the 250 pound range but not further. Interest from packers to produce heavier market weight hogs prompted the study of pig performance up to 330 pounds. Because of genetic variation in the pigs, the Fat-Free Lean Index (FFLI) equations can be updated (Goodwin, 1998).

The other objective of this project was to improve pork quality. This involved the evaluation of three primals from the pork carcass, the ham, loin, and belly. Iowa State University evaluated the loin samples for color, pH, drip loss, and intramuscular fat content. They also cooked chops to determine tenderness, juiciness, and cooking loss of fresh pork. Texas A&M University evaluated cured hams for color, pH, and intramuscular fat. The three muscle groups were processed and evaluated for cooking yields, sliceability, and sensory characteristics (Goodwin, 1998). In relation to the bacon study, the type of bacon produced (foodservice or retail) was evaluated for the incidence of shattering, lean and fat color, and cooking yields and distortion.

Genetic Lines

Six genetic lines of pigs were chosen by the NPPC Genetic Programs Committee to represent a cross section of genetic types in the pork industry. A report by the National Genetic Evaluation Program (NGEP) provided information on the different genetic types. The six genetic lines used in this project are the following: Berkshire, Duroc, Danbred, Newsham Hybrid, Hampshire, and DeKalb. The design of this project does not allow for comparison between genetic lines due to the genetic sampling scheme (Goodwin, 1998; Johnson, 1998). The goal of using the different lines was to analyze the response of the genetic types to different nutritional programs and off-test weights. For this reason the six genetic lines were identified as lines 1 through 6 with no particular order to ensure anonymity. The post test classification of the six genetic lines can be seen in Appendix A (Goodwin, 1998).

Diet

Four nutritional programs were fed in this study. Levels of metabolizable energy (ME), minerals, and vitamins were held constant within the weight ranges. Corn and soybean meal were used as the lysine source in the diets. Lysine levels varied in the diets as seen in Appendix B. Diet 1 contained the highest level of lysine which exceeded National Research Council [NRC] standards. Diet 4 contained the lowest level of lysine which was deficient by NRC standards. Diets 2 and 3 represented intermediate-high and intermediate-low levels of lysine respectively. At the beginning of the test, diet 1 contained 1.25% lysine. Diets 2, 3, and 4 decreased in lysine content in increments of 0.15%. As the pigs progressed in weight, the lysine levels were adjusted. At specific weights, the lysine level in the diet was decreased by 0.15%. Lysine levels were reduced by increasing corn levels and decreasing soybean levels (Robison, 1998; Johnson, 1998). The diets were fed in ground form at a size smaller than 750 microns. Choice white grease was used as the source of added fat (Goodwin, 1998).

Sex

Gilts and barrows both were used in this study to closely resemble the conditions in the pork industry. The sex of the pigs was balanced as closely as possible among the six genetic lines and in the three end-point slaughter weight groups.

Slaughter Weight Groups

Three end-point slaughter weights were used in this study. The slaughter weights were: 114 kg/250 lb., 132 kg/290 lb., and 150 kg/330 lb. As mentioned earlier, the use of heavier slaughter weights was the result of interest by packers for producers to market heavier market weight hogs. The data from the heavier hogs will allow for lean growth models to be established for those weight ranges (Goodwin, 1998).

Growth Trial Protocol

In this study, three pigs were entered from each litter. at between 8 and 19 days of age. The pigs were commingled and segregated in early weaning nurseries (SEW). At this time, the pigs were assigned to one of the three slaughter weights and penned by genetic type and size. Once the pigs reached 40 pounds, they were moved to the grower building. At 80 days of age, the pigs were moved to the specialized test facility which contained the FIRE (Feed Intake Recording Equipment). The FIRE system is an electronic feeding system which delivers and weighs daily feed intake of each pig by using electronic identification eartags. Feed amounts provided by the

FIRE system were weighed by scale cart to ensure accuracy. This electronic equipment allowed for collection of daily intake and weight data on each individual pig. Each pen of pigs was randomly assigned to one of the four nutritional programs. As the pigs progressed in weight, the lysine levels were adjusted as previously stated(Appendix B). The pigs remained in this building until reaching the desired slaughter weight. Some pigs did not reach the desired end-point slaughter weight due to slow growth or the protocol of selling the last pig in the pen (Goodwin, 1998; Johnson, 1998). This growth trial was conducted at the Minnesota Swine Testing Station due to the availability of facilities (Goodwin, 1998).

Bacon Type

Bacon type was one variable examined in the bacon study. Retail bacon was produced with a “simple” pickle (Appendix C). No liquid smoke was used in the production of pickle for retail bacon. Retail bacon is also sliced thicker. The goal in slicing retail bacon was to achieve 9 slices per inch.Foodservice bacon was produced with a “heavy” pickle which included liquid smoke and higher amounts of sugar. Foodservice bacon was sliced to achieve 13 slices per inch.

Origin of Bellies

The pigs were slaughtered at Geo. A. Hormel Inc., Austin, MN in three different groups. Approximate slaughter dates were July-September 1996, February- April 1997, and September-November 1997. The carcasses were fabricated at Geneva Meats, Geneva, MN. For the purposes of this study, a NAMP #409- PORK BELLY, SKINLESS (Appendix D) was used. After fabrication, the bellies were individually vacuum packaged, packed five per box, and shipped frozen to the University of Nebraska Meat Laboratory, Lincoln, NE.

Bacon Attributes of Interest

The bacon portion of QLGM project explored four distinct areas relating to bacon. The first area of interest was bacon processing parameters. Effects of th QLGM study parameters on smokehouse yields, slice yields, bacon slab length, total yield and curing properties were determined. Parameters such as shattering (defined as the breaking of fat tissue perpendicular to the length of the bacon slice), fatty acid profile of the raw bellies and lean and fat color were examined (machine vision analysis system) were examined.

Increased popularity of pre-cooked bacon prompted an examination of the effects of modern pork production parameters on cooked bacon. USDA regulations currently require a 40% or less cook yield for pre-cooked bacon. Because of thus the effects of two different cooking methods, belt and microwave, on pre-cooked bacon were also evaluated. Distortion and shrink of bacon due to cooking was examined.

CHAPTER 1 - BACON MANUFACTURE

MATERIALS AND METHODS - Bacon Manufacture

A. Belly Receiving and Storage

Frozen bellies from replication 1 and 2 were received from Geneva, MN on July 25, 1997. Replication 3 was received on April 14, 1998. Frozen bellies were held at -29EC/-14EF prior to sorting and processing. Bellies were sorted in descending order based on percent lean of the carcass and divided randomly into one of two types of bacon, foodservice or retail.

B. Defrosting Bellies

For tempering purposes, frozen bellies were placed in a 1.6^{E}C/35EF cooler for two days before injection. On the day of injection, bellies were removed from the tempering cooler, removed from vacuum bags. A one inch (2.54 cm) sample was removed from the anterior end of the belly, vacuum packaged, and frozen (-29EC/-14EF) for subsequent fatty acid analysis. Any remaining cartilage from rib removal was removed with a knife. Identification tags were attached to the bellies. The bellies were then weighed and placed in stainless steel tanks of cold water (>15EC) agitated with air, allowed to thaw(,1 hr) until they were pliable with no ice crystals, removed from the tank and any remaining skin and teat line was removed with a knife to comply with specifications and the belly weight was adjusted accordingly.

C. Pickle Production

Each batch of 40 bellies required 90.9 kg/200 lbs. of pickle (Appendix C). The order of ingredient addition to water is as follows: phosphate (BK-450, BK Ladenburg Corp., Simi Valley, CA), salt (Morton Culinox 999, Chicago, IL.), sodium nitrite (Heller Modern Cure-6.25% NO_2, Heller Seasonings and Ingredients Inc., Bedford Park, IL), sugar (granulated), erythorbate (PMP Eribate, Fujisawa Pharmaceutical Co. Ltd., Tokyo, Japan), and liquid smoke (Red Arrow- Aro P-50, Red Arrow Products Co. Inc., Manitowoc, WI) for foodservice bacon only. Ingredients were added individually and mixed with a Rotostat Model 80XP63SS (Admix, Inc., Londonderry, NH) at 2500 rpm until dissolved. After liquid smoke addition for foodservice bacon, the pickle was mixed for five minutes at 1500 rpm to prevent foaming. Once the pickle was mixed, it was transferred to the pickle tank of the injector.

D. Belly Pumping

A Townsend multineedle bacon injector Model 1450 (Townsend Engineering, Des Moines, IA) was used to inject bellies with the pickle. The identification tag was removed from each belly before it entered the injector and then replaced after exiting the injector. Bellies were placed in the injector fat side down and pumped to a target 112% of green weight. Bellies were weighed immediately after pumping to determine actual percent pump. A bacon comb was inserted in the posterior end of the belly and hung on a smokehouse truck in four rows of ten bellies each. Bellies were allowed to hang for a minimum of one hour before thermal processing.

E. Thermal Processing

The bellies were thermally processed in an ALKAR smokehouse. The thermal processing schedule was developed with the assistance of ALKAR, Inc. (ALKAR, Inc., Lodi, WI) and Red Arrow Products, Inc. (Red Arrow Products Co., Inc., Manitowoc, WI). The smokehouse schedule is shown in Appendix E. After processing, the bellies were showered and chilled overnight in a 3EC/37EF cooler. On the following day, bellies were individually weighed to determine smokehouse yield. The bellies were vacuum packaged for storage.

F. Pressing and Slicing Bacon

All bacon slabs were removed from packaging and temperature was recorded with a digital probe-type thermocouple thermomter (Omega Eng. Inc., Stamford, CT); identification tags were removed but kept with the belly, the slab weight recorded. Slabs were then pressed with an Anco Model 1411 press(Cherryburrell, Louisville, KY) and sliced(Model 3027, Cashin, Mokena, IL). After slicing, the belly complete with ends and pieces was placed on a cardboard slip-sheet and bagged in a poly bag, placed in a cardboard box for return transport to the UNL Meat Laboratory and stored at -4.4^{o}C/24^{o}F until further evaluation and sampling.

Sliced Bacon Slab Evaluation

The sliced bacon slab was divided into three sections: incomplete anterior ends, incomplete posterior ends and sliced center bacon (complete slices). The incomplete slices from anterior and posterior ends were weighed separately and recorded. Center sliced slab weight was the weight of all complete slices. Total yield and slicing yield were calculated: total yield = (center weight/initial weight) x 100; slicing yield = (center weight/cooked weight) x 100. The average smokehouse yield for all 1,527 bellies was 101.2%. Sliced slab length was measured from the anterior to posterior ends at the center of the belly.

Slab Sampling

Belly length was measured from the anterior to posterior end at a point halfway between the dorsal and ventral edges of the sliced slab. Slab width was measured from the dorsal to ventral edge at a point halfway between the anterior and posterior ends. The length of the slab was used to divide the slab into 5 locations(A-E). The sampling diagram is shown in Appendix F. Total length was divided by five to determine the five sampling locations. This procedure accommodated variable weight and length bellies. Samples from each of the five locations were labeled, and packaged for subsequent evaluation. Sampling started at the anterior end of the belly. A total of 22 slices were removed from each location A, B, C, D, and E. From each location, the first two slices were removed for video imaging analysis and subsequent proximate analysis. Five slices were removed for double belt cooking. Five slices were removed for microwave cooking. Ten slices were removed to make two backup samples for cooking or other purposes. Video imaging samples were stacked on plastic dividers and wrapped in white, polyethylene-coated butcher paper (Loxol freezer paper, James River Corp., Parchment, WI). The samples were then boxed and stored in the dark at -4.4EC/24EF. All cooking and backup samples were vacuum packaged and labeled. Double belt cooking and microwave samples were stored at 1EC/34EF. Back-up samples were frozen (-29EC/-14EF) (McEver,1999)

Proximate Analyses

Proximate composition [moisture, fat and ash and protein by difference] for diets 1 and 4 was performed on two slices for each of the five locations in the sliced bacon slab. Proximate composition for diets 2 and 3 were a composite of ten slices (2 slices x 5 locations) (Wenther and Mandigo, 1999). Proximate analysis was conducted in duplicate following AOAC (AOAC, 1990) methods for fat (ether extraction) and by use of a thermogravimetric analyzer (Leco Corp., St. Joseph, MI) for moisture and ash analysis (Ross and Mandigo, 1999).

Statistical Analyses

Data were subjected to analysis using the General Linear Model (SAS, 1990) to evaluate the effect of genetic line, diet, sex, slaughter weight and type of bacon on bacon processing parameters measured. The study was a 6(genetic line) x 4(diet) x 3(slaughter weight group) x 2(sex) x 2(bacon type) factorial design. Significant ($P < 0.05$) main effects and two way interactions were analyzed. Smokehouse yield was statistically analyzed using percent pump as a covariant. Slicing yield was statistically analyzed using temperature as a covariant

RESULTS AND DISCUSSION - BACON MANUFACTURE

The Effect of Genetic Line

Genetic line exerted by far the most dramatic effects on bacon processing parameters and proximate composition. Means by genetic line for each processing parameter are shown in Table 1 and proximate composition is shown in Table 2. Lines 1 and 4 had significantly lower pumping yield when compared to all other lines ($P < 0.05$) and were significantly different from each other ($P < 0.05$). Line 1 had the highest backfat and the smallest loineye area (Robison, 1998). Line 1 had the highest percent fat, the lowest percent moisture, ash and protein and was significantly different when compared to all other lines ($P< 0.05$). Injected pickle solutions seem to be rapidly absorbed into muscle and to a much lesser extent in fat. Lines 1 and 4 were light muscled and fat, therefore they did not "pick-up" as much pickle giving them the lowest percent pump. This is consistent with Saffle and Bratzler (1959) who reported that fatter pork carcasses produced bellies which sustained a lower level of curing during processing. Line 2 had the highest percent pump and was significantly different from lines 1, 3 and 4 ($P < 0.05$). Yield of the green and cured belly is inversely related to lean content (Kemp *et al.*, 1969; Fredeen *et al.*, 1975; Stiffler *et al.*, 1975; Jabaay *et al.*, 1976; McMillan *et al.*, 1977), which is consistent with our results.

Practical commercial differences were not found in the smokehouse yields for genetic line. Smokehouse yield and total yield were not reported due to interactions. Line 1 had the highest percent fat, lowest percent moisture, ash and protein ($P < 0.05$) in bacon proximate composition and therefore did not lose as much weight during the heating process. These results concur with Saffle and Bratzler (1959) who reported that fatter pork carcasses produced bellies which sustained lower cooking losses during processing.

Lines 2 and 5 had the lowest percent fat and were significantly different from all other lines ($P < 0.05$) which explains the higher pumping yields. These results reinforce the belief that injected pickle solutions are rapidly absorbed into muscle and to a lesser extent in fat. Lines 2 and 5 had the highest percent moisture and protein and were significantly different from all other lines ($P < 0.05$). Moisture and protein were inversely proportional to fat for line effects.

All bacon slabs were pressed to a uniform width of 25.4 cm. Sliced slabs tended to maintain their pressed width after slicing and prior to evaluation. Line 1 ranked the highest in bacon slab length and was not significantly different than line 3 ($P > 0.05$). Lines 5 and 4 were not significantly different than lines 3 and 2 ($P > 0.05$). Line 6 was significantly shorter in bacon slab length when compared to all other lines ($P < 0.05$).

The Effect of Diet

Diet effects were significant for three traits as displayed in Table 1, probably due to the lowest lysine levels. Percent pump was statistically significant, but was not commercially significant. Diets that yielded fatter bellies exhibited lower pumping percent. Again, these result agree with Saffle and Bratzler (1959) who reported that fatter pork carcasses produced bellies which sustained a lower level of curing during processing.

Diet 4 had a highly significant smokehouse yield when compared to all other diets ($P > 0.05$). This was expected as diet 4 also had the highest fat content. Diet 2 had the lowest smokehouse yield and was significantly different from diets 3 and 4 ($P<0.05$), but was not significantly different from diet 1 ($P>0.05$). Diet 4 had the highest slicing yield and total yield, but was not significant when compared to diets 1 and 3 ($P>0.05$). Diet 2 had the lowest slicing yield and total yield and was significantly lower when compared to diets 1 and 4 ($P>0.05$). Diet 3 was intermediate in slice yield and total yield which was not significantly different from all other diets ($P>0.05$). Diet 4 had the highest percent fat and lowest percent protein, thus higher yields could be expected. Therefore, diet 4 had the highest total yield. Bellies that were fatter and had less muscle also had a higher total yield which was consistent with Kemp *et al.* (1969), Fredeen *et al.* (1975), Stiffler *et al.* (1975), Jabaay *et al.* (1976), and McMillan *et al.* (1977) who reported that the yield of the green and cured belly is inversely related to lean content. Although the smokehouse yield, slicing yield, and total yield were the highest with diet 4, the impact would be detrimental to the lean to fat ratio.

Diet effects on proximate composition are shown in Table 2. With the exception of ash, all parameters were analyzed as main effects as well as for significant interactions. Diet 4 had the lowest fat content and was significantly different when compared to all other diets ($P>0.05$). This is consistent with Freisen et al. (1996), who reported that carcass lipid growth was reduced ($P<0.01$), and a greater average daily gain was achieved as a result of increased digestible lysine. Diet 4 also had the lowest moisture and protein content and was significantly different from all other diets ($P<0.05$). Numerous previous studies have reported the beneficial effects of higher levels of dietary protein on carcass lean tissue. For example, Davey and Morgan (1969) reported that pigs fed a 20% protein diet produced significantly more lean than pigs fed a 12% protein diet. Gilster and Wahlstrom (1973) also reported increased lean content in pigs fed higher levels of protein in diets ranging from 10 to 20% protein. Irvin *et al.* (1975) also observed an increase in percent lean content as dietary protein level increased from 12 to 18%. Diet 4 had the lowest ash content and was significantly different from all other diets ($P < 0.05$). This may be due to a low pumping percentage, and thus less salt was injected into the belly. Crenshaw *et* al. (1994) reported that although carcass crude protein is greater with increased digestible lysine, the cost of achieving maximum protein gain was not economically feasible. Therefore, economics will determine the level of lysine that can be offered for maximum profit.

The Effect of Sex

Sex of the animals significantly affected slicing yield and total yield (Table 1). Barrows had a significantly higher slicing yield when compared to gilts ($P < 0.05$). Barrows also had a significantly higher total yield when compared to gilts ($P < 0.05$). As barrows had a higher slicing yield, it was expected that the barrows would also have a higher total yield. This is due to the fact that barrows were fatter in the belly when compared to gilts. Sex effects on proximate composition are shown in Table 2. Percent fat, moisture and protein were analyzed as main effects as well as interactions for the effect of sex. Barrows had a higher percent of fat and were significantly different from gilts ($P < 0.05$). Gilts had a higher percent moisture and protein and were significantly different from barrows ($P < 0.05$). Moisture and protein were inversely proportional to fat for line effects. Fredeen *et* al. (1975) revealed that gilts had 2.7% less fat in the belly than barrows, which agrees with the findings in this study. Bereskin and Davey (1978) reported that gilt carcasses were leaner than barrow carcasses, but barrows deposited lean tissue faster.

The Effect of Slaughter Weight

Many processing parameters were significantly affected by slaughter weight (Table 1) and were analyzed as main effects as well as for significant interactions. All slaughter weight groups were significantly different in smokehouse yield, total yield and bacon slab length when compared to each other ($P < 0.05$). As slaughter weight increased, smokehouse yield, total yield and bacon slab length significantly increased as would be expected. The 114 kg slaughter weight was significantly different in slice yield from the 150 kg slaughter weight ($P < 0.05$), but the 132 kg slaughter weight was not significantly different from all other slaughter weights. Weight group was highly significant for all proximate composition parameters (Table 2). As expected, for heavier pigs, fat in the bellies increased and moisture, protein and ash decreased. Fredeen (1980) and Carpenter *et al.* (1963) reported the same effect for weight of pigs on the fat content of bellies. These data are consistent with Freisen *et al.* (1996), who reported that carcass crude protein decreased linearly, whereas carcass lipid gain increased linearly as a result of greater body weight.

The Effect of Bacon Type

The type of bacon produced had a significant effect on smokehouse yield (Table 1). Both types of bacon (foodservice and retail) were significantly different in smokehouse yield when compared to each other ($P < 0.05$). Retail bacon had a significantly higher smokehouse yield when compared to foodservice ($P < 0.05$). Callow (1956) stated that by increasing the strength of salt solution, it is possible to obtain a much greater gain in weight; and higher yields could be expected. Although brines with more solids (salt and sugar) are assumed to yield products with a higher smokehouse yield, this was not the case in this study. This may be due to higher osmotic pressure in the foodservice bacon and thus more water was removed from the belly (Lawrie, 1991). Retail bacon also had a significantly higher slice yield and total yield when compared to foodservice bacon ($P<0.05$). This is expected due to higher smokehouse yield in retail bacon. Foodservice bacon had a higher percent ash when compared to retail bacon ($P<0.05$), as shown in Table 2.

The Effect of Line * Sex Interaction

Line interacted with sex to influence smokehouse yield as seen in Table 3 and Figure 1. Line 3 was the only genetic line where there was a significant interaction between barrows and gilts.

The Effect of Line * Bacon Type Interaction

Slicing yield (Table 4) and total yield (Table 5) were influenced by the interaction of line and bacon type. Only lines 1 and 5 were not significantly different in slice yield and total yield when comparing foodservice and retail bacon. In both instances, significant differences were observed in all other lines with foodservice being lower in slicing yield and total yield. In general, retail bacon had a higher slicing yield when compared to foodservice bacon across all lines, with the exception of lines 1 and 5.

The Effect of Diet * Sex Interaction

Diet interacted with sex to influence fat (Table 6), moisture (Table 7) and protein (Table 8). For barrows, diets 1 and 2 differed significantly from diets 3 and 4 in fat content. For gilts, the only diet with a significantly different for fat was diet 4 (P < 0.05). As lysine level decreased, the percent fat increased in barrows. Gilts followed the same pattern with exception of diet 3. Overall, barrows had a lower percent moisture across all diets, as expected with higher fat content and a lower percent protein than gilts. As lysine level decreased, the percent moisture decreased in barrows. Both barrows and gilts had significantly lower protein in diet 4. In general, barrows had less protein than gilts.

The Effect of Diet * Slaughter Weight Interaction

Diet interacted with slaughter weight to influence smokehouse yield as shown in Table 9. Smokehouse yield increased as weight group increased in diets 1, 2 and 3. In diet 4, the 114 kg weight group was not significantly different (P > 0.05). The interactions between all diets and the 150 kg weight group were significantly different when compared to all other interactions, with the exception of the diet 4 *132 kg weight group interaction (P < 0.05). Bacon slab length was also affected by the diet * slaughter weight interaction (Table 10). Bacon slab length increased as weight group increased across all diets.

The Effect of Slaughter Weight * Bacon Type Interaction

Slaughter weight interacted with bacon type to influence slicing yield (Table 11) and total yield (Table 12). Retail bacon did not significantly increase in slicing yield as weight group increased (P > 0.05). For foodservice bacon, the 132 kg and 150 kg weight groups had significantly higher slicing yields than the 114 kg weight group (P < 0.05). The results of the retail bacon showed a significantly higher total yield in the 150 kg weight group. However, for the foodservice bacon, the total yield increased as weight group increased.

CONCLUSIONS - BACON MANUFACTURE

This study indicates that genetic line exerted by far the most dramatic effects on bacon processing parameters measured. Lines yielding fatter bellies (1 and 4) exhibited lower pumping yields. Although line was discussed for many processing parameters, practical commercial differences did not exist. Line 1 had the highest smokehouse yield, but other carcass characteristics were not economical for line 1 (Robison, 1998)]. The results suggest that the increase in smokehouse yield is a function of the fat content in the bellies.

Diet 4 data results present the same response. Diet 4 produced the highest smokehouse yield and total yield, but was detrimental to carcass characteristics such as backfat and loineye area (Robison, 1998). Diet 4 (lowest level of lysine) also had the highest percent fat and lowest percent moisture, ash and protein. These results agree with results published by Robison (1998), who reported that backfat tended to increase as lysine levels decreased. Diet 3 presented adequate smokehouse yield, slice yield and total yield without the economic implications of feeding a diet that is above NRC requirements.

Barrows had a higher percent fat. This was reflected in bacon processing characteristics. Barrows had a higher slice yield and total yield when compared to gilts. As was to be expected, as the pigs increased in weight, bacon processing characteristics such as smokehouse yield, slice yield and total yield also increased. Percent fat also increased and percent moisture, ash and protein decreased as pigs increased in weight. Traditionally, the major limitation to increasing slaughter weights has been the high carcass fat levels observed at heavier weights and the associated deterioration in feed efficiency. These two factors have moderated the rate of increase of slaughter weights over time and were emphasized as being detrimental to both carcass traits and economic benefits (Robison, 1998; Mabry, 1998). Retail bacon had a higher smokehouse yield and total yield when compared to foodservice bacon. It is economical to produce both retail and food service bacon when possible (Johns, 1994; Salvage, 1997). Pork bellies comprise about 12 to 15% of the chilled carcass weight (Carpenter *et al.,* 1963) and represents about 15 to 17% of the total carcass value.

Both genetic type and diet have a major influence on bacon processing characteristics. Bacon processing characteristics such as smokehouse yield and total yield are inversely related to carcass characteristics desired by the producer, packer and consumer. Recommendations should be based on performance and economics of the animal and product being produced as a whole. taking into consideration the value of feed efficiency, growth rate and market costs of primal cuts to determine the genetic line and nutritional program that will offer the most profitable returns (McKissick, 1998). Thus, the potential economic benefits associated with improved lean content may tend to be offset by a reduction in yield of the cured bacon.

Consumer preference studies indicate that lean to fat ratio is the single largest factor used a visual means of selecting bacon (West *et al.,* 1973). Fredeen *et al.* (I 975b) and Stiffler *et al.* (1975) found that leaner bellies produce a higher percentage of “premium slices”, while fatter bellies produce a lower percentage of "premium" bacon slices. Therefore, the initiation of certain classification systems for sorting and identifying bellies or portions of pressed bellies that possess such lean characteristics desired by the consumer should be established. Smith *et al.* (1975)

stated that in-plant classification, after slicing, appears more feasible than physical measurements of green or pressed bacon slabs for identifying differences in bacon leanness.

Table 1. Bacon Production Parameters as Affected by Genetic Line, Diet, Sex, end Weight and Type of Bacon as Main Effects.

Effect	Percent Pump	Smokehouse Yield	Slice Yield	Total Yield	Bacon slab Length (cm)
Line	0.0001	0.0001*	0.7226	0.0088*	0.0001
1	10.31[a]	101.69	91.35	92.49	55.97[d]
2	11.48[d]	100.91	91.13	91.90	54.36[b]
3	11.11[bc]	101.47	91.32	92.62	55.31[cd]
4	10.80[b]	101.05	91.19	91.78	54.51[bc]
5	11.26[cd]	100.68	90.90	91.45	54.58[bc]
6	11.20[cd]	101.18	91.37	92.42	53.27[a]
Diet	0.0194	0.0001*	0.0458	0.0114	0.1522
1	11.22[b]	101.09	91.37[b]	92.25[b]	54.30
2	11.12[b]	100.93	90.77[a]	91.57[a]	54.87
3	10.82[a]	101.22	91.22[ab]	92.04[ab]	55.00
4	10.95[ab]	101.41	91.48[b]	92.58[b]	54.49
Sex	0.7988	0.1142	0.0006	0.0007	0.8131
Gilt	11.02	101.11	91.54[b]	92.48[b]	54.64
Barrow	11.04	101.21	90.88[a]	91.74[a]	54.70
Weight	0.3000	0.0001*	0.0175*	0.0001*	0.0001*
114 kg	11.10	100.20	90.86	90.90	51.50
132 kg	11.07	101.39	91.18	92.21	54.74
150 kg	10.92	101.89	91.59	93.21	57.75
Type	0.1623	0.0001	0.0001*	0.0001*	0.2362
Food Service	11.09	100.95[a]	90.72	91.57	54.53
Retail	10.96	101.37[b]	91.70	92.65	54.81
RMS Error[f]	1.83	1.22	3.89	4.08	4.61

abcd Means within the same column and within a main effect with similar superscripts are not significantly different (P > 0.05).
e P values from Analysis of Variance for each main effect within a variable.
f RMS Error= Root mean square error from Analysis of Variance tables.
* Main effects were not analyzed for significance due to significant interactions.
** Main effects were not analyzed for significance due to significant interactions.

Table 2. Bacon Proximate Composition (percent) as Affected by Genetic Line, Diet, Sex, End Weight and Type of Bacon as Main Effects.

Effect	Fat	Moisture	Ash	Protein
Line	0.0001	0.0001	0.0001	0.0001
1	54.54^{d}	34.21^{a}	1.90^{a}	8.57^{a}
2	42.47^{a}	43.15^{d}	2.29^{e}	11.21^{d}
3	45.55^{b}	40.89^{c}	2.17^{c}	10.55^{c}
4	47.17^{c}	39.70^{b}	2.11^{b}	10.20^{b}
5	42.71^{a}	42.88^{d}	2.24^{de}	11.30^{d}
6	46.25^{bc}	40.42^{bc}	2.23^{d}	10.25^{b}
Diet	0.0001*	0.0001*	0.0001	0.0001*
1	44.96	41.30	2.20^{c}	10.67
2	45.83	40.62	2.17^{bc}	10.53
3	45.79	40.66	2.15^{b}	10.57
4	49.21	38.26	2.09^{a}	9.61
Sex	0.0001*	0.0001*	0.1777	0.0001*
Gilt	48.23	38.84	2.14	9.95
Barrow	44.67	41.58	2.16	10.74
Weight	0.0001	0.0001	0.0001	0.0001
114 kg	42.61^{a}	42.98^{c}	2.25^{c}	11.30^{c}
132 kg	46.88^{b}	39.92^{b}	2.14^{b}	10.22^{b}
150 kg	49.86^{c}	37.73^{a}	2.07^{a}	9.51^{a}
Type	0.1176	0.9383	0.0001	0.2174
Food Service	46.19	40.22	2.24^{b}	10.40
Retail	46.71	40.20	2.07^{a}	10.29
RMS Error	6.51	5.10	0.29	1.66

abcde Means within the same column and within a main effect with similar superscripts are not significantly different ($P > 0.05$).

f P values from Analysis of Variance for each main effect within a variable.

g RMS Error= Root mean square error from Analysis of Variance tables.

* Main effects were not analyzed for significance due to significant interactions.

Table 3. The Effect of Line *Sex Interaction on Smokehouse Yield.

Smokehouse Yield			
Line	Barrow	Gilt	0.0289^{e}
1	101.70^{e}	101.67^{e}	
2	100.76^{ab}	101.06^{bcd}	
3	101.30^{d}	101.65^{e}	
4	101.20^{cd}	100.90^{abc}	
5	100.66^{a}	100.70^{a}	
6	101.05^{bcd}	101.30^{d}	

^{abcd} Means with similar superscripts are not significantly different (P > 0.05).
^{e} P values from Analysis of Variance for the interaction within a variable.

Table 4. The Effect of Line *Bacon Type Interaction on Slicing Yield.

Slicing Yield			
Line	Foodservice	Retail	0.0053^{f}
1	91.46^{bcde}	91.23^{abcd}	
2	90.41^{a}	91.86^{cde}	
3	90.37^{a}	92.27^{e}	
4	91.89^{de}	91.89^{de}	
5	90.84^{ab}	90.97^{abc}	
6	90.77^{ab}	91.96^{de}	

^{abcde} Means with similar superscripts are not significantly different (P > 0.05).
^{f} P values from Analysis of Variance for the interaction within a variable.

Table 5. The Effect of Line *Bacon Type Interaction on Total Yield.

Total Yield			
Line	Foodservice	Retail	0.0215^{e}
1	92.59^{cd}	92.39^{bcd}	
2	91.06^{a}	92.75^{cd}	
3	91.63^{ab}	93.60^{d}	
4	91.04^{a}	92.52^{bcd}	
5	91.30^{a}	91.59^{ab}	
6	91.79^{abc}	93.05^{d}	

^{abcd} Means with similar superscripts are not significantly different (P>0.05).
^{e} P values from Analysis of Variance for the interaction within a variable.

Table 6. The Effect of Diet *Sex Interaction on Percent Fat.

		Fat	
Diet	Barrow	Gilt	0.0017[e]
1	46.77[b]	43.16[a]	
2	47.68[bc]	43.98[a]	
3	48.47[d]	43.12[a]	
4	50.00[d]	48.41[c]	

[abcd] Means with similar superscripts are not significantly different (P>0.05).
[e] P values from Analysis of Variance for the interaction within a variable.

Table 7. The Effect of Diet *Sex Interaction on Percent Bacon Moisture.

		Moisture	
Diet	Barrow	Gilt	0.0039[e]
1	39.94[c]	42.67[d]	
2	39.28[bc]	41.96[d]	
3	38.57[ab]	42.75[d]	
4	37.56[a]	38.96[bc]	

[abcd] Means with similar superscripts are not significantly different (P > 0.05)
[e] P values from Analysis of Variance for the interaction within a variable.

Table 8. The Effect of Diet *Sex Interaction on Percent Protein.

		Protein	
Diet	Barrow	Gilt	0.0011[e]
1	11.09[c]	11.97[d]	
2	10.91[c]	11.86[d]	
3	10.82[bc]	11.98[d]	
4	10.34[a]	10.55[ab]	

[abcd] Means with similar superscripts are not significantly different (P > 0.05).
[e] P values from Analysis of Variance for the interaction within a variable.

Table 9. The Effect of Diet *Slaughter Weight Interaction on Smokehouse Yield.

	Smokehouse Yield			
Diet	114 kg	132 kg	150 kg	0.0004[f]
1	100.07[a]	101.40[d]	101.80[e]	
2	99.79[a]	101.00[c]	102.00[e]	
3	100.40[b]	101.38[d]	101.8[e]	
4	100.57[b]	101.76[e]	101.88[e]	

[abcde] Means with similar superscripts are not significantly different (P > 0.05).
[f] P values from Analysis of Variance for the interaction within a variable.

Table 10. The Effect of Diet *Slaughter Weight Interaction on Bacon Slab Length.

	Bacon Slab Length (cm)			
Diet	114 kg	132 kg	150 kg	0.0358[g]
1	50.56[a]	54.46[cd]	57.90[ef]	
2	52.16[b]	54.14[c]	58.31[f]	
3	51.72[ab]	55.44[d]	57.84[ef]	
4	51.58[ab]	54.94[cd]	56.97[e]	

[abcdef] Means with similar superscripts are not significantly different (P > 0.05).
[g] P values from Analysis of Variance for the interaction within a variable.

Table 11. The Effect of Slaughter Weight *Bacon Type Interaction on Slicing Yield.

	Slicing Yield		
Weight Group	Foodservice	Retail	0.0088[e]
114 kg	89.97[a]	91.74[cd]	
132 kg	90.97[b]	91.40[bcd]	
150 kg	91.23[bc]	91.95[d]	

[abcd] Means with similar superscripts are not significantly different (P > 0.05).
[e] P values from Analysis of Variance for the interaction within a variable.

Table 12. The Effect of Slaughter Weight *Bacon Type Interaction on Total Yield.

	Total Yield		
Weight Group	Foodservice	Retail	0.0130[e]
114 kg	89.93[a]	91.88[b]	
132 kg	91.99[b]	92.43[bc]	
150 kg	92.79[c]	93.64[d]	

[abcd] Means with similar superscripts are not significantly different (P > 0.05).
[e] P values from Analysis of Variance for the interaction within a variable

CHAPTER 2 - BACON SHATTERING

MATERIALS AND METHODS - Bacon Shattering Study

A. Shattering Evaluation

Shattering, as defined in this bacon study, is the incidence of breaks in the fat of a slice of bacon pependicular to the length of the slice. Bellies from diets 1 and 4 were evaluated for the incidence of shattering. Shatter marks did not include the natural separation of fat tissue or the separation between fat and lean tissue. The shatter marks were classified into five categories depending on their length:5 mm, (1 -10 mm), 15 mm (11-20 mm), 25 mm (21-30 mm), 35 mm (31-40 mm), (41+ mm).

Shattering evaluation was conducted starting at the posterior end of the belly. On retail bellies, every 5th slice was inspected for shatter marks in the fat. These marks were measured and recorded. The length of the shatter mark and quadrant of the belly were recorded. The same procedure was performed on foodservice bellies with the exception of slice number. Every 10th slice was evaluated in foodservice bellies. Bellies from diets 2 and 3 were not evaluated for the incidence of shattering. After the bellies had been evaluated and slices stacked tightly, the belly length and width was measured and recorded.

B. Fatty Acid Analysis

Two samples (0.5-1 g) from the adipose tissue of each fresh belly strip were subjected to analysis. Triglycerol fatty acids were hydrolyzed by saponification and then methylated to form fatty acid methyl ester. The methyl esters were prepared by an adaptation of the boron trifluoride-methanol procedure of Metcalfe *et al.* (1966). The gas chromatograph (HP-5890 Series 11, Hewlett-Packard Company, Avondale, PA) was equipped with an automatic injector (HP 7673) and a flame ionization detector. The methyl esters were separated on a 30 m long x.25 mm internal diameter x .20 *u*m film thickness Supelco model SP2330 capillary column (Supelco, Bellafonte, PA). The injector, oven and detector temperatures were set at 270, 180 and 300EC respectively. The individual methyl esters were identified by their retention time. Peak areas were integrated and analyzed using the HP Chem Station© Version A.06.98. The results were expressed as a percentage of the total area for all the peaks analyzed. Iodine value was calculated from fatty acid composition and expressed as mg of iodine/100 g of fatty acids using the AOCS

(1993) equation Cd 1c-85 for tryglycerides.

RESULTS AND DISCUSSION

The results of this study identify differences in bacon fat content, number of slices affected by shattering, total shattering, occurrence of shatter marks and total shattering(Table 13). Fatty acid data and iodine values are still being gathered and evaluated and are not available at this time in this progress report. The data is expected soon.

Profiles and shattering of bacon slices among lines, diets, sexes and slaughter weight groups(Table 13). In general, treatments yielding fatter bellies tended to shatter more. leaner pigs, including gilts and lines 2 and 5, remained leaner across diet and slaughter weight effects. However, interactions showed pronounced changes in bacon fat content when genetically leaner pigs were exposed to diet 4 or as slaughter weight increased. Such observations and changes in the fat composition contradict work by Cisneros et al., (1996), who suggested limited impact on meat quality with increased slaughter weight. With few exceptions, the effect of fat composition on bacon shattering could be segregated from that of fat content. A close relationship between bacon fat content and fatty acid composition was observed. The relationship observed between shattering and fat composition agrees with Enser (1986) who suggested that more saturated fat is more susceptible to fracture during slicing. Larger shatter marks in retail bacon than foodservice bacon are possibly a result of greater slice thickness.

As expected, locations at the center of the belly were fatter than those at the ends of the belly and differences were as large as among main-plot effects. However, shattering values among locations did not follow the bacon fat content as closely as main-plot effects did. Differences among treatments were more accentuated in locations 2 and 3 and more subtle for location 5. This discrepancy may be attributed to differences in fatty acid profiles or fat distribution across the slice.

Results from shattering data have not been previously reported, thus it is difficult to classify any treatment as acceptable or unacceptable.

CONCLUSIONS - BACON SHATTERING

Data from the fatty acid analyses and the iodine values, when completed, should help to explain some of the differences in the shattering data found in Table 13. These data should allow for additional interpretation of shattering data.

Table 13: Least Square Means ± SE of Percentage of Slices Affected by Shattering, Occurrence of Shatter Marks, Total Shattering, Size of Shatter Marks and Bacon Fat Content for Main Effects.

Effects[w]	Slices Affected[x]	Occurrence[y]	Total Shattering[z]	Size	Fat Content (%)
Line1	76.95 ± 2.05[c]	3.02 ± 0.15[c]	28.50 ± 1.44[d]	8.81 ± 0.22[c]	54.95 ± 0.61[d]
Line 2	59.05 ± 1.92[a]	1.52 ± 0.14[a]	12.71 ± 1.35[a]	7.56 ± 0.22[a]	42.52 ± 0.57[a]
Line 3	69.59 ± 1.89[b]	2.23 ± 0.14[b]	18.85 ± 1.33[c]	7.97 ± 0.21[ab]	45.96 ± 0.57[b]
Line 4	69.38 ± 1.79[b]	2.17 ± 0.13[b]	18.53 ± 1.25[c]	8.05 ± 0.20[ab]	47.83 ± 0.53[c]
Line 5	58.60 ± 1.80[a]	1.66 ± 0.13[a]	14.28 ± 1.26[ab]	7.86 ± 0.21[ab]	43.28 ± 0.54[a]
Line 6	68.54 ± 1.86[b]	2.01 ± 0.14[b]	17.35 ± 1.30[bc]	8.14 ± 0.21[b]	46.51 ± 0.56[bc]
Diet 1	62.53 ± 1.14[a]	1.78 ± 0.08[a]	15.01 ± 0.80[a]	NS	44.75 ± 0.34[a]
Diet 2	71.50 ± 1.56[b]	2.42 ± 0.09[b]	21.74 ± 0.81[b]	NS	48.94 ± 0.35[b]
114 kg	56.04 ± 1.53[a]	1.37 ± 0.11[a]	10.27 ± 1.07[a]	7.07 ± 0.17[a]	42.78 ± 0.46[a]
132 kg	69.02 ± 1.29[b]	2.07 ± 0.09[b]	18.15 ± 0.90[b]	8.29 ± 0.15[b]	47.72 ± 0.38[b]
150 kg	77.99 ± 1.39[c]	2.85 ± 0.10[c]	26.70 ± 0.98[c]	8.83 ± 0.15[c]	50.03 ± 0.41[c]
Barrows	71.00 ± 1.11[b]	2.38 ± 0.08[b]	21.88 ± 0.78[b]	8.41 ± 0.12[b]	48.25 ± 0.33[a]
Gilts	63.04 ± 1.12[a]	1.82 ± 0.08[a]	14.87 ± 0.79[a]	7.72 ± 0.13[a]	45.44 ± 0.34[b]
Foodservice	NS	NS	16.86 ± 0.78[a]	7.63 ± 0.12[a]	NS
Retail	NS	NS	19.88 ± 0.77[b]	8.50 ± 0.12[b]	NS
Location 1	66.24 ± 0.98[c]	1.91 ± 0.06[c]	16.09 ± 0.63[c]	8.17 ± 0.12[c]	43.54 ± 0.25[a]
Location 2	80.72 ± 0.98[c]	2.87 ± 0.06[e]	25.76 ± 0.63[e]	8.32 ± 0.11[c]	47.31 ± 0.25[c]
Location 3	75.83 ± 0.98[d]	2.48 ± 0.06[d]	24.98 ± 0.63[d]	9.35 ± 0.11[d]	50.05 ± 0.25[c]
Location 4	61.55 ± 0.98[b]	1.82 ± 0.06[b]	14.99 ± 0.63[b]	7.72 ± 0.12[b]	48.75 ± 0.25[d]
Location 5	50.75 ± 0.98[a]	1.43 ± 0.07[a]	10.04 ± 0.64[a]	6.77 ± 0.13[a]	44.55 ± 0.25[b]

[abcde] Means in the same column (within an effect) containing different superscripts are different; P< 0.05
NS Effect was not significant for that variable
[w] Percentage of bacon slices with at least one shatter mark
[x] Average number of shatter marks per bacon slice
[y] Total length (mm) shattered per bacon slice
[z] Average size (mm) of shatter mark

CHAPTER 3 - MACHINE VISION ANALYSIS OF BACON

INTRODUCTION

This portion of the study employed machine vision to examine the effect of current production methods on color and fat:lean distribution. Traditionally, spectrophotometers and colorimeters have been employed to measure meat color. These instruments objectively measure color and classify colors into three-dimensional color spaces or as a function of spectral reflectance, which is the actual energy of light. However, these classification methods do not correlate well with actual human color perception.

Digital image analysis, or machine vision, could be used to more closely simulate human color perception. Machine vision systems utilize one, or a series of, digital cameras under a specific illuminant to capture images. These images are digitized and transmitted to a computer station where they can either be stored or instantly analyzed. Images can be analyzed by a variety of software programs depending on the purpose of the machine vision system. Software programs generally analyze the picture based on pixel composition.

SAMPLEX, a color classification program developed at Purdue University, was utilized for this study. This software program combines a variety of statistical procedures to classify a color image. The program can be trained to recognize and classify pixels into a predetermined number of color classes. The program is trained to recognize color classes by sampling pixels from images of product for each color class. SAMPLEX is able to statistically process this data and create a color classification system or color scale.

Machine vision color scales are generally developed by a panel who determine important color differences in a specific product that can be segregated into discernibly different color classes. Color scales produced in this manner are not necessarily infallible and must be validated before use. Validation can be performed in a number of ways. Two validation methods were employed for this study. The first validation method measured the probability of a panelist to judge if a paired sample of bacon lean sections were similar or different compared to how SAMPLEX paired them. The second validation step examined the percentage agreement of panelists, aided with a hard copy of the SAMPLEX bacon lean classification system, and the machine vision system for classifying bacon lean segments.

MATERIALS AND METHODS

For machine vision analysis specifically, the first two slices of the anterior end of each of the five sections were removed for analysis. Each set of samples was placed on plastic bacon boards, wrapped in white polyethylene coated butcher paper (Loxol freezer paper, James River Corp., Parchment, MI) and labeled with pig identification number and sampling location (1 – 5 starting at anterior end of bacon slab). Coated paper was used to exclude light that could result in color change. Packaged bacon slices were stored in a dark cooler at 1° C until machine vision analysis.

The machine vision system consists of the following components:

Machine Vision System Hardware

Hardware includes a Sony RGB CCD Vision Camera Module (XC-711, Sony Corporation, 1996) with a Computar 16mm 1:1.4 manual iris lens (M1614WI, CBC Co. LTD., Tokyo, Japan) coupled to a Maxtor Meteor video interface card (Maxtor Imaging Products Group, 1997) inside a 200 MHz Pentium computer (Dimensions XPS M200s, Dell Computer Corporation, 1996). Software includes SAMPLEX® (Precetty, Cyrill J., v. 5.0, Purdue University, 1996), which is used to classify images, MIL-lite (Burson, Dennis E., University of Nebraska-Lincoln, 1997), an image capture and calibration program developed at the University of Nebraska for this application, and PolyView™ (Polybytes, v. 2, 80.1, Snowbound Software, 1995-97, Cedar Rapids, Iowa), which was used to convert captured images to the uncompressed TIFF format required by SAMPLEX.

The visioning camera was housed inside a plywood visioning cabinet. Cabinet dimensions were 69cm deep X 91cm wide X 46cm high. The cabinet floor, back and sides are solid plywood pieces while the front panel has an aperture extending 20cm from the cabinet floor, through which samples are passed. The cabinet has no top. The camera is mounted to a copy stand (No. CS-3 Copy Stand, Testrite Inst. Co. Inc., Newark, NJ) over the center of the cabinet floor. From the bottom of the lens, the camera is mounted approximately 42.7 cm from the cabinet floor and is perpendicular to the plane of the cabinet floor.

A series of six lights, are used to illuminate the cabinet. A row of three 3200K, 150 w, 120v, General Electric model EZK Quartzline® Lamps (GE Lighting, General Electric Co., Cleveland, OH) is situated on each side of the longitudinal axis, parallel to the cabinet floor, facing the floor at an angle of 45°. These lights are able to dissipate heat that could effect the integrity of high fat samples.

Digital Image Software

The image classification used was SAMPLEX. SAMPLEX is an RGB color analysis program that classifies each individual pixel of digital color images into programmed color groups. Specific color classification schemes must be created for specific applications utilizing actual sample images. All possible colors must be included in the sample images, and subsequently in the classification scheme, to create a classification system that can function correctly in practice. This is due to the high degree of variation found in most populations.

SAMPLEX utilizes a combination of statistical pattern recognition algorithms and neural network programming to classify each pixel into a specific color class. The program outputs the number of pixels that are contained within each color class. With this information we can calculate the percentage of the sample that is a specific color. By combining all lean color class pixels together and all fat color class pixels together we can determine the lean to fat ratio of a sample.

Part I: Validation of a Bacon Cured Color Classification System

Bacon Cured Color Classification Design Process

Two methods were utilized to create a color classification system. The first was to have panelists identify different colors in a population of actual samples. The second was to graph all possible combinations of RGB data in a three-dimensional space and arbitrarily divide this graph into a number of equally spaced color classes. As the purpose of this research was to create a color classification system that best represents human color perception, the first system was ultimately used.

Prior to vision analysis the system must be allowed to warm up for no less than 30 minutes to allow the lights to heat up and equilibrate. After warm-up the system is calibrated using the MIL-lite program and a standard photography 18% gray card (Delta 1/CPM, Inc., Dallas, TX). The system is re-calibrated every 10 samples (2 slabs).

Samples were cut in half perpendicular to the length of the bacon slice and placed on black Formica boards as shown in Figure 1. Samples were placed in the center of the camera's field of view and images were captured utilizing the MIL–lite program and saved onto the hard drive to await further analysis.

Once captured images were converted to uncompressed TIFF format utilizing PolyView.

The classification system developed for this project (Garza, 1999) was loaded into SAMPLEX as the neural network. Images were then loaded by SAMPLEX for classification. Data reported by SAMPLEX was in the form of pixel count for each of the 9 programmed classes; 1 background, 5 lean color and 3 fat color.

Bacon Cured Color Classification Design Process

Two methods were utilized to create a color classification system. The first was to have panelists identify different colors in a population of actual samples. The second was to graph all possible combinations of RGB data in a three-dimensional space and arbitrarily divide this graph into a number of equally spaced color classes. As the purpose of this research was to create a color classification system that best represents human color perception, the first system was ultimately used.

Method 1

A panel consisting of four people was employed to develop a bacon cured color classification system. Twelve complete slices of bacon were displayed with a white background. Bacon slices were covered with clear film to prevent drying and were illuminated with three 500w tungsten-halogen photo floodlights. Panelists were instructed to identify differing color classes for both lean and fat. Five classes of differing lean color and three classes of differing fat color were ultimately identified.

Sections of the samples identified as belonging to specific color classes were excised from the full slices. These lean and fat sections were then placed on black Formica boards and their images were captured by the machine vision system. These images were then sampled into the SAMPLEX program to create a bacon cured lean and fat color classification system. SAMPLEX indicated good separation between color classes with little overlap as the redistribution error displayed by the program was well below the level indicated to signal similarity between two or more classes.

Utilizing this color classification system a digital bacon color chart was produced. This chart was printed out in color on glossy paper to be used for the bacon cured color classification validation portion of the study.

Method 2

Images of twenty-four random bacon slices were captured to obtain RGB data from the population. Small sections of lean and fat were digitally cut from these samples and used to create a composite image. This composite image was assumed to contain a representative sample of all possible colors from the random sample of the population. RGB data was obtained from the composite picture and plotted in a three-dimensional area.

Upon plotting a linear relationship was found between the RG and RB data. A linear regression was performed on this line to show the relationship of the RGB data. This line was then divided into 6 regions, each representing a separate color class, five for lean and one for fat. Utilizing this information a series of solid color blocks were created digitally. These blocks were used to "teach" SAMPLEX the color classification system. This resulted in a bacon cured color classification system with no overlap between color classes.

Comparison of Method 1 versus Method 2

Thirty randomly selected bacon slice images were used to compare classification systems. Analysis of variance and least significant difference (LSD) pair-wise comparisons were performed utilizing the SAS system.

SAMPLEX Color Classification Validation

Validation was performed for the bacon cured color classification system developed by the panel. Two separate validation experiments were performed utilizing a separate panel. The first validation step assessed the probability of a panelist to decide if two bacon cured colors were identical or different in comparison with the computer classification. The second step measured the ability of a panelist to classify a bacon sample into the same color class as the machine vision system. For this step panelists used computer generated color charts to aid in classification.

An R-index test was used to establish the probability of a panelist to distinguish between different color classes of the panel developed SAMPLEX color classification system. The R-index test was developed for difference testing and is defined as the probability of distinguishing between two similar products, in this case bacon lean colors. Large bacon lean sections that had been previously classified by SAMPLEX were used for the validation experiment. Samples were paired either as identical color classes or paired with up to a difference of four color classes.

Samples were vacuum packed to reduce color changes and displayed on a white background under constant commercial lighting conditions in a refrigerated room. Panelists were asked to identify the pairs color as identical, likely identical, different with doubts or different. Utilizing panelist response and actual SAMPLEX color class of each sample the R-index was calculated for each of three panels.

After calculation of R-indices the second validation experiment was performed. The second validation study utilized the same paired samples. Each panelist was provided a computer-generated color chart of the SAMPLEX cured color classification system. Panelists were then instructed to classify each bacon lean section into one of the SAMPLEX color classes using the supplied color chart. SAMPLEX color classification was evaluated for the percentage of matching classifications between the visual panel and the computer analysis.

The second validation experiment was statistically analyzed using the general linear model function of the SAS system. Statistical attributes of interest included analysis of variance and correlations.

Part II: Influence of Production Parameters on Bacon Color and Composition

Machine Vision Analysis

Bacon images were captured as outlined above. Images were analyzed with SAMPLEX and data analyzed utilizing the SAS system (SAS, 1990).

Color Determination

Bacon color is broken down into two groups, overall fat color (FatScore) and overall lean color (LeanScore). Each is an overall color score representing an average weighted value obtained by combining the color classes recognized by the machine vision system. FatScore is the weighted value of the three cured fat color classes (white, beige and dark) and LeanScore is the weighted value of the five cured meat color classes (very pale, pale, medium, medium dark and very dark). For FatScore values of 1, 0 and –1 were respectively assigned to the white, beige and dark fat color classes. Values of 2, 1, 0, -1 and 2, were assigned respectively to the very pale, pale, medium, medium dark and very dark lean color classes. Equations used to determine FatScore and LeanScore are as follows:

FatScore = [((white pixel # x 1) + (beige pixel # x 0) + (dark pixel # x –1)) / total pixel #]

LeanScore = [((very pale pixel # x 2) + (pale pixel # x 1) + (medium pixel # x 0) + (dark pixel # x –1) + (very dark pixel # x –2)) / total pixel #]

Statistical Analysis

A split-plot experimental design (Dowdy and Wearden, 1985) was used with whole units arranged in a randomized complete block design. Sampling locations within the bacon slab were used as sub-unit and pig as the whole unit. Season was used as the blocking factor. The treatment design consisted of a 6 (breed type) X 4 (diet) X 3 (target finishing weight) X 2 (sex type) factorial arrangement of treatments.

The Mixed Models procedure of SAS (SAS, 1990) was utilized to evaluate the effect of treatments on color and proximate composition of bacon. Significant ($P < 0.05$) main effects and two-way interactions were both analyzed. Deviation of final weight from target finishing weight group was utilized as a covariate in all analyses.

RESULTS AND DISCUSSION

Part I: Validation of a Bacon Cured Color Classification System

Comparison of SAMPLEX Cured Color Classification Systems

Thirty randomly selected bacon slice images were used to compare classification systems. Each image was classified utilizing each classification system. LSD pair-wise comparisons were performed between systems and significant differences were found. These results indicate that the classification systems group pixels from a digital image differently.

Because the purpose of this study was to develop a classification system modeled after human vision, the classification system developed by the panel was chosen for further analysis. The other classification system could be useful for other applications such as determining lean-to-fat ratios or color analysis that does not rely on human vision emulation.

SAMPLEX Color Classification Validation Study

Method One: R-index

R-index was used to determine the overall probability of a panelist to find the same differences or similarities between color classes as the panel developed SAMPLEX classification system. High R-index values indicate that panelists are finding the same differences in color of samples as the machine vision system. For all panels, R-indices ranged from 0.95 to 0.98 indicating that the panel designed SAMPLEX cured color classification system is able to emulate the validation panels ability to discern between color classes.

Method Two: Color Class Charts

Classification of bacon lean samples by panelists using computer-generated color charts as references was less successful than the R-index experiment. Panelists assigned bacon lean samples to the same class as the machine vision system 63.7% of the time. The majority of the errors, 94.7%, were errors with a one class deviation.

Part II: Influence of Production Parameters on Bacon Color and Composition

While the objective of this study includes determining differences of bacon from different locations within a slab, the proximate analysis data is presented as an average of the five locations sampled from each bacon slab except when location differences are discussed. Individual proximate analysis data for each sampling location was collected for approximately half of the bacon slabs, this data will be used to discuss differences between locations.

Effects of Genetic Line

Differences of proximate composition measures with regards to breed type were all significant ($P < 0.05$). Means of each by breed type are shown in Table 14. Line 1 bellies produced processed bacon with the highest percent fat and the lowest percent moisture, protein and ash and was significantly different from all other lines ($P < 0.05$). According to Robison (1998), animals from line 1 also deposited backfat faster than all other lines and had the slowest rate of increase in loineye area. Lines 2 and 5 produced bacon with the lowest percent fat and the highest percent moisture, protein and ash. Throughout all bacon samples percent fat and moisture were highly correlated ($R^2 = -0.98$, $p < 0.01$). Line interacted significantly ($P < 0.05$) with weight group for fat color. Across breed types, bacon from animals of the 113 kg and 150 kg weight groups had more variable fat colors than those of the 131 kg target group. Animals in the 131 kg weight group tended to produce bacon with similar fat colors, regardless of line. Of all line/weight group combinations the 113 kg target weight animals from breed types 2 and 5, the least fat lines overall, produced bacon with the darkest colored fat. Bacon produced from the fattest breed type/heaviest target weight combination (Line 1/150 kg) produced the lightest colored fat. For all breed types, fat color became lighter with each successive increase in target slaughter weight, these differences were not always significant ($P < 0.05$).

Breed type had an effect on bacon lean color. Line interacted significantly ($P < 0.05$) with sampling location in regards to lean color (Figure 7). A general lean color trend is seen across locations within all breed types, the trend is as follows. Bacon from locations 1 and 3 had the lightest colored lean and were similar to each other while bacon from location 5 had the darkest colored lean. Lean color values at locations 2 and 4 were similar to each other and intermediate to the two extremes. The only deviation from this trend was seen in bacon from breed type 1 where similar lean values are found at sampling locations 1 and 2.

Bacon from breed type 6 had the lightest lean color across all locations. Bacon produced from breed type 3 animals was the darkest at all sampling locations with the exception of location

1 where line 1 had a slightly darker value, although these values were not significantly different ($P < 0.05$).

Effects of Diet

The effects of diet were significant for proximate composition measures and fat color (Tables 14 and 15). Across all four diets energy, minerals and vitamins were held constant for pre-determined weight ranges; however, lysine levels differed (Robison, 1998). Lysine levels decreased across diets with diet 1 exceeding NRC recommendations and diet 4 being deficient in lysine.

Decreased dietary lysine levels resulted in fatter bacon with bacon from diet 4 having the highest percent fat and the lowest percent moisture, protein and ash. Increasing dietary lysine level resulted in decreased fat content and increased moisture, protein and ash content of bacon. Increasing the level above NRC guidelines did not result in bacon of a significantly different composition ($P < 0.05$). Diet 3 bacon was slightly fatter than bacon from diets 1 and 2 but not significantly so ($P < 0.05$). Bacon from animals fed lysine levels below NRC guidelines had the whitest colored fat. Diets containing lysine levels within and above NRC guidelines, resulted in darker fat ($P < 0.05$).

Diet interacted significantly ($P < 0.05$) with target finishing weight group (Figure 6) in regards to lean color. No significant lean color difference was found between the 113 and 131 kg target finishing weight groups across diets except for diet 3 where a lighter lean color value was found for the 113 kg group. Overall the 150 kg target group had the darkest colored lean except when animals of this target weight were fed a diet deficient in lysine. Diets containing lysine levels within and above NRC guidelines produced darker colored lean as target finishing weight increased.

A slight interaction was found between target finishing weight group and sampling location in regards to fat color. This is discussed in the 'effect of location' section below.

Effects of Sex Type

The effect of sex type was significant for proximate composition, fat color and lean color (Table 15). Bacon slabs from barrows were fatter and had lower moisture and protein contents than those from gilts, this is in agreement with research done by Fredeen (1975 and 1980) and Ellis (1983). Sex type did not affect percent ash significantly ($P < 0.05$) Barrows produced both a significantly whiter colored fat and paler colored lean ($P < 0.05$) than gilts.

Effects of Weight Group

Weight group did have a significant effect ($P < 0.05$) on proximate composition of bacon. As animals progress further into their growth curves and attain greater weights proximate composition changes as shown by Taylor (1985). Fat percentage of bacon increased as target weight increased. Fat percent increased approximately 3.5 percent with each 18 kg/40 lb. increase in target finishing weight. In relation to fat, percent moisture, percent protein and percent ash followed inverse trends across target weight groups.

Target finishing weight group had significant ($P < 0.05$) two-way interactions with both breed type and sampling location (Figures 2 and 5) for fat color and with diet for lean color. These interactions are discussed in the corresponding sections.

Effects of Location Within Slab

The effect of sampling location was significant for all proximate composition measures. Sampling location 3, the center of the slab, was significantly ($P < 0.05$) fatter than all other locations. Fat content of bacon decreased from the center towards either end with bacon from either end having the lowest fat contents of all locations sampled. Fat content from the ends, locations 1 and 5, were similar but significantly different from each other. Locations intermediate to the center and ends, locations 2 and 4, showed fat contents intermediate to the center and end locations. Moisture, protein and ash contents showed inverse trends to fat content.

A significant interaction ($P < 0.05$) was found between target weight group and sampling location (Figure 2) for fat color with a greater color difference between the 113 kg and 131 kg target slaughter groups than between the 131 kg and 150 kg target slaughter groups. This interaction was weak with each factor having the same trend across levels. For all sampling locations, FatScore values increased significantly with each successive increase in target finishing weight. Similarly, within in all weight groups the same FatScore trends were seen across all five sampling locations.

Small differences in fat color were seen between the anterior and center locations, 1 through 3. Sampling location 2 tended to have the whitest colored fat but never significantly whiter than location 3. Bacon from the anterior end of the slab (location 1) presented a slightly darker fat color than locations 2 or 3. Bacon from the posterior end of the slab, locations 4 and 5, had darker fat colors with location 5 producing the darkest fat color. For lean color, sampling location interacted with line, this is discussed above.

All treatments affected color and proximate composition of bacon. Breed type had the greatest effect on bacon composition with an approximately 13% difference in fat content between the fattest and leanest breeds. Dietary lysine level also had a major effect. Diets with lysine levels below NRC guidelines resulted in bacon with significantly higher fat contents than those diets containing lysine levels within or exceeding the guidelines. This is in agreement with Noblet et. al. (1987) who found an increase in daily gain of adipose tissue with a decrease in dietary lysine levels. Bacon from barrows was found to be of a higher fat content than that from gilts, this is in agreement with Freeden (1975 and 1980). Bacon derived from animals of increasing weight were found to produce fatter bacon, this is in agreement with Taylor (1985) who reported increasing carcass fat content with increased body weight and age. For all treatments increased bacon proximate fat resulted in decreased moisture, protein and ash contents.

Effect of treatments on fat content of bacon tended to have the most influence on bacon fat color. For all treatments, except sampling location, trends for fat content of bacon and lean color paralleled each other, suggesting a link between the two. Increased fat levels may lead to a whiter fat color in bacon. Increased levels of saturated fatty acids in the fatter bacon slabs may be the cause of this.

Sampling location is the only treatment that deviates from the above trend. Sampling location interacted with weight group with respect to fat color with the general trend in fat color across locations being the same for each weight group. While fat content increased similarly from either end towards the middle of the slab, fat color did not follow the same trend. For all weight groups locations 2 and 3 had the whitest colored fat with fat color becoming darker in either direction of these locations (Table 14). When the general makeup of each sampling location is considered (Figure 3) it is seen that the same muscles are found in these two locations, no other location has this makeup. Perhaps the way in which fat is deposited between these muscles affects the fatty acid composition, which in turn effects the color of the fat. Both locations have a layer of superficial muscles across the medial surface of the belly and three muscles located deep within the belly. These superficial muscles may protect the intermuscular fat from being subjected to heat of sufficient magnitude to darken its color.

Sampling location within the bacon slab interacted weakly with breed type, obvious trends were present for both attributes. Overall, location had the biggest effect on lean color of bacon. For location, lean color and fat content followed similar trends, with the exception of location 1, with increasing fatness resulting in paler colored lean. Bacon from location 1, closest to the anterior end, had a light colored lean comparable to bacon from the fattest location, location 3. Of all locations, bacon from location 1 tended to have the least superficial muscle area on the medial surface of the slice. Instead the majority of location 1 bacon muscle area consisted of the Pectoralis profundi and the Latissimus dorsi which are situated deep in the slice. These muscles, located deep within the belly, tended to be lighter in color than those located superficially. This may be explained by the drying action of the smokehouse on muscle tissue located superficially resulting in lowered moisture content and darker color. The light lean color of location 3 may be explained by a combination of the superficial muscle layer and high fat content at this location. Superficial muscles may insulate those muscles found deep within the belly from heat sufficient to dry the muscle tissue while the abundance of fat results in a hydrophobic barrier that moisture from the muscles is unable to escape through. While dietary lysine level and target slaughter weight interacted significantly with respect to lean color no strong trends are evident. Heavier hogs tended to produce darker colored lean if their diets contained lysine levels that met or exceed NRC guidelines but differences between weight groups were erratic.

Barrows produced bacon with significantly darker colored lean than gilts did, this may be explained by the insulating effects, during processing, of the increased fat content. Breed type did have an effect on lean color but because of lack of genetic information on lines the effect is unexplainable here.

CONCLUSIONS

Lean-to-fat ratio and lean and fat colors have been found to be the most important attributes in consumer purchasing of bacon. West (1973) found bacon with a lean content of 40% or more, in comparison to bacon of higher fat contents, to be more desirable to consumers.

West reported that only 21.3 percent of bacon evaluated in his study exceeded 30 percent lean content. Results from this study show that bacon produced from the majority of animals raised under modern production methods has a lean-to-fat ratio that meets or exceeds consumer preference (>40%). However, increased leanness can lead to a decrease in belly thickness, which may affect consumer preference. Of all treatments considered in this study, no individual treatment or combination of treatments resulted in bacon with a fat content of more than 55%. Only animals of breed type 1 produced bacon that exceeded 50% fat.

While fat and lean color differed across treatments the data shows color to be relatively consistent. Average color values for fat and lean fell within a relatively narrow range of the color scales used. Fat colors tended to fall within the “white fat” category while lean colors tended to fall within the “pale lean” category. The “paleness” of the overall lean scores is probably due to the contribution of muscles deep within the slab as these muscles tended to be lighter in color than those located superficially. Research on the consumer acceptance of differences in color of bacon lean and fat should be considered as it would allow a more complete use of this data set.

Table 14. Bacon Lean and Fat Color as Affected by Genetic Line, Diet, Sex, Slaughter Weight Group and Sampling Location.

Effect	FatScore	Standard Error	LeanScore	Standard Error
Line				
1	0.37*	0.14	0.37*	0.04
2	0.26*	0.14	0.41*	0.04
3	0.31*	0.14	0.36*	0.04
4	0.34*	0.14	0.44*	0.04
5	0.24*	0.14	0.38*	0.04
6	0.26*	0.14	0.47*	0.04
Diet				
1	0.29^{a}	0.14	0.39*	0.04
2	0.25^{b}	0.14	0.39*	0.04
3	0.28^{ab}	0.14	0.39*	0.04
4	0.36^{c}	0.14	0.44*	0.04
Sex				
Barrow	0.32^{a}	0.14	0.42^{a}	0.03
Gilt	0.27^{b}	0.14	0.38^{b}	0.03
Weight				
113 kg	0.23*	0.14	0.43*	0.04
131 kg	0.30*	0.14	0.40*	0.03
150 kg	0.35*	0.14	0.38*	0.04
Location				
1	0.32*	0.14	0.48*	0.03
2	0.35*	0.14	0.36*	0.03
3	0.34*	0.14	0.50*	0.03
4	0.25*	0.14	0.37*	0.03
5	0.22*	0.14	0.30*	0.03
* Because of significant interactions the significance of main effects were not analyzed.				
abc Means with the same superscript within the same column and main effect were not significantly different ($P < 0.05$)				

Table 15. Bacon Proximate Composition as Affected by Genetic Line, Diet, Sex, Slaughter Weight Group and Sampling.

Effect	Fat	S.E.	Moisture	S.E.	Ash	S.E	Protein	S.E.
Line								
1	54.74^{a}	0.83	34.34^{a}	0.65	1.79^{a}	0.06	9.14^{a}	0.26
2	42.65^{b}	0.81	43.38^{b}	0.63	2.18^{b}	0.06	11.79^{bd}	0.25
3	45.95^{c}	0.81	40.69^{cd}	0.63	2.06^{ce}	0.06	11.31^{be}	0.25
4	47.76^{d}	0.8	39.57^{c}	0.63	1.98^{d}	0.06	10.69^{ce}	0.25
5	41.95^{b}	0.81	43.91^{b}	0.64	2.15^{b}	0.06	11.99^{d}	0.25
6	45.79^{c}	0.81	41.04^{d}	0.63	2.13^{be}	0.06	11.04^{e}	0.25
Diet*								
1	45.06^{a}	0.74	41.61^{a}	0.58	2.11^{a}	0.06	11.22^{a}	0.22
2	44.93^{a}	0.74		0.58	2.1^{a}	0.06	11.36^{a}	0.22
3	46.14^{a}	0.74	40.6^{b}	0.59	2.01^{b}	0.06	11.24^{a}	0.23
4	49.76^{b}	0.74	38.12^{c}	0.58	1.97^{b}	0.06	10.15^{b}	0.22
Sex*								
Barrow	48.26^{a}	0.66	39.09^{a}	0.53	2.04^{a}	0.06	10.62^{a}	0.19
Gilt	44.69^{b}	0.66	41.89^{b}	0.53	2.04^{a}	0.06	11.37^{b}	0.19
Weight*								
113 kg	43.02^{a}	0.74	43.01^{a}	0.58		0.06	11.86^{a}	0.22
131 kg	46.46^{b}	0.69	40.48^{b}	0.56	2.07^{a}	0.06	10.98^{b}	0.21
150 kg	49.93^{c}	0.71	37.97^{c}	0.57	1.96^{b}	0.06	10.14^{c}	0.21
Location**								
1	43.48^{a}	0.4	42.21^{a}	0.33	2.24^{a}	0.05	12.07^{a}	0.12
2	47.71^{b}	0.4	39.85^{b}	0.33	2.02^{b}	0.05	10.43^{b}	0.12
3	51.03^{c}	0.4	37.45^{c}	0.33	1.88^{c}	0.05	9.64^{c}	0.12
4	48.93^{d}	0.4	38.78^{d}	0.33	2^{b}	0.05	10.29^{b}	0.12
5	44.66^{e}	0.4	41.78^{e}	0.33	2.12^{d}	0.05	11.44^{d}	0.12

abc means with the same superscript within the same column and main effect were not significantly different ($P < 0.05$)

* Proximate composition values derived from all bacon slabs studied (individual and composite proximate analysis) different ($P < 0.05$)

** Proximate composition values derived from bacon slabs of animals fed diets 1 and 4 only (individual proximate analysis)

Figure **1. Sample Orientation for Visioning**

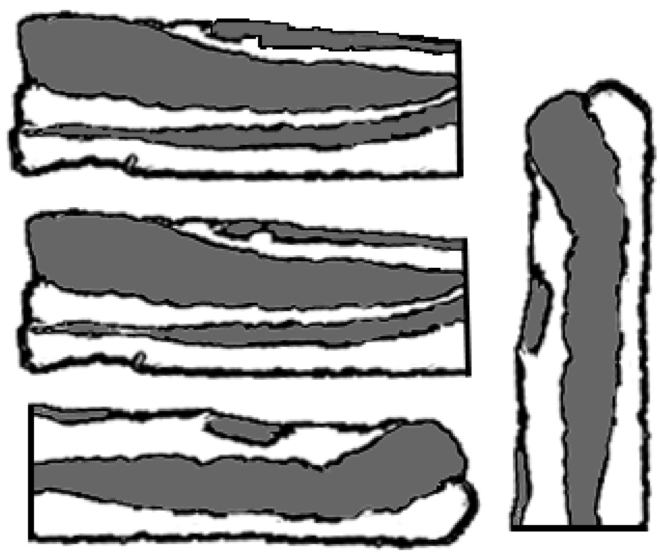


Figure 2. Effect of the Interaction of Target Slaughter Weight Group and Bacon Sampling Location on Bacon Fat Color.

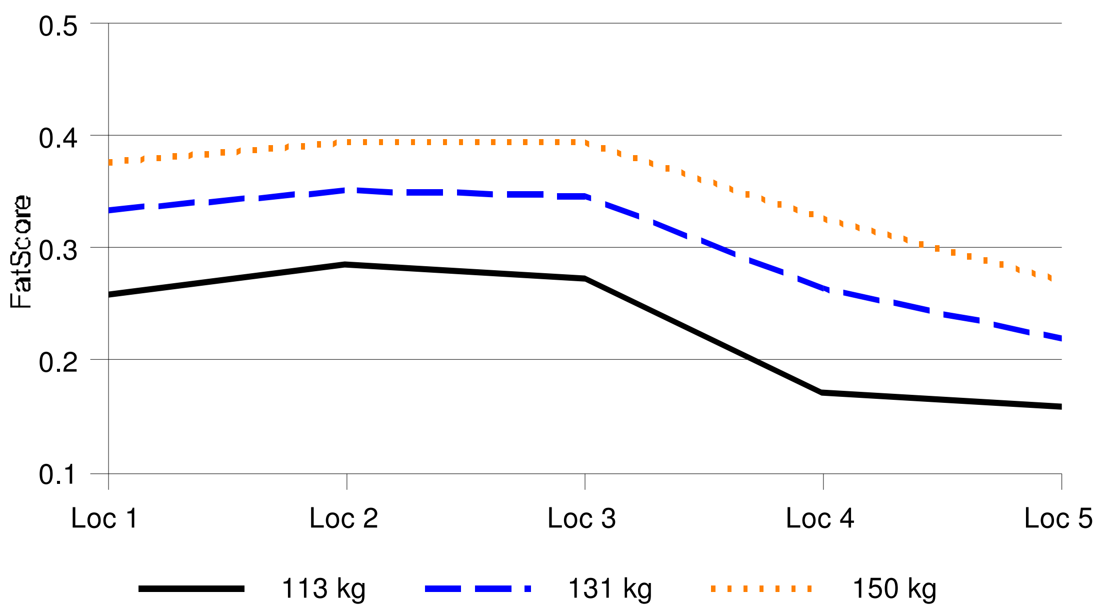
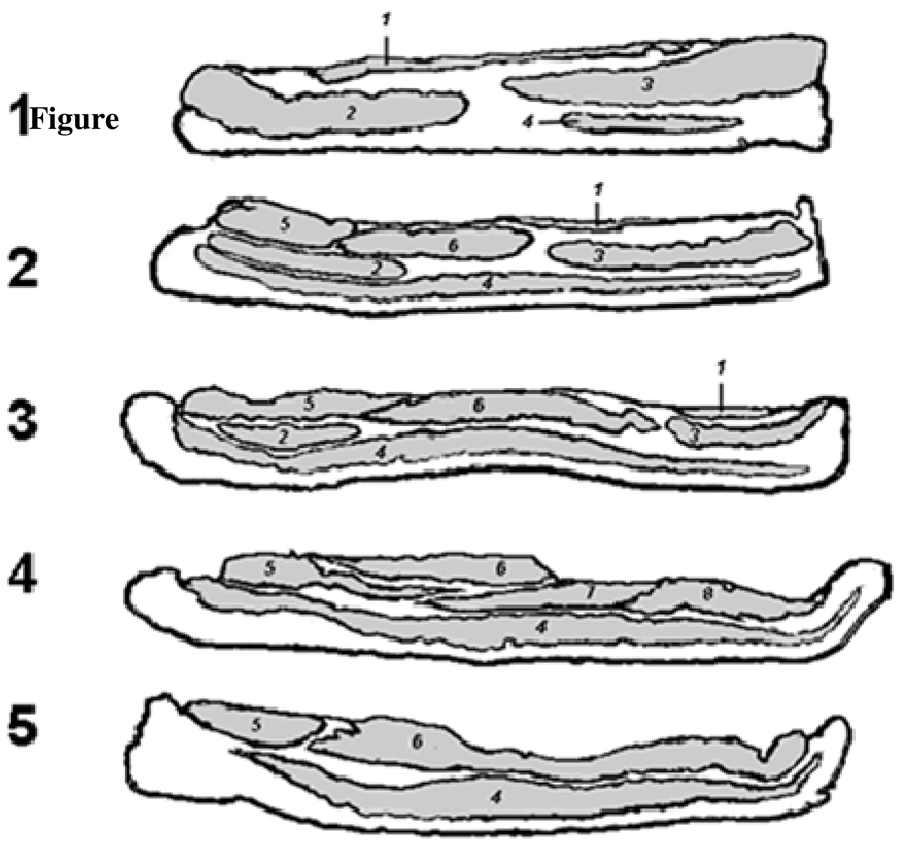


Figure 3: Orientation of Belly Muscles at each Sampling Location



1 - *Serratus ventralis*
2 - *Pectoralis profundi*
3 - *Latissimus dorsi*
4 - *Cutaneus trunci*
5 - *Rectus abdominis*
6 - *Obliquus externus abdominus*
7 - *Intercostalis externi*
8 - *Serratus dorsalis caudalis*

Figure 4: Bacon Sampling Diagram

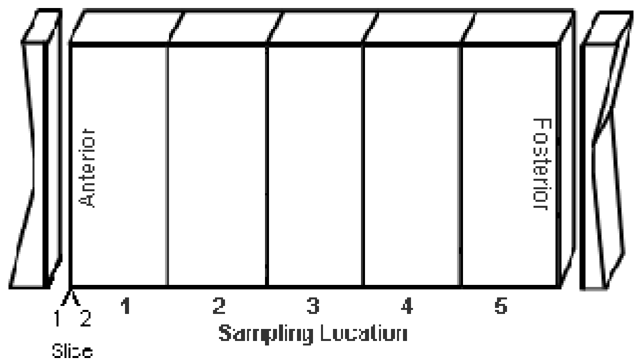


Figure 5. Effect of the Interaction of Genetic Line by Slaughter Weight Group on Bacon Fat Color.

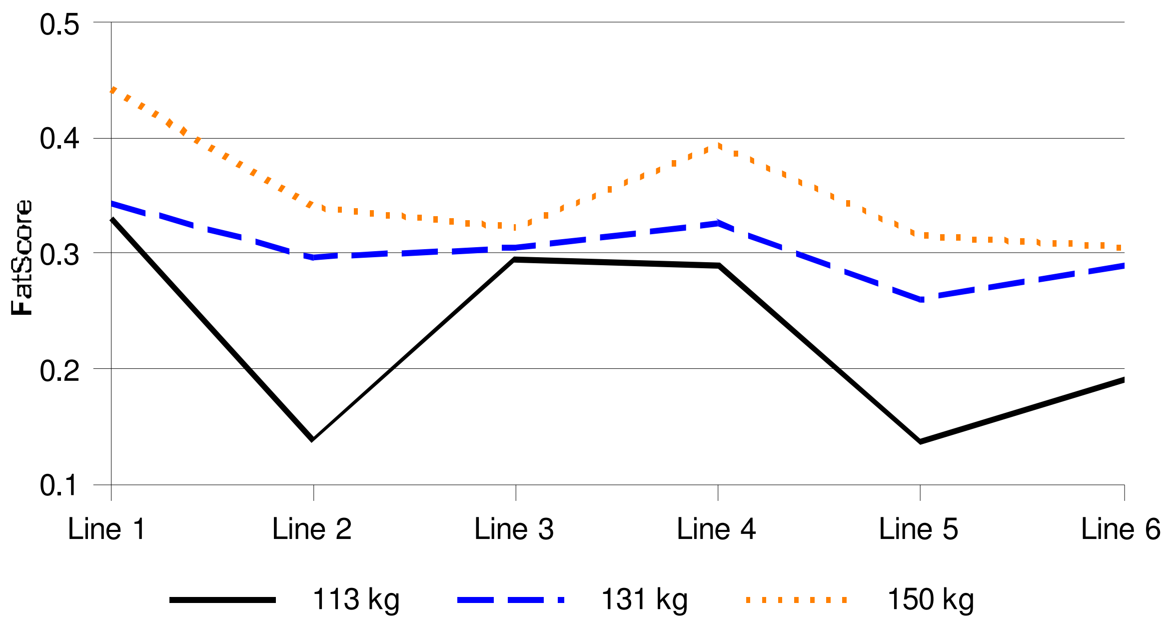


Figure 6. **Effect of the Interaction of Slaughter Weight Group and Diet on Bacon Lean Color.**

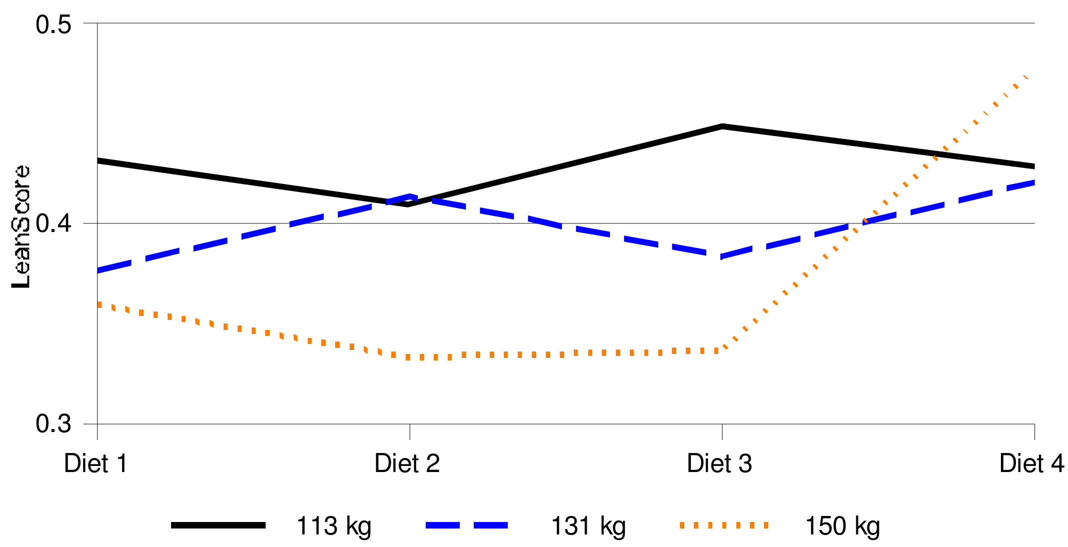
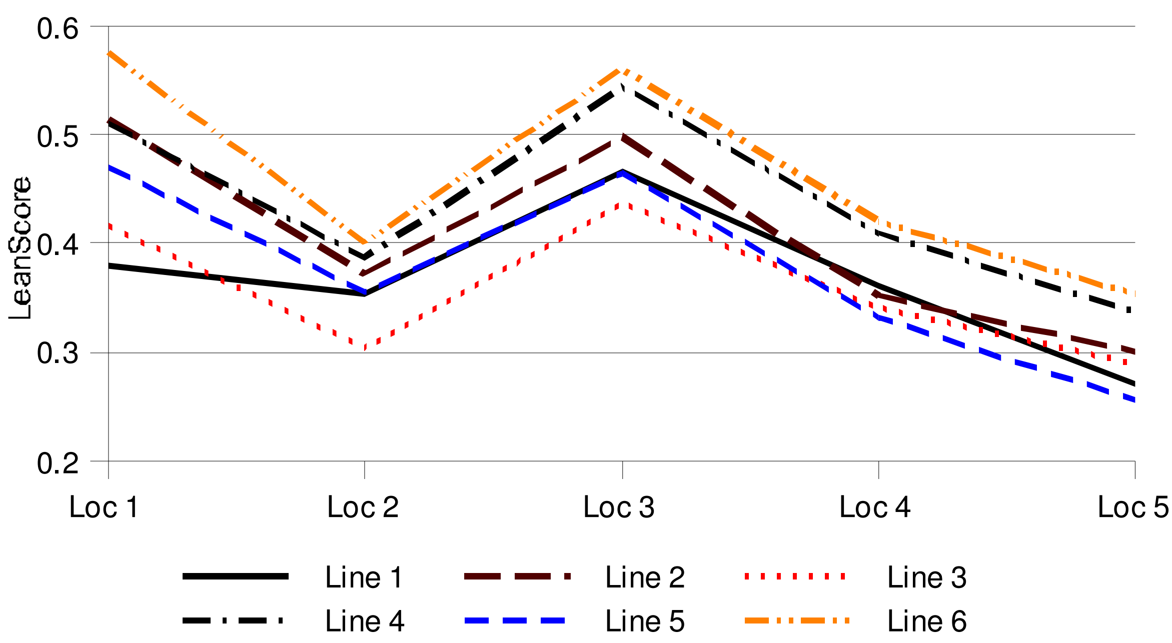


Figure 7. **Effect of the Interaction of Genetic Line and Bacon Sampling Location on Lean Color.**



CHAPTER 4 - PRE-COOKED BACON

INTRODUCTION

Bacon manufacture has recently become a growing industry (Anonymous, 1998). The precooked bacon industry has seen a large increase in market share. Industry produces precooked bacon primarily with the use of microwave technology (Schiffman, 1992). New double belt cooking technology has been developed to quickly cook uniformly thick products. Cooking occurs by conduction of heat. Heated platens cook both sides of the product as teflon conveyor belts move the product between the platens. Bacon has been readily adapted to this process due to uniformity of thickness and the short time required for cooking. The advent of the double belt conveyor cooker warrants the examination of the two cooking methods for comparison of cooking efficiency. The effect of genetic line, diet, sex, and slaughter weight on cook yield, slice shrinkage, and distortion of bacon slices was studied.

MATERIALS AND METHODS

1. Commercial Double Belt Conveyor Cooking Procedures

Foodservice and retail bacon samples were cooked on a Magi-Grill PGB-60 (Magikitch'n, Quakertown, PA) double belt conveyor cooker. Cook yield, dimensional changes in length and width, and distortion scores were determined and recorded for these samples.

Preliminary trials were conducted to determine the correct settings for the double belt cooker to yield the proper degree of doneness in samples. The appropriate degree of doneness was determined to be a color described as "golden brown" but not crisp. Cooked yield is required to be #40% of raw weight to comply with USDA/FSIS regulations (USDA, 1996). The target cook yield was 37-39% based on cooked color. As a result of these trials the temperature of the top and bottom platens was set at 204.4EC with a clearance between platens of 0.33 cm during the cooking process. The preheat temperature was also set at 204.4EC. The belt speed of the cooker was adjusted to control cooking times. Program "A" was designated for foodservice bacon. The belt speed was set so that 35 seconds would elapse from the time of sample entry until exit from the belt cooker. Program "B" was designated for retail bacon. The belt speed was set at 45 seconds for retail samples due to thickness.

Cooked samples were evaluated for percent change in length (at the midpoint of the slice), width (at three points across the slice in one third intervals), and weight from the raw weight. A distortion scale was developed to evaluate the change in bacon shape (Appendix G). Distortion refers to the amount of "wrinkling" in the bacon slice. Five distortion scores were developed. A distortion score of one characterized a flat piece of bacon with little or no distortion. A score of five characterized a severely distorted slice. Scores of 2, 3, and 4 represent distortion percentages of 25%, 50%, and 75% respectively.

Bacon samples were removed from the cooler (1EC/34EF) prior to cooking. The slices were removed from the packaging, separated, and weighed individually. Slices 2, 3, and 4 were measured for length and width. The slices were then placed in order (1-5) on a paper plate. Locations B, C, D, and E were treated in the same manner. The slices were placed on the cooker in order with spaces of two inches (5 cm). An eight inch gap (20.3 cm) was left between locations to prevent mixing slices from different locations. As the slices exited the belt cooker, they were placed in order on clean paper plates and allowed to cool for 30 seconds before weighing and measuring. All slices were then weighed, Slices 2, 3, and 4 were then measured for length and width. A distortion score was then assigned to slices 2, 3, and 4. Video imaging analysis of bacon from diets 1 and 4 was then performed on the cooked bacon. Diets 2 and 3 were not video imaged.

2. Microwave Bacon Cooking Procedures

The microwave cooking system was designed to allow cooking of slices from individual bacon slabs with comparable results to commercial precooked bacon manufacturing. The microwave cooking system was developed through consultation with a commercial precooked bacon plant (MPS, Omaha, NE) and Amana microwave engineers (Amana Industries, Amana, IA). Modifications to the commercial methods include the use of a Litton Menumaster 70/80 (Litton Industries, Minneapolis, MN) microwave oven delivering 2000 watts of power. Microwave trays (Bacon and Roasting Racks, Anchor Hocking, St. Paul, MN) approximately 26 cm x 30 cm were used. Commercial microwave belting (Amana Industries, Amana, IA) was cut to approximately 25 cm x 28.6 cm to fit into the microwave trays. The microwave belting was used as a top and bottom belt similar to the commercial microwave oven application.

Preliminary trials were performed to increase cooking uniformity of microwave bacon. To ensure a cooked yield #40%, individual cooking times were developed for a range of weights for the 5 slices of each location. Cooking times increased with an increase in weight of the five slices of the locations. Five slices of retail bacon ranged in weight from 34-200 grams. Cooking times for this weight range were from 60-120 seconds of continuous cooking. Five slices of foodservice bacon ranged in weight from 15-171 grams. Cooking times for this weight range were from 40-100 seconds. Specific weight ranges and times are listed in Appendix H.

The microwave was set to the "Full Power". The bacon was separated and weighed individually to obtain raw slice weights. Slices 2, 3, and 4 were measured for length and width. The slices were then placed on the microwave belt The other piece of belt material was placed on the top of the slices. The bacon was then cooked for the specified amount of time. The tray was removed from the microwave. The top piece of belt material was removed, and the slices were allowed to cool for 30 seconds. The slices were then weighed to determine cooked weight, and slices 2, 3, and 4 were measured for length and width. A distortion score was then assigned to slices 2, 3, and 4.

Part I- Validation-Materials and Methods

Within each group, ten bacon slabs from foodservice type or retail type were randomly chosen to form a subsample. The entire subsample was composed of sixty foodservice type and sixty retail type (6 fat groups x 10 bacon slabs/group). The normal distribution of raw fat content data for the replication was divided into six groups. Based on the percentage of fat, the normal distribution was examined. This normal distribution curve was the typical bell shape. The distribution was divided into six groups of equal fat percentage range. These groups provided insufficient sample number. Therefore, six groups of ten bacon slabs each were selected. The four central groups varied from 4-6% fat within groups. The highest and lowest had 15 and 12% fat respectively, to represent the tails of the distribution. This process was conducted for both retail and foodservice type bacon.

Statistical Analyses - Validation

Experimental design was a split plot design with whole plot treatment factors as bacon type (2 types) and raw fat group (6 groups). The split plot factor, cooking method, was composed of two methods (belt and microwave cookery). Ten bellies within each fat group and bacon type (2 types X 6 raw fat groups) were each cooked by the two methods. Hartley's Fmax test was used to prove homogeneity of cooking parameters within type and cooking method (Dowdy and Wearden, 1985).

Means and variances for yield, cooked fat content and moisture content were calculated using the PROC MEANS procedure of SAS (SAS, 1985). Analysis of variance was performed using the

Mixed Model of SAS (Littell *et al.*, 1996). When a significant interaction between raw fat group, bacon type and cooking method resulted, interaction means were reported. Differences between means were evaluated using the LSMEANS procedure.

Dimensional changes and distortion were examined in bacon slices from the subsample. Three of the five slices per location (slices 2, 3 and 4) were used for dimensional analyses. Three width measurements were taken at approximately one quarter, one half and three quarters the length of the slice. One length measurement was taken from the middle of the end of each slice. A preliminary study developed a five- point distortion scale (Appendix G) to objectively measure the distortion of cooked bacon. All dimensional designated slices (slices 2, 3 and 4) were measured before and after cooking and assigned a distortion score.

Statistical Analysis - Dimensional Analysis

The experimental design was a split plot with the whole plot being the bacon type and raw fat content group (2 bacon types x 6 raw fat groups) and the split plot being the cooking method and the split-split plot being the location within the bacon slab when appropriate (10 bacon slabs). The PROC MIXED program of SAS (Littell *et al.*, 1996) was utilized. Means of significant interactions and main effects were separated by the LSMEANS procedure.

Part II- Examination of Genetic Lines, Diet, Sex, and Slaughter Weight

The study by Ross and Mandigo, 1999 was followed by a study by McEver and Mandigo, 1999 to examine cook yields, shrink in length, shrink in width, and distortion for all of replication one in the Quality Lean Growth Modeling (QLGM) Project.

Part 1- Validation-Results and Discussion

Proximate Analysis

For all types and cooking methods, as raw fat content increased cooked fat content increased and moisture content decreased. Cooked ash content followed no distinct pattern. All Fmax ratios within bacon type and cooking method across a raw fat content group were less than the table value (12.1) for $\forall$=.01. The conclusion was to fail to reject the null hypothesis (H_O) for all treatments meaning that variances within a fat group, bacon type and cooking method were equal. In foodservice type bacon, microwave cooking had less variation in cooked fat and moisture contents than belt grill cooking.

For cooked proximate analyses, significant differences were seen within a raw fat content group across type and cooking method in cooked fat, moisture and ash content. The belt cooking method resulted in a lower cooked fat content than microwave cooking for bacon with a raw fat content of 52.99% or less regardless of type. Fatter bacon (53.00% raw fat or more) followed no visible pattern for cooked fat content. The microwave cooked bacon with exception of a raw fat content of 47.00 to 56.99% resulted in a lower moisture content than belt cooked bacon regardless of type. Retail type bacon had less ash content than foodservice type bacon regardless of cooking method and raw fat content.

Cook Yield

The target yield of 40% or less was reached with exception of the following: raw fat content 23.00-37.99 foodservice belt cooked and retail belt and microwave cooked. Microwave cookery yielded less than double belt cookery in both bacon types. Foodservice, microwave cooked bacon had the least yield across all raw fat groups. Leaner bacon yielded more and fatter bacon yielded less.

Consistent cooking was proven by statistically equal variances in cooked proximate composition (fat, moisture and ash) and cook yield. Hartley's Fmax test was useful to determine that cooking procedures were consistent within a bacon type. Validation of these procedures was pertinent for current and continued research of precooked bacon.

Although cooking procedures were consistent, the double belt cooking method holds sources of variation not accounted for (Table 19). In general, the belt cooking method resulted in higher variances for cook yield. Microwave cooking yield variances were lower. More sources of variability are able to be controlled in microwave cookery versus double belt cooking.

All treatment combinations with exception of the leanest fat group (foodservice belt, retail belt and microwave) yielded 40% or less as mandated by the USDA (USDA, 1996). Retail bacon yielded more within each cooking method compared to foodservice type bacon (Table 16). Microwave cooked bacon yielded less in both types of bacon. Foodservice type bacon was sliced thinner which may cause faster cooking compared to thicker sliced, retail type, bacon. Internal tissue of foodservice type bacon would become heated quicker than a thicker bacon which may have resulted in precooked bacon with a quicker end point doneness. Berry and Blumer (1981) reported cooking loss for precooked bacon of 59.2-76.5%.

Cooking yield by location within the bacon slab was dependent on cooking method (Table 17). Belt grill cookery yielded more than microwave cookery across all locations ($P<.007$). The most anterior and most posterior locations had higher yields than the middle locations which had similar yields within a cooking method in disagreement with Berry and Blumer (1981). Previous research found a high degree of variability in the anterior and posterior ends (Jabaay *et al.*, 1976; Stiffler *et al.*, 1975; Schroder and Rust, 1974).

Dimensional Changes

Some slices did not incur width or length changes during cooking and these slices were set to have a shrink of 0.00% in the statistical analyses. A characteristic of the double belt grill is the occurrence of lean separation in the bacon slice. This cannot be consistently replicated and could be a factor in the measurement for dimensional analysis. Efforts were made to bring the slices back to normal shape during measurement when this occurred. The degree of lean separation of belt grilled slices was not a factor when assigning distortion scores to dimensional slices.

Raw fat content and location within the bacon slab effected the length shrink for a particular cooking method (Table 18). For the same fat content and from the same location within the belly, bacon shrunk more lengthwise when cooked on the belt grill with the following exceptions: raw fat content of 53.00 - 69.00 % at the 40% and 60% locations. More length shrink was seen in the anterior part of the belly than the posterior part of the belly. Berry and Blumer (1981) found that the blade and flank ends of the belly shrink in length more than the center section of the belly when cooked. Retail type bacon tended to shrink more lengthwise across locations when microwave cooked. Food service type bacon shrunk more across all locations regardless of cooking method than retail type bacon ($P<.05$). The least length shrink was seen in the locations at 40% and 60% for all bacon types and cooking methods. As raw fat content increased more length shrinkage occurred (Table 18). More shrinkage would agree with a lower yield at the higher raw fat content levels.

In agreement with Berry and Blumer (1981), the most width shrink was seen in the locations 40% and 60% the distance from the anterior edge to the posterior edge of the bacon slab. Retail type, belt grilled bacon shrunk the least width-wise across the whole bacon slab ($P<.02$) while foodservice type, microwave cooked bacon shrunk the most. Similar to length shrinkage, width shrinkage increased as raw fat content increased. Retail type, belt grilled bacon incurred the least width shrink across all raw fat content groups ($P<.0.05$). Foodservice type bacon shrunk more when comparing similar cooking methods than retail type bacon.

Slice distortion was effected by raw fat content, location within the belly, cooking method and bacon type. Microwave cooked bacon resulted in less distorted slices than belt grilled bacon across raw fat content groups and belly slab location (Table 20). Belt grilled bacon tended to have more distortion in the anterior and posterior ends than in the middle of the bacon slab. Table 19 relates the effects of raw fat content, bacon type and cooking method on distortion. Microwave cooked bacon tended to result in less slice distortion in foodservice and retail type bacon. For retail type bacon, as raw fat content increased more slice distortion was observed. A greater difference existed in distortion across raw fat content in retail type bacon than in foodservice type bacon. Within bacon type, belt grilled bacon resulted in more distortion across the bacon slab than microwave cooked bacon (Table 20; P<.008). Except for retail type, belt grilled bacon, more distortion occurred in the ends of the bacon slab within bacon type and cooking method. Dimensional changes of the slice during cooking may in part be due to the pressing of the bacon slab prior to slicing. All bacon slabs were pressed to the same dimensions. Bacon slabs with wide center sections were forced to become more uniform in shape which changed the natural state of the bacon slab. Fatter bacon slabs were observed to incur more dimensional changes due to pressing which may effect slice distortion during cooking.

Lean bacon (both retail and foodservice types) is high yielding and minimally distorted. Smith *et al.* (1975) also found that lean bacon had the most yield. As raw fat content increased, the yield decreased and more shrinkage occurred. Kemp *et al.* (1969) likewise found that fatter bacon yielded less and shrunk more due to rendering of fat during cooking. In agreement with Jabaay *et al.* (1976), slices from the ends of the belly had a more distorted shape than slices from other parts of the belly. Foodservice type bacon had lower cooking yields than the retail type bacon within a cooking method. Microwave cookery produced lower yielding bacon. Suzuki *et al.* (1984) found that microwave cooked bacon was crisper.

Slice distortion within each location of the bacon slab may in part be due to the collagen content. Collagen shrinkage during cooking could influence shrinkage and would cause slice wrinkling.

RESULTS AND DISCUSSION

Cook Yield

Each of the lines of pigs responded inversely to fat in regard to cook yield. The fatter lines yielded a lower percentage of cooked bacon, and the leaner lines yielded a higher percent of cooked bacon. Lines 1 and 6 yielded the lowest percentage of cooked bacon. The leanest line, line 2, yielded the highest percentage of cooked bacon. Diet 4 which was fattest yielded the lowest percentage of cooked bacon. There was no significant difference in cook yield between diets 1, 2, and 3. Diet 3 did yield the highest percentage of cooked bacon. Within sex, the leaner gilts, as seen in the fat analysis, yielded a higher percentage of cooked bacon than the barrows. The same trend was seen in weight groups. The leanest weight group, 114 kg, yielded a higher percentage of cooked bacon; whereas, the 150 kg weight group yielded the lowest percentage of cooked bacon. The type of bacon, foodservice or retail, was significant. Retail type bacon yielded a higher percentage of cooked bacon.

The yield per location also followed the fatness trend of locations. Locations A and E, which were leanest, yielded the highest percentages of cooked bacon. Location C yielded the lowest percentage of cooked bacon. Within each line, locations A and E yielded a higher percentage of cooked bacon with location C consistently yielding a lower percentage of cooked bacon (Table 21). In each location, diet 3 yielded a higher percentage of cooked bacon with diet 4 yielding the lowest percentage of cooked bacon. In locations A, B, and E, diet 1 yielded a higher percentage of cooked bacon than diet 2 in disagreement with the main effect of diet. In each location of the belly, gilts yielded a higher percentage of cooked bacon than barrows. There was no significant difference in yield for gilts in locations B, C, and D. As already witnessed, locations A and E yielded the highest percentage of cooked bacon. Retail type bacon consistently yielded a higher percentage of cooked bacon than foodservice bacon across the five locations. Locations B, C, and D were not significantly different in yield. The leanest weight group of pigs (114 kg) yielded a higher percentage of cooked bacon across all locations. The difference was not significant at location A for the 114 kg and 132 kg weight group. A difference of 2.09% can be seen at location E for the 114 kg and 132 kg weight group.

Between the two cooking methods, there is a small difference in percent yield of cooked bacon. The double belt cooker yielded 0.90% more cooked bacon than the microwave. Across the lines of pigs, this trend held true except for line 6. Microwave cooking yielded 0.89% more cooked bacon in line 6. Also, there was no significant difference in the yields of microwave and belt cooking in line 5. Lines 2 and 3 produced the highest percentage of cooked bacon for both cooking methods. In each diet, belt cooking yielded a higher percentage of cooked bacon. Once again diet 3 yielded the highest percentage of cooked bacon with no significant difference between diets 1, 2, and 3. Diet 4 yielded the lowest percentage for both belt and microwave cooking. The lightest weight group (114 kg) yielded the highest percentage of cooked bacon in each cooking method with a linear decrease in yield with an increase in weight. There was no significant difference in yield for the two cooking methods for barrows. Gilts yielded a higher percentage of cooked bacon for both cooking methods. Retail bacon showed higher yields than foodservice bacon for both cooking methods with no significant difference between the two cooking methods. Locations A and E yielded a higher percentage of cooked bacon for both cooking methods. There was no significant difference in yields for locations B and D of microwave and location C of belt.

Shrink in Slice Length

Of the different breeds, line 1 and 6 exhibited the greatest shrink in length. Lines 2 and 3 showed the least shrink in length with no significant difference between them. Diets behaved differently for each line. In lines 1, 2, and 6, diet 4 produced the greatest percent shrink in length. In line 5, diet 1 resulted in the greatest shrink in length. Diets 2 and 3 produced lower percentages of shrink in length in most lines. There was no significant difference in diet 2 and 4 for line 4. There was a 1.45% difference in sexes. Bacon from gilts did not shrink as much as that from barrows. There was a minimal difference in bacon type. Foodservice bacon shrank more in length. There was no difference in shrink for gilts and barrows of the food service type bacon. Retail bacon shrank less than foodservice for both sexes.

Across locations there was a difference in percent shrink in length of 7%. Locations A and B showed the highest shrink with no significant difference between them. Locations C and D showed the least shrink with no significant difference between them. For each location, the lines behaved similarly to the main effects (Table 23). Lines 1 and 6 in location A and B produced the greatest percent shrink in length. For location A, B, and C, diets 1 and 4 produced the greatest shrink in length. At location D, diet 3 was equal to diets 1 and 4. Diet 3 produced the greatest percent shrink in length for location E. Bacon slices from gilts shrank less across all locations except location A. There was no significant difference in shrink for gilts and barrows at location A. Retail type bacon shrank less than foodservice bacon across all locations. For locations A and E, there was no significant difference between the weight groups. At locations B, C, and D, there was no significant difference in shrink in length for the 114 kg and 132 kg weight groups. Bacon slices from the 150 kg weight group shrank less at locations B, C, and D.

Microwave cooking produced a greater percent shrink in length, although not significant on a commercial level. Slices from lines 1 and 6 shrank more on the belt cooker than in the microwave (Table 24). Lines 2, 3, and 4 showed a higher percent shrink in the microwave. Line 5 showed no difference between the two cooking methods. For barrows, the belt cooker produced more shrink in length; whereas, for gilts the microwave produced more shrink in length. Bacon type followed the same trend. Foodservice bacon shrank more on the belt cooker, while retail bacon shrank more in the microwave. Difference in shrink for cook and weight group was minute. For the 114 kg and 132 kg weight group, microwave cooking produced a higher percent in shrink length. At the 150 kg weight group, belt cooking caused more shrinkage in length. At locations A and B, microwave cooking was responsible for more shrink in length. At locations C and E, there was no difference in cooking methods. Belt cooked slices shrank more at location D.

Shrink in Slice Width

Of the six lines of pigs, the fattest pigs produced the highest percent in width shrink. Line 1 had the highest percent of shrink in width. The leanest line, line 2, produced the least shrink in width. Diet 4 produced the most shrinkage in width. Diets 1 and 3 were not significantly different. Slices of bacon from gilts shrank 3.25% less than bacon from barrows. Retail bacon also shrank less than foodservice bacon. The three weight groups behaved in a linear manner. Shrinkage increased with an increase in weight.

Of the five locations of the belly, location E showed the least shrink in width. Locations A and B were slightly higher with no significant difference between them. Location C shrank the most at 32%. In each line, locations C and D showed more shrink in width with lines 1 and 6 shrinking the most (Table 25). In lines 1 and 2, location A shrank less than location B. In lines 3-6, location A shrank more than location B. Across all locations, diet 4 produced the most shrinkage. At the anterior and posterior ends of the belly, diet 2 produced more shrinkage than diet 1, but the reverse was true in the middle of the belly. Bacon from barrows resulted in the most shrink in width across locations with the greatest shrink being in the center of the belly. Bacon from gilts resulted in less shrinkage across all locations. Results for the type of bacon was very similar to sex by location. Food service bacon shrank more across all locations with the highest shrinkage in the middle of the belly. Weight group 3 (150 kg) produced more shrinkage across all locations. Once again the greatest shrinkage was in the middle of the belly.

Microwave cooking resulted in the highest percentage shrink in width as was seen in shrink in length. The difference in the two cooking methods was only 1.25%. Microwave cooking produced the most shrinkage in width across all lines except line 1 (Table 26). There was no significant difference in cooking methods in line 1. Diet 4 produced more shrinkage in slices for both cooking methods. Diet 1 and 2 were not significantly different. Shrinkage due to belt cooking was only 1% higher in barrows. Gilts showed more shrinkage with microwave cooking. Bacon type once again followed the trend for sex. The difference between cooking methods for foodservice bacon was <1%. Retail bacon shrank more due to microwave cooking. Microwave cooking produced more shrinkage in the two lighter weight groups. There was no significant difference between cooking methods in the 150 kg weight group. Microwave cooking produced the highest shrink in width in the middle of the belly. There was little difference in cooking methods in locations A, B, and E.

Distortion

The scores applied to bacon slices for distortion were subjective. With the aid of a distortion scale reference, one person would apply a distortion score to the bacon slices. An examination of the frequency of scores showed that the scores of 2 and 3 were most prominent. Bacon slices with a distortion score of 2 showed the highest frequency in all effects. The data suggests that fat could be an influence in distortion. The fatter lines of pigs showed more distortion. Barrows and heavier weight groups produced more distortion. In contrast, the fattest locations of the belly had the lowest distortion. This could be due to the change in belly composition over the five locations. The anterior end of the belly has more muscle from the shoulder. The posterior end of the belly has more muscle from the ham end. Foodservice bacon distorted more than retail bacon. The thickness of the slices could be a factor. The rapidity of cooking for the thin foodservice slices could be producing more distortion. The belt cooker produced more distortion in bacon slices. In microwave cooking, the bacon slices were sandwiched between the microwave belts with no movement during cooking. The belt cooker uses belts to move the slices between the two heating platens. There is room between the belts for the bacon to distort. The space between the belts of the belt cooker could be great enough to allow more distortion with this cooking method.

TABLE 16. **YIELD (%) MEANS AND VARIANCES BY RAW FAT CONTENT WITHIN BACON TYPE AND COOKING METHOD.**

Fat content range (%)	Food service				Retail			
	Belt		Microwave		Belt		Microwave	
	mean	var*	mean	var	mean	var	mean	var
23.00 - 37.99	41.28	9.78	39.07	7.75	41.40	3.79	40.47	3.85
38.00 - 42.99	34.37	15.39	34.26	8.73	38.24	16.72	38.10	7.69
43.00 - 46.99	34.35	11.55	32.74	5.29	37.56	11.47	36.12	9.53
47.00 - 52.99	31.18	11.55	30.48	3.42	35.32	5.47	33.42	10.32
53.00 - 56.99	27.92	3.57	27.52	2.37	34.59	8.21	29.63	1.98
57.00 - 69.00	27.28	14.09	25.93	4.94	34.12	16.26	28.59	4.06

* var = variance

TABLE 17 - YIELD (%) BY LOCATION WITHIN THE BACON SLAB.

Distance from anterior edge to posterior edge of the bacon slab	Cooking Method	
	Belt	Microwave
00%	37.33[b]	34.41[a]
20%	34.25[b]	32.41[a]
40%	33.35[b]	32.28[a]
60%	33.78[b]	32.31[a]
80%	35.68[b]	33.66[a]

Unlike letters within a row indicate significance (at least P<.007).
SEM = 0.35

TABLE 18. THE EFFECT OF RAW FAT CONTENT AND LOCATION WITHIN THE BELLY ON LENGTH SHRINK (%) OF BELT AND MICROWAVE COOKED BACON.

Distance from anterior edge to posterior edge of the bacon slab	Cooking method	Raw fat content range					
		23.00 - 37.99	38.00 - 42.99	43.00 - 46.99	47.00 - 52.99	53.00 - 56.99	57.00 - 69.00
00%	Belt	34.46[a]	35.48[ab]	36.23[ab]	36.36[ab]	37.97[b]	37.59[b]
	Microwave	35.12[a]	36.46[ab]	36.51[ab]	38.78[bc]	39.52[bc]	39.06[c]
20%	Belt	34.23[ab]	32.49[a]	36.12[bc]	37.35[cd]	39.49[d]	38.49[cd]
	Microwave	35.29[a]	34.50[a]	37.53[ab]	37.81[ab]	40.56[c]	38.64[bc]
40%	Belt	27.86[a]	28.83[a]	28.45[a]	30.21[ab]	32.70[bc]	34.10[c]
	Microwave	28.29[a]	29.34[ab]	29.38[ab]	31.21[bc]	32.65[c]	31.90[bc]
60%	Belt	25.98[a]	27.73[ab]	29.35[bc]	30.50[cd]	32.33[de]	33.89[e]
	Microwave	27.41[a]	27.38[a]	29.79[ab]	29.18[ab]	30.63[b]	28.83[ab]
80%	Belt	28.18[a]	29.99[ab]	32.40[bc]	33.44[c]	39.53[d]	37.88[d]
	Microwave	33.14[a]	33.87[ab]	33.47[a]	32.79[a]	36.37[b]	35.13[ab]

Unlike letters within a row indicate significance (at least $P<.05$).
SEM = 0.96

TABLE 19 - DISTORTION BY FAT GROUP.

Raw fat content range (%)	Food service		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}

Unlike letters within a row indicate significance (at least P<.02).
SEM = 0.07

TABLE 20 - DISTORTION BY LOCATION.

Distance from anterior edge to posterior edge of the belly	Food service		Retail	
	Belt	Microwave	Belt	Microwave
00%	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}

Unlike letters within a row indicate significance (at least P<.008).
SEM = 0.05

TABLE 21. Least Square Means ± SEM of Percentage of Cook Yield for all Interactions with Location.

Effects	Location	A	B	C	D	E	SEM	P > F
Line	1	32.54^{a}	29.61^{a}	29.48^{a}	29.96^{a}	30.97^{a}	0.54	0.0352
	2	38.60^{b}	36.17^{b}	35.18^{b}	35.79^{b}	37.19^{b}	0.67	
	3	37.60^{c}	35.15^{bc}	34.33^{bc}	34.87^{b}	36.59^{bc}	0.52	
	4	35.18^{d}	32.67^{def}	31.33^{d}	32.37^{cd}	34.13^{de}	0.47	
	5	36.36^{cd}	33.92^{ce}	33.18^{c}	33.34^{c}	35.25^{cd}	0.54	
	6	33.89^{e}	31.47^{f}	30.88^{d}	31.24^{ad}	33.25^{e}	0.47	
Diet	1	36.12^{a}	33.33^{ab}	32.22^{ab}	32.88^{ab}	34.91^{a}	0.49	0.0057
	2	35.80^{a}	33.27^{ab}	32.86^{a}	33.36^{a}	34.81^{a}	0.43	
	3	36.56^{a}	33.78^{a}	33.15^{ab}	33.53^{ab}	35.04^{a}	0.41	
	4	34.31^{b}	32.28^{b}	31.36^{b}	31.93^{b}	33.49^{b}	0.45	
Barrows		34.51^{a}	31.66^{a}	31.08^{a}	31.78^{a}	33.69^{a}	0.33	0.0001
Gilts		36.88^{b}	34.67^{b}	33.72^{b}	34.08^{b}	35.43^{b}	0.32	
114 kg		36.16^{a}	34.06^{a}	33.50^{a}	34.71^{a}	36.25^{a}	0.43	0.0001
132 kg		35.89^{ab}	33.20^{a}	32.24^{b}	32.45^{b}	34.16^{b}	0.37	
150 kg		35.04^{b}	32.23^{b}	31.44^{b}	31.62^{b}	33.28^{b}	0.40	
Foodservice		34.27^{a}	31.90^{a}	31.26^{a}	31.91^{a}	33.43^{a}	0.31	0.0006
Retail		37.12^{b}	34.43^{b}	33.53^{b}	33.94^{b}	35.70^{b}	0.32	
Belt		36.73^{a}	33.53^{a}	32.60^{a}	33.23^{a}	34.90^{a}	0.25	0.0001
Microwave		34.66^{b}	32.80^{b}	32.19^{b}	32.62^{b}	34.23^{b}	0.25	

P > F Indicates significance of interaction (at least P<0.05).

$^{a\ bc}$ Unlike letters within a column for each effect indicate significant difference (P<0.05)

TABLE 22. Least Square Means ± SEM of Percentage of Cook Yield for all Interactions. with Cooking Method.

Effects	Belt	Microwave	SEM	P > F
Line 1	31.33[a]	29.70[a]	0.52	0.0001
2	37.13[b]	36.05[b]	0.64	
3	36.82[b]	34.59[bc]	0.50	
4	33.62[c]	32.66[d]	0.45	
5	34.61[c]	34.21[c]	0.52	
6	31.70[a]	32.59[d]	0.45	
Diet 1	34.28[a]	33.50[ab]	0.48	0.0001
2	34.37[a]	33.66[a]	0.41	
3	35.21[a]	33.61[a]	0.40	
4	32.93[b]	32.42[b]	0.44	
Barrows	32.62[a]	32.47[a]	0.32	0.0001
Gilts	35.78[b]	34.13[b]	0.31	
114 kg	35.14[a]	34.73[a]	0.41	0.0001
132 kg	34.12[a]	33.06[b]	0.36	
150 kg	33.34[b]	32.11[b]	0.39	
Foodservice	33.27[a]	31.85[a]	0.30	0.0001
Retail	35.13[b]	34.75[b]	0.31	

P > F Indicates significance of interaction (at least P<0.05).

[a bc] Unlike letters within a column for each effect indicate significant difference (P<0.05)

TABLE 23. Least Square Means ± SEM of Percentage of Shrink in Length for all Interactions with Location.

Effects	Location	A	B	C	D	E	SEM	P > F
Line	1	37.28[a]	37.34[a]	31.27[ab]	31.24[a]	36.51[a]	0.42	0.0001
	2	35.38[bc]	33.85[b]	27.92[c]	28.33[bc]	33.47[bc]	0.52	
	3	35.45[b]	35.10[b]	28.85[c]	28.06[b]	32.25[b]	0.41	
	4	37.55[a]	37.16[a]	30.72[a]	29.62[d]	34.29[c]	0.36	
	5	36.67[ac]	36.00[c]	30.29[a]	29.29[cd]	33.98[c]	0.42	
	6	38.44[d]	37.93[a]	32.12[b]	31.84[a]	34.86[c]	0.37	
Diet	1	37.43[a]	36.49[a]	30.37[ab]b	30.07[a]	34.29[ab]	0.38	0.0001
	2	36.19[b]	36.08[a]	29.71[a]	28.91[b]	33.50[b]	0.33	
	3	36.22[b]	35.82[a]	29.97[ab]	29.94[a]	34.69[a]	0.32	
	4	37.34[a]	36.52[a]	30.73[b]	29.99[a]	34.41[a]	0.35	
Barrows		36.83[a]	37.30[a]	31.06[a]	30.64[a]	34.98[a]	0.26	0.0001
Gilts		36.77[b]	35.16[b]	29.33[b]	28.82[b]	33.47[b]	0.24	
114 kg		36.78[a]	36.26[ab]	30.31[ab]	29.94[ab]	34.24[a]	0.33	0.0051
132 kg		36.81[a]	36.73[a]	30.57[a]	30.07[a]	34.28 [a]	0.29	
150 kg		36.80[a]	35.69[b]	29.71[b]	29.17[b]	34.16[a]	0.31	
Foodservice		37.65[a]	37.65[a]	31.73[a]	31.04[a]	35.23[a]	0.24	0.0001
Retail		35.94[b]	34.80[b]	28.66[b]	28.42[b]	33.22[b]	0.25	
Belt		36.26[a]	35.71[a]	30.09[a]	30.30[a]	34.30[a]	0.21	0.0001
Microwave		37.33[b]	36.74[b]	30.30[a]	29.16[b]	34.15[a]	0.21	

P > F Indicates significance of interaction (at least P<0.05).

[a bc] Unlike letters within a column for each effect indicate significant difference (P<0.05)

TABLE 24. Least Square Means ± SEM of Percentage of Shrink in Length for all Interactions with Cooking Method.

Effect		Belt	Microwave	SE	P > F
Line	1	35.28[a]	34.17	0.38	0.0001
	2	31.33[b]	32.25	0.47	
	3	31.59[b]	32.30	0.37	
	4	33.41[c]	34.32	0.33	
	5	33.16[c]	33.32	0.38	
	6	35.21[a]	34.86[b]	0.33	
Barrows		34.37[a]	33.95[a]	0.24	0.0001
Gilts		32.29[b]	33.13	0.22	
114 kg		33.19[a]	33.83	0.30	0.0001
132 kg		33.53[a]	33.86	0.27	
150 kg		33.28[a]	32.93	0.28	
Foodservice		34.84[a]	34.48	0.22	0.0001
Retail		31.82[b]	32.60	0.23	

P > F Indicates significance of interaction (at least P<0.05).

[abc] Unlike letters within a column for each effect indicate significant difference

TABLE 25. Least Square Means ± SEM of Percentage of Shrink in Width for all Interactions with Location.

Effect	Location	A	B	C	D	E	SE	P > F
Line	1	30.95	32.24	37.23[a]	37.05	29.64[a]	0.77	0.0001
	2	24.00	24.26	28.42[b]	26.81	21.77[b]	0.95	
	3	25.74	24.61	30.27[b]	28.58	23.44[bd]	0.74	
	4	27.97	27.81	33.56[c]	32.23	26.95[c]	0.67	
	5	27.60	26.65	31.45[d]	30.72	24.90[d]	0.77	
	6	28.54	28.29	33.37[c]	33.16	27.21[c]	0.67	
Diet	1	26.26	27.32	32.93[a]	31.39	24.63[a]	0.70	0.0001
	2	27.90	27.52	31.66[a]	31.27	25.76[a]	0.61	
	3	27.18	26.32	30.86[b]	30.59	24.43[a]	0.59	
	4	28.51	28.10	34.10[c]	32.45	27.79[b]	0.64	
Barrows		28.73	29.17	34.17[a]	33.22	27.10[a]	0.47	0.0138
Gilts		26.20	25.46	30.60[b]	29.63	24.20[b]	0.45	
114 kg		24.86	24.20	28.94[a]	27.45	21.70[a]	0.60	0.0001
132 kg		27.37	27.16	32.74[b]	32.11	26.74[b]	0.53	
150 kg		30.17	30.58	35.47[c]	34.72	28.51[c]	0.57	
Foodservice		30.20	29.77	34.68[a]	33.65	28.35[a]	0.44	0.0266
Retail		24.73	24.86	30.09[b]	29.20	22.95[b]	0.45	
Belt		27.26	26.94	31.27[a]	30.18	25.50[a]	0.37	0.0001
Microwave		27.67	27.69	33.50[b]	32.67	25.81[a]	0.37	

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

[a bc] Unlike letters within a column for each effect indicate significant difference ($P<0.05$)

TABLE 26. Least Square Means ± SEM of Percentage of Shrink in Width for all Interactions with Cooking Method.

Effect		Belt	Microwave	SE	P > F
Line	1	33.42	33.42	0.72	0.0001
	2	23.60	26.51	0.89	
	3	24.57	28.49	0.69	
	4	29.15	30.26	0.62	
	5	27.85	28.68	0.72	
	6	30.78	29.45	0.62	
Diet	1	28.10	28.91	0.66	0.0292
	2	28.30	29.34	0.57	
	3	26.96	28.79	0.55	
	4	29.56	30.82	0.60	
Barrows		31.00	29.96	0.44	0.0001
Gilts		25.46	28.98	0.42	
114 kg		24.23	26.63	0.57	0.0001
132 kg		28.57	29.87	0.50	
150 kg		31.88	31.90	0.53	
Foodservice		31.72	30.94	0.42	0.0001
Retail		24.74	27.99	0.42	

P > F Indicates significance of interaction (at least P<0.05).

[a bc] Unlike letters within a column for each effect indicate significant difference

TABLE 27. Least Square Means ± SEM of Average Distortion Scores for all Interactions with Location.

Effect	Location	A	B	C	D	E	SE	P > F
Line	1	2.57	2.27	2.20	2.10[a]	2.43	0.04	0.0001
	2	2.59	2.21	2.10	1.98[bc]	2.26	0.05	
	3	2.51	2.20	2.06	1.98[b]	2.21	0.04	
	4	2.55	2.28	2.15	2.03[ac]	2.24	0.03	
	5	2.62	2.32	2.18	2.04[ac]	2.32	0.04	
	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	0.02	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	0.03	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	0.02	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	

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

[abc] Unlike letters within a column for each effect indicate significant difference ($P<0.05$)

TABLE 28. Least Square Means ± SEM of Average Distortion Scores for all Interactions with Cooking Method.

Effect		Belt	Microwave	SEM	P > F
Line	1	2.66	1.97	0.03	0.0001
	2	2.47	1.99	0.04	
	3	2.42	1.96	0.03	
	4	2.48	2.01	0.03	
	5	2.54	2.06	0.03	
	6	2.53	2.06	0.03	
Diet	1	2.46	1.99	0.03	0.0001
	2	2.56	1.99	0.03	
	3	2.57	2.00	0.02	
	4	2.48	2.05	0.03	
Barrows		2.63	2.07	0.02	0.0001
Gilts		2.41	1.94	0.02	
114 kg		2.44	1.97	0.03	0.0026
132 kg		2.50	1.97	0.02	
150 kg		2.60	2.08	0.02	
Foodservice		2.64	1.95	0.02	0.0001
Retail		2.39	2.06	0.02	

P > F Indicates significance of interaction (at least P<0.05).

[abc] Unlike letters within a column for each effect indicate significant difference

APPENDIX A. POST TEST CLASSIFICATION OF GENETIC TYPES

Genetic Type	Intake [a]	Growth [b]	Backfat [c]	Drip loss [d]
Line 1	High	Medium	Low	High
Line 2	Low	Low	High	Low
Line 3	Medium	Medium	High	High
Line 4	High	High	Medium	Medium
Line 5	Low	Low	High	Medium
Line 6	Medium	Low	Medium	Low

[a] Feed intake (lb/d): High (>5.7); Medium (5.4-5.7); Low (<5.4).
[b] ADG (lb/d): High (>1.7); Medium (1.61-1.69); Low (<1.6).
[c] Tenth rib backfat (in): High (<0.9); Medium (0.91-1.05); Low (>1.05).
[d] 48 hr loin drip loss (%): High (<2.05); Medium (2.05-3.0); Low (>3.0).

(Goodwin, 1998)

APPENDIX B. QLGM Nutrition Programs

Metabolizable Energy (Kcal)	**Pig Weight (lb.)**	**Added Fat (%)**	**Lysine Levels-by diet (%)** 1	2	3	4
1598	90-140	5	1.25	1.10	0.95	0.80
1560	141-190	3	1.10	0.95	0.80	0.65
1501	191-240	0	0.95	0.80	0.65	0.50
1502	241-290	0	0.80	0.65	0.50	0.35
1502	291-330	0	0.80	0.65	0.50	0.35

(Goodwin, 1998)

APPENDIX C. PICKLE FORMULATIONS FOR BACON PUMPING

Ingredient	Retail %	Retail weight (kg)	Food Service %	Food Service weight (kg)
Water	75.023	68.062	69.61	63.145
Salt [Morton Culinox 999]	1.75	13.227	2.00	15.118
Sugar [Granulated]	0.75	5.670	1.00	7.561
Natural Smoke Flavoring [Red Arrow AroSmoke P-50]	0.00	0.000	0.15	1.134
Sodium Phosphate [BK-450]	0.25	1.891	0.25	1.891
Sodium Erythorbate [PMP Eribate]	550 ppm	0.416	550 ppm	0.416
Sodium Nitrite [Heller Modern Cure - 6.25% NO_2]	120 ppm	1.451	120 ppm	1.451

APPENDIX D. NAMP #409 PORK BELLY, SKINLESS

NAMP. 1997. The Meat Buyers Guide. North American Meat Processors Association, Reston, VA.

The belly is prepared from the side after removal of the leg, shoulder, loin, fat back and spareribs. All bones and cartilages, and practically all leaf fat shall be excluded. The fat back shall also be excluded by a straight cut not more than 1.5 inches (3.8 cm) from the outermost dorsal curvature of scribe line. The anterior (shoulder) and posterior (leg) ends of the belly shall be reasonably straight and parallel. No side of the belly shall be more than 2.0 inches (5.0 cm) longer than its opposing side. The width of the flank muscle (rectus abdominis) shall be at least 25 percent of the width of the belly on the leg end. The fat on the ventral side of the belly and adjacent to the flank shall be trimmed to within 0.75 inch (19 mm) from the lean. The area ventral to the scribe line shall be free of scores and "snowballs" (exposed areas of fat) which measure 3.0 square inches (19.4 sq cm) or more. The belly shall be free of enlarged, soft, porous, dark or seedy mammary tissue. The scribe line is not considered a score but shall not be more than 0.25 inch (6 mm) in depth at any point. Skin is removed leaving a smooth skinned surface which is practically free of hair roots and scores.

APPENDIX E. THERMAL PROCESSING SCHEDULE FOR BACON

Step	Time (min.)	Dry Bulb	Wet Bulb	Relative humidity (%)	Dampers/ smoke	Comments
1	120	60°C/140°F	-----------	------	Open	
2	20	heat off/fans off**	-----------	------	closed	smoke applied*
3	45	60°C/140°F	21.2°C/100°F	26	auto	
4	IT>53.3°C/128°F	65.5°C/150°F	48.8°C/120°F	42	auto	IT>53.3°C/128°F
5	10	----------	-----------	-----	auto	Shower
6	10	----------	-----------	-----	auto	Dry

IT= Internal Temperature
* Red Arrow Products Charsol Supreme Hickory
** Liquid smoke atomization settings as follows: 60 psi to nozzle, 42+ psi to tank, flow 2.0 gph, 21.11 kg Charsol Supreme Hickory

APPENDIX F. MICROWAVE COOKING TIMES FOR RETAIL AND FOODSERVICE BACON

Type	Weight Range (g)*	Continuous Cook Time (sec)
Retail	34-88	60
	88-116	80
	116-144	90
	144-172	105
	172-200	120
Food service	15-43	40
	43-71	55
	71-99	75
	99-127	85
	127-171	100

* Weight of 5 slices for a location

APPENDIX G. PROXIMATE ANALYSIS PROCEDURES MODIFIED FROM AOAC (AOAC, 1990) AND THERMOGRAVIMETRIC ANALYZER

AOAC, 1990. Official Methods of Analysis, 14th ed. Association of Official Analytical Chemists, Washington, DC.

SAMPLE PREPARATION

Bacon samples were stored in a freezer (-20°C) prior to analysis. The sample was removed from the plastic bag with tweezers and frozen in liquid nitrogen for approximately 1-2 minutes. The sample was then removed with tweezers and put into a blender cup (250ml cup for location samples and 1L cup for composite samples) that had been supercooled in liquid nitrogen. Composite samples were divided into three subsets for ease of powdering. The sample was then powdered in a Waring Commercial Blender (Dynamics Corporation of America, New Hartford, CT) for approximately 1 minute or until the sample was completely homogenized. The powdered sample was then transferred into a clean plastic bag. An additional bag with the identification tag was placed over the sample bag and secured with a rubber band. The bagged sample was then immediately transferred to an ultra-low freezer (-90°C) for storage.

FAT (Modified from Section 27.006a, p.159)

Sample Preparation

Powdered samples were removed from the ultra-low freezer and prepared for extraction. Prior to each use, the balance (Mettler-Toledo, Inc., Highstown, NJ) was cleaned and checked for level. After zeroing the balance, the sheet of weigh paper, identification paper, and paper clip were weighed. This weight was then entered into the computer. Two grams of powdered sample was then added to the weigh paper with a supercooled spatula. The sample weight was then entered into the computer. After removing the sample from the balance, the weigh paper was folded and secured with a weighed paperclip and identification tag. Each sample was weighed in duplicate. The samples were then ready for extraction. If the extraction was not performed immediately, samples were stored in a cooler (4°C).

Extraction Procedure

A thin film of silicone grease was applied to the ground joints of the extraction tube. The boiling flask was filled with anhydrous ether until it was approximately ¾ full. A boiling stone was placed in each flask. The extraction tube was then placed on the flask. The joints were checked for firm attachment by rotating the tube ¼ turn and back again. Weighed samples were placed in the extraction tube. Each tube held twenty samples. The flask and extraction tube were setup in the extraction room and connected to the condenser. The apparatus was checked for a firm connection. The distillation water was turned on by turning the spigot ¼ of a turn. The temperature on the hot plate was set between 4½ and 5, and the solution was allowed to distill for 72 hours. All connections were checked daily. After the extraction was complete, the hot plate was turned off and allowed to cool before the flask and extraction setup were moved back into the fume hood (1½ h). The water was turned off, and the ether was poured back into the recovery container for reuse or redistillation. The finished samples were left in the hood for 2 hours to vent off any remaining ether. Samples from each distillation setup were kept in a separate pan. The samples were then transferred to the drying oven (105°C) for 24 hours before recording weights. This procedure removed fat and moisture from each sample. Fat percentage was calculated using the following equation:

[((Dry sample weight-extracted sample weight)/sample weight)-moisture)]*100

% Moisture was determined using the TGA-601

MOISTURE AND ASH (Thermogravimetric Analyzer (TGA-601) Leco Corp., St. Joseph, MI)

This method measures the weight loss of the sample as a function of temperature in a controlled environment. The analyzer consists of an electronic chassis for furnace control and data management and a multiple sample furnace which allows up to 19 samples to be analyzed simultaneously.

After the analysis method was selected, empty crucibles were loaded into the furnace carousel. This method controls the carousel, furnace, and balance operation. Once the crucibles were tared, each crucible was individually presented to the operator for sample loading. The starting sample weight was measured and stored automatically. Once all the crucibles were loaded, the analysis began. The weight loss of each sample was monitored, and the furnace temperature was controlled according to the selected analysis method. The percent weight loss in each sample for each analysis step was printed at the end of the analysis as the carousel turned and lowered the sample onto the balance. The analyzer contains a menu-driven program which allowed analysis methods to be customized. Temperature, temperature ramp rate, and atmosphere could be adjusted and saved in the TGA-601 computer.

Powered samples were removed from the ultra-low freezer. Samples were stored in a small styro-foam cooler containing liquid nitrogen to prevent thawing while loading subsamples into the TGA-601. Samples were placed on a rack to prevent direct contact with the liquid nitrogen. Sample identification numbers were entered into the computer. The method of operation was then selected (User defined).

Name	Covers	Ramp Rate	Ramp Time	Start Temp	End Temp
Moisture	Off	6 d/m	:17 min	25EC	130EC
Ash	Off	20 d/m	:30 min	130EC	600EC

Name	Atmosp	Flow Rate	Hold Time	Const. Wt.	Const Wt. Time
Moisture	N	High	:00 min	0.05%	:09 min
Ash	O	High	:00 min	0.05%	:09 min

General Setting

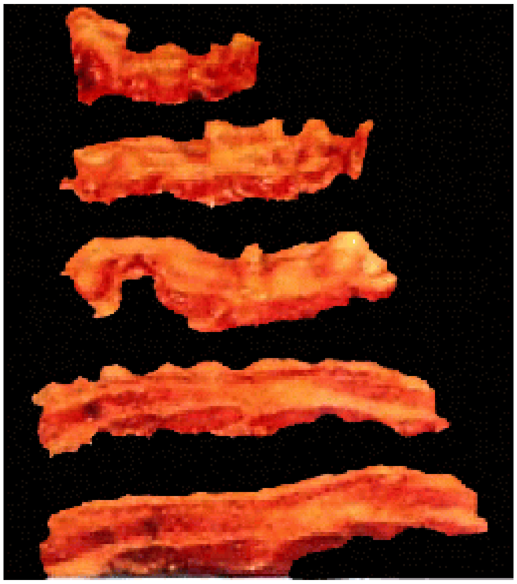
Crucible Density	3.00
Cover Density	3.00
Sample Density	1.00

Equations

Initial Wt.	W[Initial]
Moisture	[(W[Initial]-W[Moisture])/W[Initial])]*100
Ash	(W[Ash]/[Initial])*100
Ash Dry Basis	E[Ash]*[(100/(100-E[Moisture])]

Select "Analysis" and click on "collect." Next choose the furnace to be used. Load empty crucibles into selected furnace. TGA-601 will weigh all crucibles to obtain a tare weight. After tare is obtained the machine will call to load each sample (1g). Return samples to ultra-low freezer. After all samples are loaded the machine will automatically start. When analysis is finished click the "save" icon on toolbar and print a hard copy of results. Remove crucibles after they have cooled down for 30 minutes. Wash them in soapy water and allow too dry in drying oven for at least 1 ½ h. Remove dry crucibles and transfer to desiccator until future use. Before doing another run machine must cool down to 25EC. Margin of error for fat samples is 1.5% difference between duplicate samples. Margin of error for moisture is 2% difference between duplicate samples. Margin of error for ash is .5% difference between duplicate samples. The average of the original run and the rerun sample will be the reported value for fat, moisture, and ash.

APPENDIX H. BACON DISTORTION SCALE.



5

4

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