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Summary and Implications

The objective of this study was to determine the effects of genetic line, diet, sex, slaughter weight and location within the slab on the proximate composition and color of bacon lean and fat. Bacon slabs manufactured from bellies of 756 barrows and gilts of six different genetic lines equally distributed among four feeding regimes, with differing lysine levels, and three weight groups and processed into sliced retail bacon (nine slices/inch) were used. Sliced bacon slabs were divided into five equally sized sections and two bacon slices were taken from the anterior end of each for machine vision and proximate analyses. All treatments were found to have an effect on fat color, lean color and proximate composition of bacon ($P<0.05$). Genetic line had the greatest effect on bacon composition. Bacon with increased fat tended to have whiter colored fat, suggesting a link between the two attributes. Decreased dietary lysine and increased slaughter weights both led to fatter bacon slabs with whiter colored fat. Bacon produced from barrows, in comparison to gilts, and from fatter genetic lines also had lighter colored fat. Fat cell hypertrophy in fatter animals may lead to increased fat cell volume and a subsequent decrease in the concentrations of intracellular organelles and cell wall components, per unit of tissue, resulting in whiter colored fat. It appears that a number of factors combine to affect lean color as each animal production parameter in this study affected lean color in a different way. While values were statistically different between treatments ($P <0.05$), results from this study show bacon lean and fat color to be relatively consistent across treatments. Means for each were classified toward "paler" and "whiter" ends of the color scale used in this study. Understanding quality attributes of the very valuable sliced bacon market is crucial to producer understanding of the value-added component bacon contributes to the value of the pig in the marketplace.

Introduction

During the late 1980s many consumers used the nutritional merit of foods as a major food purchasing criteria; however, these same consumers are now increasingly choosing foods based on their flavor. Because of this change in consumer attitudes, bacon is enjoying a resurgence in popularity. Increasing bacon sales, primarily in the food service sector, have led to an increase in the value of raw bellies and bacon.

The increase in belly value has led to an increased interest in the effects of modem pork production methods on the belly and subsequently on bacon produced from the belly. Previous consumer preference studies have shown that lean-to-fat ratio and lean and fat color are the most important attributes in bacon purchasing decisions. The present study determined the effects of various current production methods on these factors.

Procedures

This research was just one portion of the National Pork Producers Council Quality Lean Growth Modeling (QLGM) project, which was comprised of 1,588 pigs in three test groups. The meat quality portion of the project evaluated the yield and processing characteristics of the bellies, loins and hams from these animals. Variables of interest included genetic line, target slaughter weight, actual slaughter weight, diet, sex and in the bacon portion of the study the type of bacon produced, either food service or retail, and location within the bacon slab. Because of problems with background colors bleeding through the thin sliced food service bacon, this report deals specifically with the thicker sliced retail portion of the bacon, consisting of 756 bacon slabs. Animal finishing, slaughter and fabrication were completed at NPPC owned and contracted facilities in Minnesota. Animals in the QLGM study were of six genetic lines, including Berkshire, Danbred, Duroc, Hampshire, Newsham hybrids and DeKalb. These genetic lines were selected to assure a full range of performance for growth, carcass composition and meat quality. The sampling methods used in the project do not allow these results to represent a valid genetic evaluation. Therefore, genetic lines are identified as numbers (1-6) with no particular order.

Animals were randomly assigned to three slaughter weight groups (250, 290 and 330 lb). Pens of animals were randomly assigned one of four diets (1-4). The four diets were developed with constant energy, mineral and vitamin contents but differed in protein (lysine) levels (1—high lysine, 2—intermediate high, 3—intermediate low and 4—low lysine). Intermediate diets contained lysine levels within National Research Council (NRC) 1988 guidelines while diets 1 and 4, respectively, exceeded and failed to meet these guidelines. Diets were adjusted at prespecified intervals (90, 140, 190, 240 and 290 lb) for metabolizable energy, added fat and lysine levels.

Following slaughter, bellies were removed from one side of each carcass and cut to common industry specifications. Bellies were then individually vacuum packaged, frozen and shipped to the Loeffel Meat Laboratory at the University of Nebraska where they were held in frozen storage to await further processing.

Using industrial equipment and common industry procedures and formulations, raw bellies were processed into cooked bacon slabs, which were then held in frozen storage. Slabs were transported in a refrigerated truck to a cooperating commercial bacon processor in Omaha where they were pressed and sliced. Retail-style bacon slabs were sliced to approximately nine slices per inch. Sliced bacon slabs were placed on cardboard sheets, placed in plastic bags and boxed for transfer, by refrigerated truck, to the University of Nebraska Meat Laboratory. Sliced slabs were held in frozen storage until evaluation.

Upon evaluation, damaged and partial bacon slices were removed from both ends of the slab. The slab was then measured and divided into five equal segments. The first two slices of the anterior end of each section were removed for machine vision analysis. These sample slices were packaged in paper to exclude light, which could cause color changes, and stored in a refrigerated area until machine vision analysis. A machine vision system consisting of a digital RGB camera housed in a wooden chamber with a fixed light source connected to a computer with the necessary hardware and software was used. The system was equipped with SAMPLEX® software to classify and analyze digital images.

Bacon samples were prepared and digital images were captured by the machine vision system. The color classification system used in this project was previously developed at the University of Nebraska specifically for the classification of bacon color. Data reported by SAMPLEX® were in the form of pixel counts for each of the nine programmed classes: one for background color, five for lean color, and three for fat color.

Bacon color was divided into two groups: overall fat color (FatScore) and overall lean color (LeanScore). Each was a composite color score representing an average value obtained by combining the color classes recognized by the machine vision system. FatScore was the average value of the three cured fat color classes (white, beige and dark) and LeanScore was the average value of the five cured meat color classes (very pale, pale, medium, medium dark and very dark). FatScore values of 1, 0 and -1 were assigned, respectively, to the white, beige and dark fat color classes. LeanScore 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 were as follows:

Table 1. Bacon proximate composition as affected by genetic line, diet, sex, target slaughter weight group and sampling location as main effects.^{abc}

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}	0.80	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	41.61^{a}	0.58	2.10^{a}	0.06	11.36^{a}	0.22
3	46.14^{a}	0.74	40.60^{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, lb*								
250	43.02^{a}	0.74	43.01^{a}	0.58	2.11^{a}	0.06	11.86^{a}	0.22
290	46.46^{b}	0.69	40.48^{b}	0.56	2.07^{a}	0.06	10.98^{b}	0.21
330	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}	0.40	42.21^{a}	0.33	2.24^{a}	0.05	12.07^{a}	0.12
2	47.71^{b}	0.40	39.85^{b}	0.33	2.02^{b}	0.05	10.43^{b}	0.12
3	51.03^{c}	0.40	37.45^{c}	0.33	1.88^{c}	0.05	9.64^{c}	0.12
4	48.93^{d}	0.40	38.78^{d}	0.33	2.00^{b}	0.05	10.29^{b}	0.12
5	44.66^{e}	0.40	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 composition values derived from bacon slabs of animals fed diets 1 and 4 only (individual).

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 #]

Proximate composition for protein, moisture, fat and ash was determined for the vision samples of each bacon slab.

Results and Discussion

All treatments affected color and proximate composition of bacon ($P < 0.05$). Genetic line had the greatest effect on bacon composition with an approximately 13% difference in fat content between the fattest and leanest genetic lines. Dietary lysine level also had a major effect. Diets with lysine levels below NRC guidelines resulted in bacon with significantly ($P < 0.05$) higher fat contents (Table 1) than those containing lysine levels within or exceeding the guidelines agreeing with previous research showing increased daily gain of adipose tissue with decreased dietary lysine levels. Bacon from barrows was found to have a higher fat ($P<0.05$) content than that from gilts. Bacon derived from heavier weight animals was found to be have a higher fat content.

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Table 2. Bacon lean and fat color as affected by genetic line, diet, sex, target slaughter weight group and sampling location as main effects.[abc]

Effect	FatScore[d]	S.E.	LeanScore[e]	S.E.
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[c]				
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	0.4*	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, lb				
250	0.23*	0.14	0.43*	0.04
290	0.30*	0.14	0.40*	0.04
330	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 ($P < 0.05$).

[d] FatScore is the average value of three fat color classes recognized by the machine vision system.

[e] LeanScore is the average value of five lean color classes recognized by the machine vision system.

For all treatments except sampling location, increased fat content resulted in whiter fat color in bacon, suggesting a link between the two criteria. A number of different factors could contribute to this link. One possibility is that fat cell size and/or density influences fat color. Previous research has shown that increased fat content after five or six months age in the pig is caused primarily by hypertrophy (an increase in size) of existing fat cells rather than hyperplasia (increase in number of fat cells). Following this logic, leaner bellies would have a higher density of fat cells per unit of tissue. This could lead to a darkening of fat color caused by increased concentrations of intracellular organelles and cell wall components. Increased cellular lipid content of fatter bellies would lead to a lower density of fat cells per unit of tissue. This could dilute the effect of intracellular organelles and cell walls on fat color.

Sampling location was the only treatment that deviates from the above trend. Sampling location interacted ($P < 0.05$) with weight group for 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 (Table 2), sampling locations 1, 2 and 3 each had significantly whiter colored fat than the two posterior-most locations (4 and 5). When the general makeup of locations I through 3 are considered it is seen that these locations each contain the *Pectoralis profundi* and the *Latissimus dorsi* muscles, which are found at no other locations. Perhaps either the way in which these muscles respond to processing condition or their intramuscular fat content affects overall fat color at these locations.

In comparison to all other treatments, sampling location had the largest effect on lean color of bacon. For location, lean color and fat content followed similar trends, with the exception of location 1 where increasing fatness resulted in a paler lean color. Bacon from location 1, closest to the anterior end, had a light colored lean, comparable to bacon from the fattest location (3). Of all locations, bacon from location 1 tended to have the least superficial muscle area on the medial surface of the slice. The majority of muscle area at location 1 consisted of the Pectoralis profundi and the Latissimus dorsi, which are situated deep in the slab. These muscles tended to be lighter in color than those located superficially. One possible explanation, for the light lean color at location 1, is that muscles situated deep within the slab may have an increased moisture content, compared to superficial muscles. Superficial muscles would be exposed to more severe conditions during heat processing, which could lead to a reduced moisture content and a darker color. Additionally, intermuscular fat may act as a hydrophobic barrier preventing the escape of moisture from muscle located deep within the slab.

While it appeared that fat color and fat content were related, there were no obvious linkages in regards to lean color. This research suggests that a number of factors combine to influence lean color, as each production parameter seemed to affect lean color in a different way.

In this study, reduced dietary lysine levels in the diet led to lower fat contents and darker lean colors agreeing with previous research finding that decreased fat deposition resulting in a darker colored lean. This could be a consequence of decreased intramuscular fat deposition. However, we found opposite results for slaughter weight, with darker colored lean found in bacon produced from fatter, heavier weight animals.

Divergent results suggest that a number of factors combine to effect muscle color. Color has been found to be affected by genetic differences within and between breeds as well as by changes in animal production practices. Factors such as muscle fiber type and pigment concentrations have been found to influence lean color. Prior research has found a significant variation in the metabolic profiles of muscles between breeds. Differences in sensory properties of meat have been attributed to differences in the enzymatic activities of muscles. Additionally, differences have been found in the concentration of heme pigments in muscles of different breeds.

Conclusions

Lean-to-fat ratio and lean and fat colors have been reported to be the most important attributes in consumer purchasing of bacon. Bacon with a lean content of 40% or more, when compared to bacon of higher fat contents, has been found to be more desirable to consumers. However, increased leanness can lead to a decrease in belly thickness, which could affect consumer preference. Furthermore, it has been demonstrated that leaner bacon generally contains a higher percentage of unsaturated fatty acids than fatter bacon. This is of concern because unsaturated fat has a greater susceptibility to the development of oxidative rancidity than saturated fat, which could decrease bacon shelf-life. Of all design criteria considered in this study, no individual treatment or combination of treatments resulted in bacon with an average fat content of more than 55%. Only animals of genetic line 1 produced bacon that, on average, exceeded 50% fat.

While fat and lean color differed significantly 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.

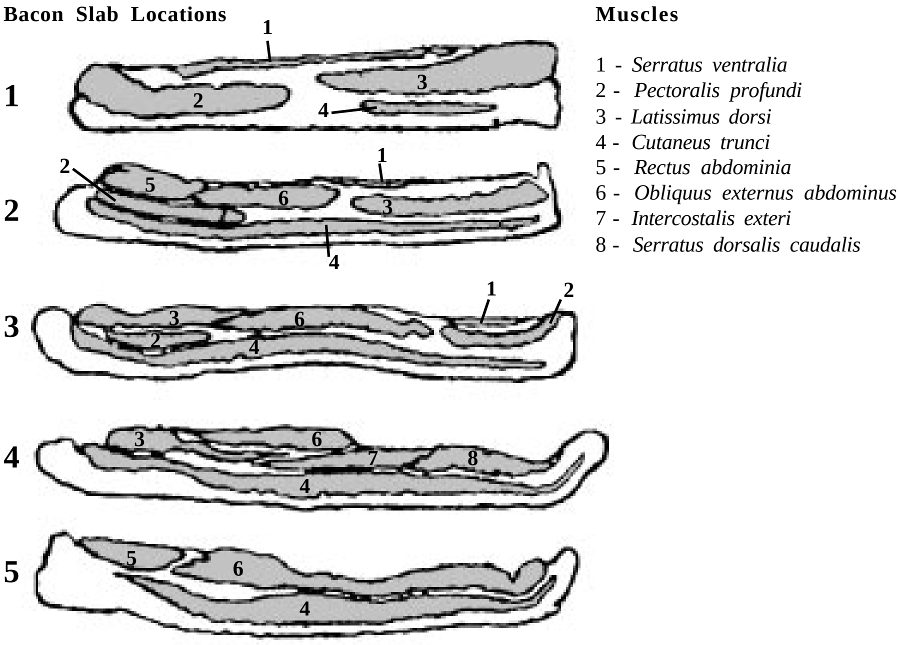

Figure 1. Orientation of belly muscles at each sampling location (Garza, 2001).

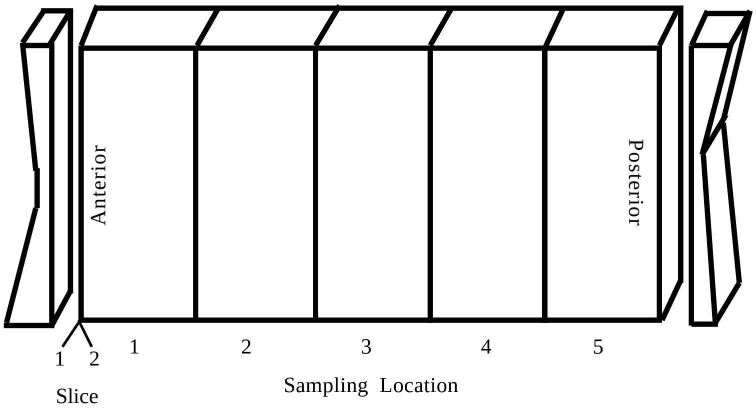

Figure 2. Bacon sampling diagram.

Like most products, there are no universal standards for "perfect" bacon. However, pork processors can use data from this project to help select raw materials that best fit the demands of their customers. 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.

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