

BENCHMARKING VALUE IN THE PORK SUPPLY CHAIN: QUANTITATIVE
STRATEGIES AND OPPORTUNITIES TO IMPROVE QUALITY IN
HAM AND BELLY PROCESSING

A Thesis

by

RYAN CHRISTOPHER PERSON

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of
MASTER OF SCIENCE

August 2003

Major Subject: Animal Science

BENCHMARKING VALUE IN THE PORK SUPPLY CHAIN: QUANTITATIVE
STRATEGIES AND OPPORTUNITIES TO IMPROVE QUALITY IN
HAM AND BELLY PROCESSING

A Thesis

by

RYAN CHRISTOPHER PERSON

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of
MASTER OF SCIENCE

Approved as to style and content by:

Jeffrey W. Savell
(Chair of Committee)

William L. Mies
(Member)

James M. McGrann
(Member)

John McNeill
(Head of Department)

August 2003

Major Subject: Animal Science

ABSTRACT

Benchmarking Value in the Pork Supply Chain:
Quantitative Strategies and Opportunities to Improve Quality in
Ham and Belly Processing.

(August 2003)

Ryan Christopher Person, B.S., Texas A&M University

Chair of Advisory Committee: Dr. Jeffrey W. Savell

Fresh bone-in hams were sorted into “high pH” (5.6 or greater) and “low pH” (5.5 or less) groups and processed into spiral sliced, bone-in hams. Randomly selected hams from each group were evaluated for objective color and purge loss during a 75-day storage period and at a “holiday thaw” or 137-day storage date. At slicing, the “high pH” group displayed lower levels ($P < 0.05$) of fluid loss. When evaluated during the “holiday thaw” period, the “high pH” group had lower L^* and higher a^* values ($P < 0.05$), as well as lower purge loss values ($P < 0.05$).

Boneless inside cushion muscles (*M. semimembranosus*) were sorted into four treatment groups: Control, Low PSE, Intermediate PSE, and High PSE. There were differences ($P < 0.05$) found between all treatments for fresh muscle pH. The Low PSE group had the lowest L^* and highest a^* values, whereas the High PSE group had the highest L^* and lowest a^* values as fresh muscles. The sorted muscles then were manufactured into 4x6 sliced ham, water added product. The Low PSE group displayed lower yield loss values during slicing. Randomly selected finished product was evaluated

for objective color and purge loss during a 75-day storage period. The Low PSE and Control groups had lower mean L^* , and lower mean purge loss values ($P < 0.05$). At day 45, consumer panel evaluations and textural measurements were collected. The Low PSE group had higher purchase intent ratings ($P < 0.05$) when compared to all other treatments.

Fresh bellies were sorted into three treatments (Thin, Average, Thick) according to thickness. Information collected included processing and slicing yields, consumer panel sensory and visual characteristics, and proximate composition values. While the Thick treatment showed yield advantages during processing and slicing, the Thin and Average groups were clearly preferred ($P < 0.05$) when the consumer panel visually evaluated the slices.

These data suggest that sorting for higher lean quality, if feasible, can be advantageous for ham manufacturing. In addition, thick bellies have proven to have an advantage during processing; however, consumers still prefer bacon that is visually leaner.

DEDICATION

I dedicate this thesis to my family. I would like to thank my parents Monte Person and Nancee Fieguth who have given me the opportunity to pursue my dreams and the guidance I need to be successful in my pursuits. They have always been there for me, and have provided an unconditional love that will never be forgotten. I would also like to recognize my sister Erin Person who has been my lifelong best friend, and who has always provided the necessary encouragement when I most needed it. Furthermore, this thesis is dedicated to my grandparents: Lorraine Person, Merle Person, and Howard and Jean Brune. My Grandma Lorraine has always been a constant supporter of my endeavors and to the judging teams I have coached. Her dedication to her family has set a lasting impression on me. My Grandpa Merle was one of my childhood heroes and has instilled many values in me that I strive to live up to in his memory. My Grandma and Grandpa Brune have always shown me unconditional support and I will always be thankful for their love. In addition, I would like to dedicate this thesis to my Stepfather Walter Fieguth and his sons Adrian and David who I was blessed to have added to my life and family four years ago.

Finally, I would like to also dedicate this thesis to the rest of my family: aunts, uncles, and cousins who have given me the love and support necessary to complete my tenure at Texas A&M.

ACKNOWLEDGEMENTS

The author would like to acknowledge and thank the members of his thesis committee: Dr. Jeffrey W. Savell (chair), Dr. William L. Mies, and Dr. James M. McGrann. It has been a pleasure and a wonderful experience to have collaborated with such highly regarded professionals. A special thanks to Dr. Savell who has been a monumental force behind the completion of my degree and who has always provided the necessary guidance and support at the appropriate times. It has been a pleasure and an unforgettable experience to work under the best.

Secondly, I would like to thank all those who made this project possible. Thanks to the American Meat Science Association, National Pork Board, and all the investors who assisted in the funding and outline of this project. In addition, thank you to the faculty and students at the University of Illinois and Colorado State University, it was a pleasure conducting this study with you all. Furthermore, I would like to thank to the people at Wright Brand Foods for the use of their facilities and input into the belly processing research.

Next, I would like to especially thank Dr. Bob Johnson and the Tyson Foods Family. Bob was the person that made this phase of the project possible, and provided the facilities and means in which we were able to collect the necessary data to make this project a success. Also, he provided a constant flow of industry insight, was a wealth of knowledge, and “make no mistake about it” provided many stories and experiences along the way.

The author would also like to acknowledge the 2001 and 2002 Texas A&M Meat Judging Teams which he had the wonderful opportunity to coach. It was truly an honor to coach these wonderful people. You guys have provided me with lifelong memories that I will always cherish. I hope that along the way you also learned an equal amount from me. I would especially like to thank Kristin Voges who served not only as a judge under me and as my assistant in 2002, but you have been a true friend. In addition, I would like to recognize Dr. Davey Griffin, the meat judging team advisor, for all of his insight and support not only during my coaching tenure, but also throughout my time as a grad student.

I would like to thank my fellow graduate students: Barret Kollé, Andy King, Tara Tschirhart, Jason Behrends, Pat Mies, John Ellebracht and Dave McKenna. It has been a great time and we have established long term friendships that I will always be grateful for. A special thanks goes out to Dave McKenna and John Ellebracht who provided extensive help and assistance throughout the length of this study. Also, thanks to the undergraduate students who assisted with this project: Stacy Mueller, Celeste Schuehle, Lesley Rakowitz, Joe Brhlik, Valerie Loeffler, Kelton and Ashlei Mason, and Lindsay Rinard. Without your help, this project would have been a much harder task to accomplish. Thank you for providing help whenever it was asked of you.

Finally, to all the others who have become my family here in Aggieland. We have forged many great relationships that I will always remember and cherish the rest of my life. Especially to all my boys who have lived in the “Bullpen”: Dalen, Grant, Tarr, Dalby and Doug “Duece” Richardson, along with the occasional visits from Betty and

Phatty. You guys have made my experience at Texas A&M one that will forever rank up there as the greatest in my life. It has been a great trip! Thanks to all of you.

TABLE OF CONTENTS

	Page
ABSTRACT	iii
DEDICATION	v
ACKNOWLEDGEMENTS	vi
TABLE OF CONTENTS	ix
LIST OF FIGURES	xi
LIST OF TABLES	xiii
INTRODUCTION	1
LITERATURE REVIEW	3
MATERIALS AND METHODS	10
Bone-in Ham Data	10
Boneless Ham Data	13
Belly Data	18
Statistical Analysis	20
RESULTS AND DISCUSSION	21
Bone-in Ham Data	21
Color	21
Water-Holding Capacity	24
Processing Yields	24
Boneless Ham Data	24
Raw Materials Selection and Processing	24
Slicing Yields and Appearance Defects	29
Finished Product Objective Quality Measurements	29
Sensory and Texture Evaluations	34
Belly Data	35
Raw Material Selection	35
Processing	38
Slicing	38
Consumer Panel Sensory and Visual Evaluation	43
Proximate Composition	43

CONCLUSIONS	51
Bone-in Hams.....	51
Boneless Ham Manufacturing.....	51
Belly Processing.....	52
LITERATURE CITED	53
VITA	57

LIST OF FIGURES

		Page
Figure 1	Locations of objective color measurements taken on bone-in hams....	12
Figure 2	Locations of pH and objective color measurements taken on inside cushion muscles used to manufacture boneless, sliced ham product...	12
Figure 3	Picture on top indicates sliced ham sorted out as normal rework and picture on bottom indicates sliced ham sorted out as “PSE-Outs”.....	16
Figure 4	Indicates the four quadrants used for objective color measurements on boneless, sliced ham product.....	17
Figure 5	Processing yields for bone-in, spiral sliced hams.....	23
Figure 6	Post transportation purge loss data for boneless ham raw materials...	28
Figure 7	Sliced, boneless ham, 4x6 package visual appearance defects. Frequency of packages with minor defects.....	30
Figure 8	Sliced, boneless ham, 4x6 package visual appearance defects. Frequency of packages with major defects.....	30
Figure 9	Sliced, boneless ham, 4x6 package visual appearance defects. Frequency of packages with no defects.....	31
Figure 10	Consumer purchase intent of finished, 4x6 ham product.....	37
Figure 11	Processing yields for three belly treatments.....	40
Figure 12	Yields of #1 and #2 slices for each belly treatment.....	41
Figure 13	Yield losses incurred during slicing.....	42
Figure 14	Consumer panel responses for bacon flavor characteristics with number of respondents per selection included	46
Figure 15	Consumer panel responses for bacon saltiness characteristics with number of respondents per selection included.....	46
Figure 16	Consumer panel responses for bacon fattiness characteristics with number of respondents per selection included.....	47

		Page
Figure 17	Consumer panel responses for bacon crispiness characteristics with number of respondents per selection included.....	47
Figure 18	Consumer panel responses for overall bacon taste acceptability with number of respondents per selection included.....	48
Figure 19	Consumer panel responses for purchase intent of bacon based on taste characteristics with number of respondents per selection included....	48
Figure 20	Consumer panel responses for visual lean to fat ratio characteristics of uncooked bacon, with number of respondents per selection included.....	49
Figure 21	Consumer panel responses for visual pink color characteristics of uncooked bacon, with number of respondents per selection included..	49
Figure 22	Consumer panel responses for overall visual acceptability of uncooked bacon, with number of respondents per selection included..	50
Figure 23	Consumer panel responses for purchase intent of uncooked bacon, based on visual appearance, with number of respondents per selection included.....	50

LIST OF TABLES

		Page
Table 1	Least squares means for color values and filter paper drip loss for bone-in hams manufactured from different quality groups.....	22
Table 2	Least squares means for color and purge measurements over storage time for each quality group of bone-in hams.....	22
Table 3	Least squares means for color values and purge loss for bone-in hams manufactured from different quality groups collected at a “holiday thaw” date.....	23
Table 4	Least squares means for color and pH values for <i>M. semimembranosus</i> sorted into quality groups.....	27
Table 5	Percentage slicing yield loss due to “normal” rework and “PSE-Outs” in each quality group.....	28
Table 6	Least squares means for color values for sliced ham packages manufactured from different quality groups taken post slicing.....	31
Table 7	Least squares means for color and purge measurements over storage time for each quality group of finished 4x6 ham packages.....	32
Table 8	Least squares means for consumer responses for visual and palatability characteristics and Allo-Kramer shear values for ham from different quality groups.....	36
Table 9	Purchase intent of consumers for ham manufactured from different quality groups.....	36
Table 10	Least squares means of belly thickness measurements taken at selection.....	37
Table 11	Least squares means of yield measurements using raw belly weight as a covariate.....	40
Table 12	Least squares means for consumer responses for sensory palatability and visual characteristics of sliced bacon.....	45
Table 13	Least squares means for proximate composition values for percentage of moisture and fat for raw and cooked bacon.....	45

INTRODUCTION

It has been 10 years since the last Pork Chain Audit was conducted for the U.S. pork industry (Cannon et al., 1995), and in those 10 years, the type, size, and value of U.S. pork has changed dramatically. It is important to understand the current issues related to pork quality facing the U.S. pork industry, and what measures and research can be conducted in the future to resolve these issues.

As consumers continue to demand a lean meat product and as packers continue to allocate incentives for the production of leaner carcasses with a higher percentage of lean, the commercial hog producer has become more aware of the improved efficiency of a faster growing, leaner, more muscular animal. As a result, the seedstock industry has been required to find ways to create leaner genetics for their customers. However, the sometimes-blind selection of extremes in leanness and muscularity has caused a recurrence of such problems that some of the same efforts produced in the 1970's and 1980's. The increased efforts put into the selection of these extreme type animals has caused the occurrence of genetic defects in relation to stress and consequently inferior meat quality. Furthermore, with the production of today's larger, leaner market hog, questions have arisen about proper and adequate chilling and its effect on ham quality. In addition, questions have been triggered with regard to adequate belly thickness and suitability for quality bacon production.

This thesis follows the style and format of the Journal of Animal Science.

The purpose of this research project was to determine the effect of inferior quality raw materials on the processing, slicing, and consumer appeal characteristics of bone-in and boneless ham products. Furthermore, due to the change in the type of live hog produced today, this research project was aimed to determine the effect of belly thickness on belly processing, as well as the slicing and consumer appeal characteristics of bacon.

LITERATURE REVIEW

The Germans prior to World War II, the Danes immediately after the War, and some researchers at the University of Wisconsin in the late 1960s all observed and/or described a condition that later became known as pale, soft, and exudative (PSE) muscle (Christian, 1997). This PSE condition has been associated with decreased processing yields, increased cooking losses, and decreased juiciness (Hedrick et al., 1993). Later in a study by Topel et al. (1968) at Iowa State University, the phenomenon known as the porcine stress syndrome (PSS) was identified. Each year since its documentation, research has added to the knowledge base concerning this genetic defect. The locus that has been linked with the PSS is also referred to as the HAL locus. However, there are still many questions on how exactly this gene is expressed, and how, if at all, technology related to the expression of this gene can be used in the pork industry.

Another genetic factor that has had a lasting affect on pork quality has been the Redement Napole (RN⁻) gene. The identification of the RN⁻ gene is based on glycolytic potential (GP). If GP is high (>180 to 200 $\mu\text{mol/g}$ of meat), the animal is considered a RN⁻ gene carrier (Monin and Sellier, 1985). The same study indicated that low ultimate pH values were dependent upon glycolytic potential in Hampshire bred hogs. Due to its frequency of occurrence in the Hampshire breed, the RN⁻ gene has also been referred to as the Hampshire gene. RN⁻ carrier pigs produce meat that is somewhat lighter in color and has a lower water-holding capacity when compared to normal RFN pork (McKeith et al., 1998). A study by Gariépy et al. (1999) found that meat from RN⁻ pigs used in the

production of extended cooked cured ham product could be utilized, but would still result in inferior yields and quality when compared to product of normal quality.

There are many genetic factors that can have effects on pork quality. Inferior quality pork is known to have a detrimental effect on the value of pork as it moves through the processing scheme. The International Pork Quality Audit identified five areas in which U.S. pork needed improvement (Morgan et al., 1995). Of those concerns, the most prevalent was the variation in lean quality. To be more competitive on a domestic and international level, the U.S. producers, packers, processors and traders need to be successful in providing a higher quality, more desirable product to meet their customers' specifications.

Hedrick et al. (1993) describes the effect of stress on inferior pork quality. They state that animals highly susceptible to stress have unusually high temperatures, rapid glycolysis (pH drop), and an early postmortem onset of rigor mortis. With the accelerated rise in antemortem muscle temperature, lactic acid buildup, and depletion of ATP, an exaggeration of the conversion of muscle-to-meat (i.e., pH drop and protein denaturation) occurs. The result is a pale, soft and watery muscle after a normal 18 to 24 hour chilling period.

Glycogen is the major source of carbohydrate energy in muscle, and it is the storage form of glucose in the muscle tissue. When energy is needed, glycogen is broken down to glucose and glucose is metabolized in the glycolytic pathway. As a result of glucose metabolism, a net yield of ATP occurs supplying the body with an energy source during muscle contraction. The end product of this metabolism is lactic acid. In living

tissue, this lactic acid is shuttled to the liver and reconverted to pyruvic acid and used as an energy source (Miller, 2000). However, this production of lactic acid in postmortem muscle accounts for pH decline.

Myosin degradation is the main factor attributed to the unacceptable exudation in PSE pork (Offer and Knight, 1988). However, Warner et al. (1997) found that we cannot find the same conclusions for red, soft, and exudative (RSE) pork, as the study showed that myosin denaturation in RSE pork is not significantly higher than that in red, firm, and normal (RFN) pork. The only recorded consistent difference between RSE and RFN pork is that the ultimate pH of RSE meat is 0.1 unit lower than that of RFN meat (Warner et al., 1997). This could possibly be a factor affecting the decrease in water-holding capacity of RSE versus RFN pork. Although there is no clear-cut explanation to the added exudation found in RSE pork, Warner et al. (1997) suggested that the occurrence of RSE pork might be related to the presence of the RN^- gene. In a later study conducted by van Laack and Kauffman (1999), results showed that there is no relation between the occurrence of RSE and the RN^- gene.

Fox et al. (1970) reported that hams derived from higher quality product bound more water ($P < 0.01$) than hams from average or inferior quality product. While Dalrymple and Kelly (1966) found that PSE and normal hams did not differ in cooking loss, results from Jeremiah and Wilson (1987) contradict this showing that cooking loss is higher in PSE product. Owen et al. (2000) found that cooking loss during cooking and smoking was not affected by any quality treatment. The same research also concluded that Warner-Bratzler Shear force (WBS) ratings were not different between quality

treatments. However, studies by Kemp et al. (1971) reported that WBS values of hams made from PSE *semimembranosus* muscles were significantly lower than those made from normal or high quality muscles. Cross et al. (1971) reported that sensory tenderness values of cured hams from normal *semimembranosus* muscles were lower than those from hams with inferior (PSE) quality.

Another negative result of inferior quality pork is the occurrence of two-toning. The occurrence of this phenomenon has been attributed to both genetics and postmortem handling. Gariépy et al. (1999) found that the occurrence of the RN⁻ gene had no effect on two-toning of the ham muscle. Monin and Sellier (1985) reported similar results, however, they went on further to show that two-toning was more related to HAL positive rather than RN⁻ pigs. Crenwelge et al. (1984) showed that ham color could be affected by use of different chilling methods. Blast and brine chilling showed to have intensifying effects on ham color versus the use of conventional chilling. Huff-Lonergan et al. (2001) described the effect of different chilling methods on pork ham color. This report states that the removal of heat has a great impact on the quality of the meat product. If heat is not removed quickly enough and pH rapidly declines, there is great potential to produce a PSE product. This can result in a product with a lower water-holding capacity. On the other hand, too rapid of a temperature decline can result in a tougher product and there is potential for crust freezing of the exterior of the muscle. This could cause the locking-in of heat on the interior of the muscle causing a two-toning phenomenon.

On average, the ham, loin and belly represent almost 52% (ham 17.4%, loin 17.7%, belly 16.6%) of the weight of a pork carcass (AMI, 1991); at the packing level,

these three cuts account for approximately 56% of the wholesale value of an average (83.92 kg carcass with 20.32 – 25.146 mm of last rib backfat) pork carcass (USDA-AMS, 2000). When marketed at a retail level, the products from these wholesale cuts will be sold as fresh, non-enhanced loin chops (~\$5.49/lb), enhanced loin chops (~\$4.79/lb), bacon (~\$3.94/lb) and boneless hams (~\$4.36/lb). Miller (2002) stated that currently the ham comprises about 18% of the live pig and 24% of the pork carcass. The increase in ham weight or percentage compared to the above factors can be contributed mostly to the increase in lean weight production of market hogs over the past decade. As the market hog has gone from an average live market weight of 250 to 290 lbs., the ham primal has increased in weight significantly, resulting in an increase in value (Miller, 2002).

Although the 1992 Pork Chain Audit concluded that the U.S. pork industry sacrificed \$10.10 (at the packing level) for each of the 88 million barrows and gilts slaughtered in 1992 (Cannon et al., 1995), even greater economic losses resulting from quality defects were undoubtedly incurred downstream as value-added pork neared the ultimate consumer.

Upon completion of the 1992 Pork Chain Audit, solutions were recommended to the U.S. pork industry to reduce the approximate 10% of total carcass value forfeited by the industry due to defects at the packing level. It is reasonable to deduce that these value losses could have been five to ten times greater had they been quantified at the processing or retail levels.

Since completion of the Pork Chain Quality Audit, the U.S. pork industry has forged its way through the lowest market prices since 1972, with market pig prices falling

to an average of \$13.92/cwt in December of 1998 (NPPC, 2000/2001). Despite the depressed pork markets, production of pork continues to increase, with growth estimates for 2001 and 2002 exceeding 3%, pushing federally inspected (FI) slaughter estimates for 2002 up to 104 million hogs (Grimes and Plain, 2000). To match this increase in production, consumer demand, which has been relatively stable over the last 20 years and ranged from a retail weight low of 48.7 pounds per capita in 1997 to a high of 51.7 pounds per capita in 1989 (NPPC, 2000/2001), must also be stimulated by improving consumer perceptions of satisfaction received per dollar spent for pork at retail.

Because consumers have become more concerned about health and diet issues, they have demanded leaner meat products (Burke Marketing Research, 1987). As a result, producers have engaged in genetic selection aimed at leaner, more muscular animals. In an effort to improve consumer acceptability of pork products, namely bacon, pork producers have followed this same suit. Currently, the market hogs being produced are much leaner and more muscular, and require fewer days on feed to reach ideal market readiness (Plain, 2000). Mandigo (2002) reported similar findings, stating that bacon accounts for 11% of the hog carcass today versus 15-18% two to three decades ago. This report also states that the amount of separable fat in a belly has changed dramatically over the past 40 years from 68 to 75% to the 45 to 55% found in today's bellies.

In the 1970's, work reported by West et al. (1973) and Jabaay et al. (1976) found that consumers gave higher ratings to leaner bacon with greater muscle distribution when viewing uncooked slices. Slices with greater amounts of lean distribution also had higher appearance ratings after being cooked. West et al. (1973) reported that consumers

surveyed determined that bacon with less than 30% distribution of lean was unacceptable. Consumer appearance rankings for cooked bacon paralleled these results found for uncooked bacon. It is clear that leaner bellies used for bacon production have a distinct advantage in consumer acceptance, however, Jabaay et al. (1976) reported that fatter, thicker bellies possessed advantages in processing yields compared to the leaner bellies. Stites et al. (1991), however, found no significant relationship between belly weight and processing yields.

Little research has been done to look at the relationship between bellies sorted on thickness and their processing, slicing and consumer preference attributes. Because we have seen an 0.8 lb. increase, per year, in market hog slaughter weight for the last 40 years, while also now producing hogs that are 31% leaner than those in 1983 (Plain, 2000), it should be advantageous to know if these drastic improvements in leanness have had an effect on processing and slicing yields. It would also be valuable information to know if these changes have affected consumer acceptance or preference of sliced bacon.

Due to the unique nature of the pork industry and the large value discrepancies between carcasses, fresh muscle items and processed products, it is necessary to characterize further the cost of quality defects at processing levels downstream to the packer in the marketing chain.

MATERIALS AND METHODS

Bone-in Ham Data

Fresh bone-in hams were sorted on the fabrication line according to pH in the *M. psoas major*. The hams were sorted into two groups, a “high pH” group (pH equaled 5.6 or higher) and a “low pH” group (pH equaled 5.5 or lower). After sorting, the hams were processed under the normal, plant-specific, commercial procedure and made into bone-in, spiral-sliced hams. During the process, data were collected for cook and chill shrink, pack-off yield, and final yield. Hams then were cut and packaged into rump and shank sections where data were collected for the occurrence of #1 and #2 packages. #1 packages were defined as premium quality product with no visible defects in the package, while #2 packages were defined as secondary quality product with visible defects in the package that would cause a lack of consumer appeal.

At 10 minutes after bisection, hams (n = 20) per group were selected randomly for a filter-paper (Kauffman et al., 1986) drip loss test according to guidelines outlined by National Pork Board (2000). After packaging, samples were again randomly selected and HunterLab CIE L*, a*, and b* measurements (HunterLab MiniScan™ XE, equipped with a 25.4 mm aperture, HunterLab Associates Laboratory, Inc., Reston, Virginia) were recorded for each group. Measurements were taken in the visual middle of the *M. semimembranosus*, *M. biceps femoris*, and *M. semitendinosus* muscles and recorded (See Figure 1).

Random samples ($n = 24$) were selected from each group, alternating between rump and shank sections, and were shipped to Texas A&M University. The samples were stored in a 2°C cooler where CIE L^* , a^* , b^* , and purge loss in package data were collected at 30, 45, 60, and 75 days. Three hams were selected randomly per group to be assessed at each treatment day, with the remaining 12 samples stored in a -10°C freezer for 137 days, with the same measurements taken at a holiday thaw date around the

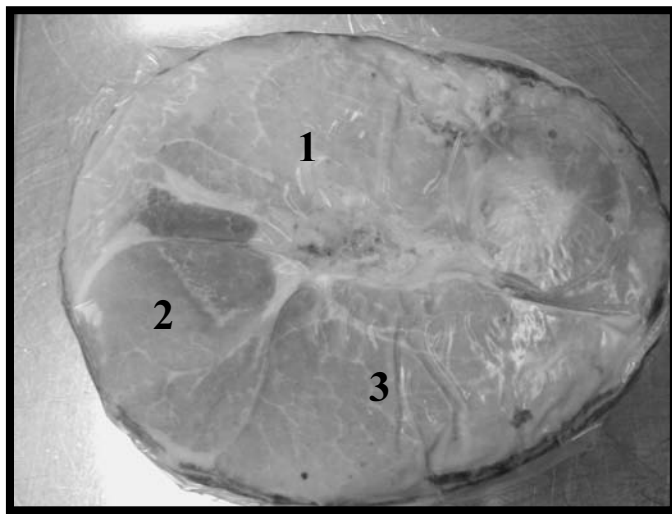


Figure 1. Locations of objective color measurements taken on bone-in hams. (1 = *m. semimembranosus*, 2 = *m. semitendinosus*, 3 = *m. biceps femoris*)



Figure 2. Locations of pH and objective color measurements taken on inside cushion muscles used to manufacture boneless, sliced ham product. Picture on left references “inside” measurement and picture on right indicates “outside” measurement.

Christmas holiday. Those samples were allowed to thaw at 2°C for 24 days before measurements were taken.

Boneless Ham Data

Boneless, inside cushion, cap-on muscles (*M. semimembranosus* and *M. gracilis*), characterized subjectively by the amount of pale and soft lean according to NPPC (1999) guidelines for color, were sorted into commercial combo bins (~771.12 kg) off the processing line. Muscles were sorted into three treatment groups with between three to four combos representing each treatment group. The three treatment groups were Low PSE, Intermediate PSE, and High PSE. Also, four combos were collected during a normal processing run and were labeled as the Control group. At the time of sorting, CIE L*, a*, b*, and pH (SFK pH Star) measurements (n = 100) were taken at two spots (See Figure 2) on the medial side of randomly selected muscles in each treatment.

The raw materials selected then were shipped to a commercial processing plant for further processing. At the time of receiving, a PSE cut-out was performed on ~ 45.36 kg per treatment group to validate the visual sort. We found the following ranges of percentage of PSE lean in each group: Low PSE (< 5%), Intermediate PSE (~ 20% to 30%), and High PSE (~ 40% to 60%). Purge amount was collected for each combo and averaged per treatment group to analyze purge loss between raw material selection and further processing. The inside cushion muscles then were injected, emascerated, tumbled, formed, cooked, and sliced under plant-specific, commercial procedures to make a 4x6 sliced ham, water added product (4 inch by 6 inch package of sliced ham

weighing approximately 16 oz.).

After thermal processing and a chill/storage period (2°C), the 4x6 ham logs were sliced and yields were recorded. Data were collected to represent the slicing losses due to “normal” rework (i.e., small tears, end pieces, or any other minor defect not related to inferior quality product), “PSE – Outs” (product sorted off the line due to severe quality defects), and a total yield loss, which is the combination of “normal” rework and “PSE-Outs” (Figure 3). At the time of slicing, CIE L*, a*, and b* color measurements were obtained from four quadrants (See Figure 4) on randomly selected packaged products (n = 100).

Each package produced also was evaluated for visual appearance defects related to the amount and severity of PSE type muscle in the finished product. Scores of minor, major or no-defect were assigned subjectively to each package in each treatment to attempt to relate merit relative to consumer appeal. Those packages with minor color uniformity blemishes, or one or two small pale spots, were considered to have minor appearance defects. Packages with major color uniformity blemishes, large or numerous pale spots, or small pockets due to PSE muscle (exhibited by clear lack of protein functionality) were considered major defects. Those packages exhibiting uniform color, and very minimal, if any, pale spots were rated as no-defect.

Some finished, packaged product was selected randomly and shipped to Texas A&M University to be evaluated at 15, 30, 45, 60, and 75 days of storage for CIE L*, a*, and b* color measurements (using the same method performed at slicing), and for purge loss in the package. Purge loss was measured by collecting and weighing the purge

inside the package, and verified by weighing the amount of sliced ham product plus
purge, plus tarred weight of package minus the initial weight of packaged product before

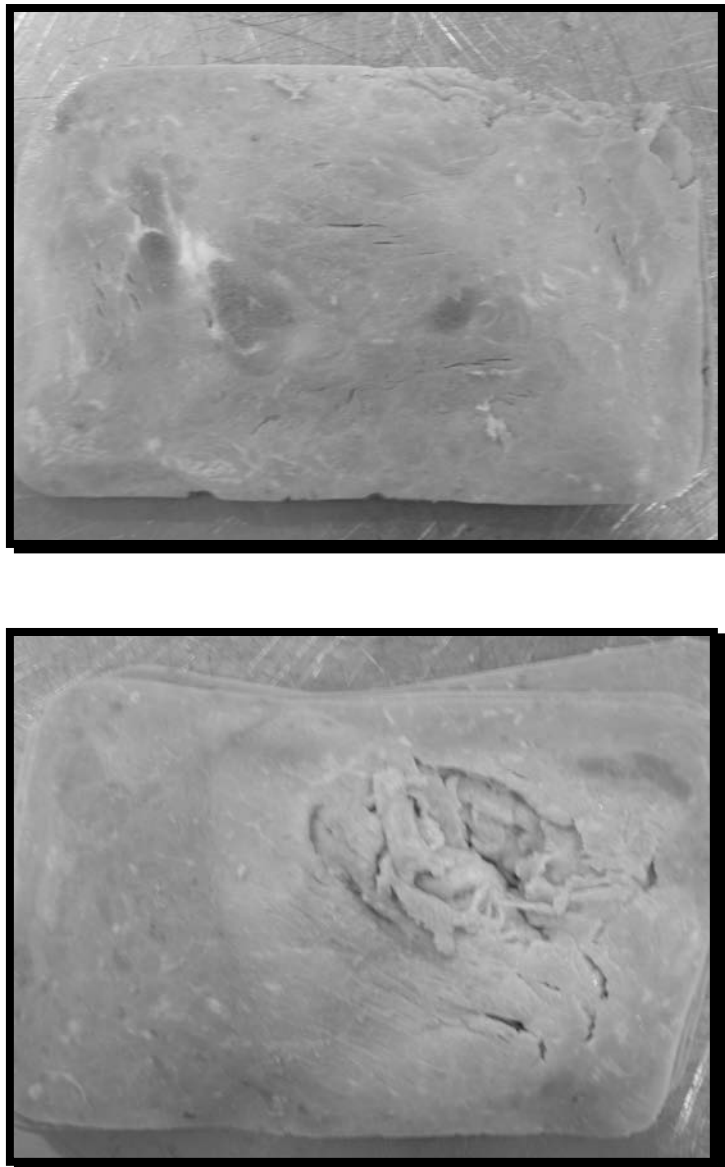


Figure 3. Picture on top indicates sliced ham sorted out as normal rework and picture on bottom indicates sliced ham sorted out as “PSE-Outs”.

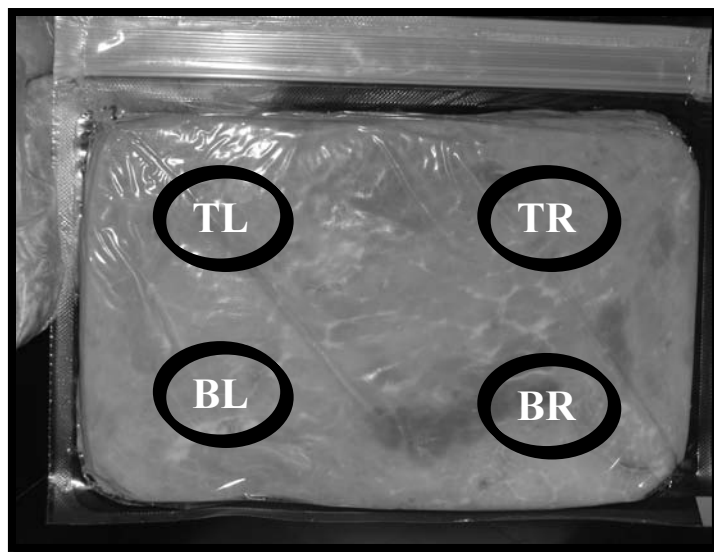


Figure 4. Indicates the four quadrants used for objective color measurements on boneless, sliced ham product (TL = Top Left, TR = Top Right, BL = Bottom Left, BR = Bottom Right).

purge was collected. At day 45, Allo-Kramer shear measurements were taken on samples from each treatment group (200 slices per treatment group with two measurements per slice) and were reported on a kg/g basis. At day 45, sensory evaluation was performed by a consumer panel. Panelists were asked to evaluate randomly assigned samples from each treatment group for flavor, overall like of flavor, visual appeal, and color. For each of the evaluations, panelists ranked the samples on an 8-point scale (1 = extremely dislike and 8 = extremely like). Also, purchase intent information was collected by asking the panelists to select and rank three packages from a random assortment of 12 packages. Within the 12 packages were three packages from each of the treatment groups and the control group. After ranking, panelists were asked to give a brief reasoning for their selection.

Belly Data

At a large commercial bacon processing company, bins (~544.32 kg) of fresh bellies (5.44 to 6.35 kg, and 6.35 to 7.26 kg) were used to select and sort bellies that were characterized by thickness as thin, average, and thick. Bellies (n = 96) from each thickness group were selected and measured, using a calibrated ruler at six positions on the raw belly. Measurements were taken at the blade, center, and ham end of the bellies on both the dorsal and ventral side.

The raw bellies then were transferred to the skinning line where the outer skin surface was removed. At this step, skin weights were taken for skinning yield values. After skinning, the bellies were pumped, chilled, cooked/smoked, chilled, pressed, and

sliced using the commercial plant's normal processing procedures. During this process weights and measurements were recorded to assess cook yield, slice yield, and #1 vs. #2 slices. #1 slices were defined as slices that met all consumer specifications for secondary lean and slice thickness, while #2 slices were those slices that didn't meet specifications for secondary lean or for slice thickness, and would be sold at a discount. Cook yield was analyzed using weight as a covariate as some bellies in the thick group were taken from a heavier weight range to achieve an equal number of bellies per treatment.

At slicing, an equal number of samples were selected randomly from the center portion of every third belly ($n = 32$ per treatment) and were packaged to be evaluated for consumer sensory analysis and proximate analysis at the University of Illinois. Bacon was cooked for 12 min on racks in a convection oven at 450°F. Racks were rotated at 6 minutes to ensure even cooking throughout the slice. Bacon was drained on paper toweling and presented in random order as individual slices on paper plates. Panelists ($n = 120$) evaluated one slice of cooked bacon from each treatment group for sensory characteristics. For visual evaluations, bacon slices in vacuum packages were evaluated under fluorescent (cool white) light against a white background with one package of each treatment in a separate evaluation cubicle to prevent visual comparison.

Both sensory and visual evaluations were scored on 5-point scales: for flavor, fattiness, saltiness, crispiness, leanness, and pinkness (1 = much too little, 2 = somewhat too little, 3 = just right, 4 = somewhat too much, 5 = much too much), and for taste and visual acceptability (1 = extremely unacceptable, 2 = moderately unacceptable, 3 = neither, 4 = moderately acceptable, 5 = extremely acceptable). Furthermore, purchase

intent for taste and appearance was scored (1 = definitely, 2 = probably, 3 = might, 4 = probably not, 5 = definitely not).

Five slices of raw and five slices of cooked bacon were chosen randomly from each treatment, and then were ground and analyzed for moisture content by using standard methods (AOAC, 1993). Furthermore, bacon samples were evaluated for fat content using a 2:1 chloroform:methanol mixture method for lipid analysis as described by Bligh and Dyer (1959).

Statistical Analysis

Statistical analyses including descriptive statistics, frequency distributions and analysis of variance (ANOVA) were performed using SAS (SAS, 2001). Data were analyzed by ANOVA using the General Linear Models procedure of SAS (SAS, 2001). The alpha level was set at 0.05 throughout the study.

RESULTS AND DISCUSSION

Bone-in Ham Data

Results for data collected at the plant during product selection, during the storage period, and after the “holiday thaw” period are shown in Tables 1, 2 and 3, respectively.

Color. There were minimal differences in the objective color evaluations taken during product selection at the plant. Mean a^* values were higher ($P < 0.05$) for the “high pH” treatment, indicating a slightly redder color (Table 1). During the storage period, there was a trend for the color to get lighter over the storage period as the L^* values tended to be higher as they reached day 75 (Table 2). Both the “low pH” and “high pH” groups displayed the highest L^* values at day 75, however, these values did not differ significantly from those L^* values of the “low pH” hams at days 30 and 60. Day 45 of the “low pH” group, however, did display higher mean L^* values ($P < 0.05$) compared to those previously mentioned. Mean L^* values at days 30, 45 and 60 for the “high pH” group were lower ($P < 0.05$) compared to the rest of the treatment/day comparisons.

The only significant values observed in the mean a^* evaluation were those of the “high pH” group with product at days 30, 45 and 60 being higher ($P < 0.05$) than the rest of the combinations. There were no significant differences found in the mean b^* values.

Objective color measurement differences were the most significant between the two treatment groups at the holiday thaw period (Table 3). Mean L^* values were significantly lower and mean a^* values were higher ($P < 0.05$) for the “high pH” group.

Table 1. Least squares means for color values and filter paper drip loss for bone-in hams manufactured from different quality groups

Group	Parameter			Fluid Loss	Drip Loss
	L*	a*	b*	(mg)	(%)
High pH	63.89 ^a	12.31 ^a	10.85 ^a	68.08 ^a	3.98 ^a
Low pH	64.48 ^a	11.48 ^b	10.85 ^a	90.24 ^b	5.31 ^b
SEM ^c	0.60	0.25	0.19	5.19	0.31

^{a,b}Least squares means within a column lacking a common superscript are different ($P < 0.05$).

^cSEM is the standard error of the least squares means.

Table 2. Least squares means for color and purge measurements over storage time for each quality group of bone-in hams

Parameter	Group	Storage day			
		30	45	60	75
L*	High pH	60.59 ^e	62.79 ^{de}	63.32 ^{cde}	66.51 ^{ab}
	Low pH	65.56 ^{abcd}	63.84 ^{bcd}	65.92 ^{abc}	67.29 ^a
	SEM ^f	1.04	1.04	1.04	1.04
a*	High pH	12.85 ^a	12.22 ^{ab}	12.62 ^a	11.23 ^{bc}
	Low pH	11.30 ^{bc}	12.14 ^{ab}	11.33 ^{bc}	10.94 ^c
	SEM ^f	0.39	0.39	0.39	0.39
b*	High pH	9.97 ^a	10.84 ^a	10.46 ^a	10.74 ^a
	Low pH	10.17 ^a	10.55 ^a	10.22 ^a	10.77 ^a
	SEM ^f	0.40	0.40	0.40	0.40
Purge loss (g)	High pH	43.27 ^a	24.69 ^a	32.99 ^a	40.35 ^a
	Low pH	55.23 ^a	46.44 ^a	33.31 ^a	53.97 ^a
	SEM ^f	12.95	12.95	12.95	12.95
Purge loss (%)	High pH	1.08 ^a	0.71 ^a	0.93 ^a	1.26 ^a
	Low pH	1.54 ^a	1.39 ^a	0.98 ^a	1.48 ^a
	SEM ^f	0.34	0.34	0.34	0.34

^{a,b,c,d,e}Least squares means within a parameter lacking common superscripts are different ($P < 0.05$).

^fSEM is the standard error of the least squares means.

Table 3. Least squares means for color values and purge loss for bone-in hams manufactured from different quality groups collected at a “holiday thaw” date

Group	Parameter				Drip Loss (%)
	L*	a*	b*	Fluid Loss (mg)	
High pH	62.89 ^a	12.17 ^a	10.95 ^a	71.77 ^a	4.19 ^a
Low pH	67.88 ^b	10.65 ^b	10.79 ^a	105.30 ^b	6.89 ^b
SEM ^c	0.71	0.29	0.15	6.88	0.44

^{a,b}Least squares means within a column lacking a common superscript are different ($P < 0.05$).

^cSEM is the standard error of the least squares means.

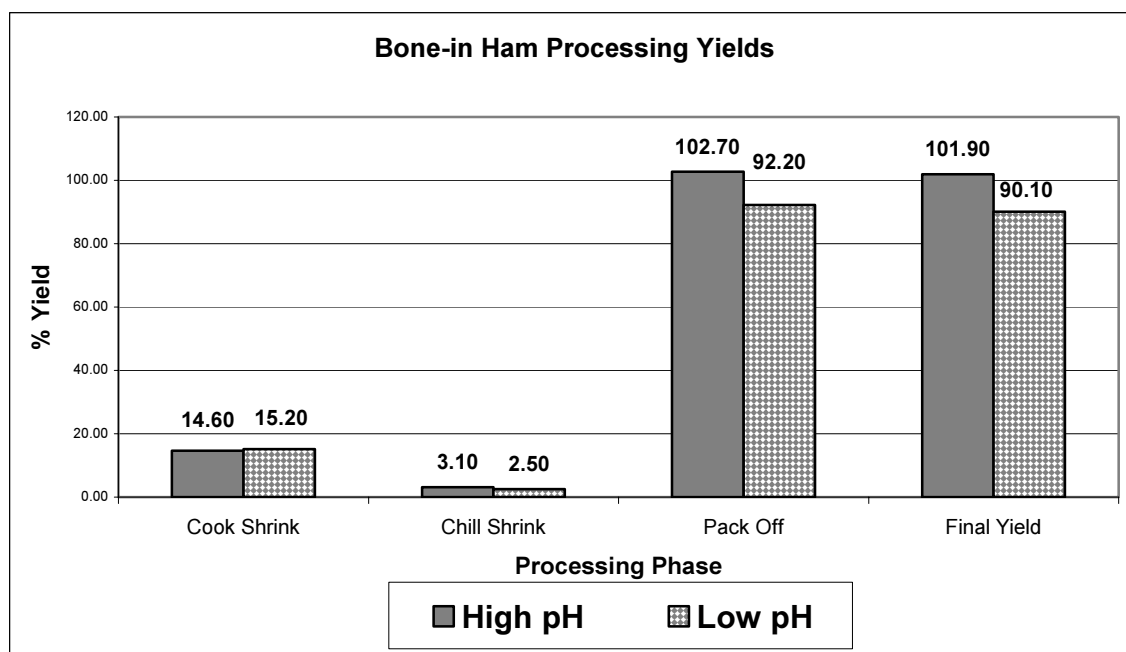


Figure 5. Processing yields for bone-in, spiral sliced hams.

Water-Holding Capacity. Measurements from the filter paper test taken at bisection of the bone-in hams were analyzed and expressed as both mg of fluid loss and percentage of drip. In both cases, the “high pH” treatment displayed lower ($P < 0.05$) levels of fluid or drip loss (Table 1).

Purge loss values collected over the 30, 45, 60, and 75 day storage periods and at the holiday thaw period were evaluated and expressed as grams of fluid loss and percentage of fluid lost. There were no significant differences found for any of the treatment/day combinations. However, purge values collected at the holiday thaw were lower ($P < 0.05$) for the “high pH” treatment for both grams of fluid loss and percent fluid loss (Table 3). When these results were compared with those of the objective color results taken at the holiday thaw period, it appears there could be a loss of protein quality and functionality taking place during this storage period.

Processing Yields. Figure 5 displays the simple mean yields calculated during processing. Percentage values obtained for cook and chill shrink show minimal differences. However, the values calculated for pack-off yield (after slicing and packaging) and final yield (after #2 hams removed) were clearly in the favor of the “high pH” hams. This indicates significant product loss during slicing most likely due to soft and watery product.

Boneless Ham Data

Raw Materials Selection and Processing. Table 4 represents the objective color and pH values recorded during the sorting process of the boneless, inside cushion

muscles. These values were for the color and pH measurements taken at 1) the “inside” and 2) the “outside” of the medial surface of the *M. semimembranosus* muscle, and 3) the mean of these two measurements. Figure 2 illustrates these points of measurement.

There were significant value differences found between all of the treatment groups for objective color values, which validates the visual sorting process employed. The only mean L^* and b^* values not significantly lower when the Low, Intermediate, Control, and High PSE groups were compared were the Control and Intermediate group when measured at the “outside” area. Also, objective a^* values were highest ($P < 0.05$) for the Low PSE group at all three evaluations when compared to all groups. Inversely, these values were also the lowest ($P < 0.05$) for the High PSE group when compared to all groups, with exception to the “outside” measurement, which was not different.

Fresh muscle pH measurements were different ($P < 0.05$) between all treatment groups and at all measurement areas. These measurements differed on an average range of ~ 0.20 between the groups. The highest pH measurements were found in the Low PSE group while the lowest was in the High PSE group. Those measurements taken at the “inside” area were slightly higher than those taken at the “outside” area of the muscle.

Before further processing of the inside cushion muscles, values were collected for purge loss accumulated during the transportation process. These values were expressed as a percentage loss compared to the combo weight and presented in Figure 6. There was little difference found in the loss of fluids between the Low PSE and Control groups, however, there was an increase of $\sim 0.3\%$ to 0.4% loss in the Intermediate group and a

significant increase of fluid loss of greater than 1.5% in the High PSE group when compared to all groups on combos of raw materials.

Table 4. Least squares means for color and pH values for *M. semimembranosus* sorted into quality groups

Parameter	Group	Location		Mean
		Inside	Outside	
L*	Control	59.19 ^c	55.74 ^b	57.47 ^c
	Low PSE	55.68 ^d	53.38 ^c	54.53 ^d
	Intermediate PSE	63.23 ^b	56.43 ^b	59.83 ^b
	High PSE	67.89 ^a	60.51 ^a	64.20 ^a
	SEM ^e	0.44	0.45	0.36
a*	Control	6.95 ^b	7.73 ^b	7.34 ^b
	Low PSE	8.22 ^a	8.55 ^a	8.39 ^a
	Intermediate PSE	7.30 ^b	8.09 ^{ab}	7.70 ^b
	High PSE	5.99 ^c	6.44 ^c	6.22 ^c
	SEM ^e	0.17	0.18	0.14
b*	Control	11.05 ^c	10.47 ^b	10.76 ^c
	Low PSE	9.45 ^d	8.95 ^c	9.20 ^d
	Intermediate PSE	12.63 ^b	10.34 ^b	11.49 ^b
	High PSE	14.54 ^a	12.21 ^a	13.38 ^a
	SEM ^e	0.17	0.16	0.14
pH	Control	6.02 ^b	5.94 ^b	5.98 ^b
	Low PSE	6.23 ^a	6.05 ^a	6.14 ^a
	Intermediate PSE	5.87 ^c	5.77 ^c	5.82 ^c
	High PSE	5.64 ^d	5.60 ^d	5.62 ^d
	SEM ^e	0.02	0.02	0.02

^{a,b,c,d} Least squares means within a parameter and column lacking a common superscript are different ($P < 0.05$).

^eSEM is the standard error of the least squares means.

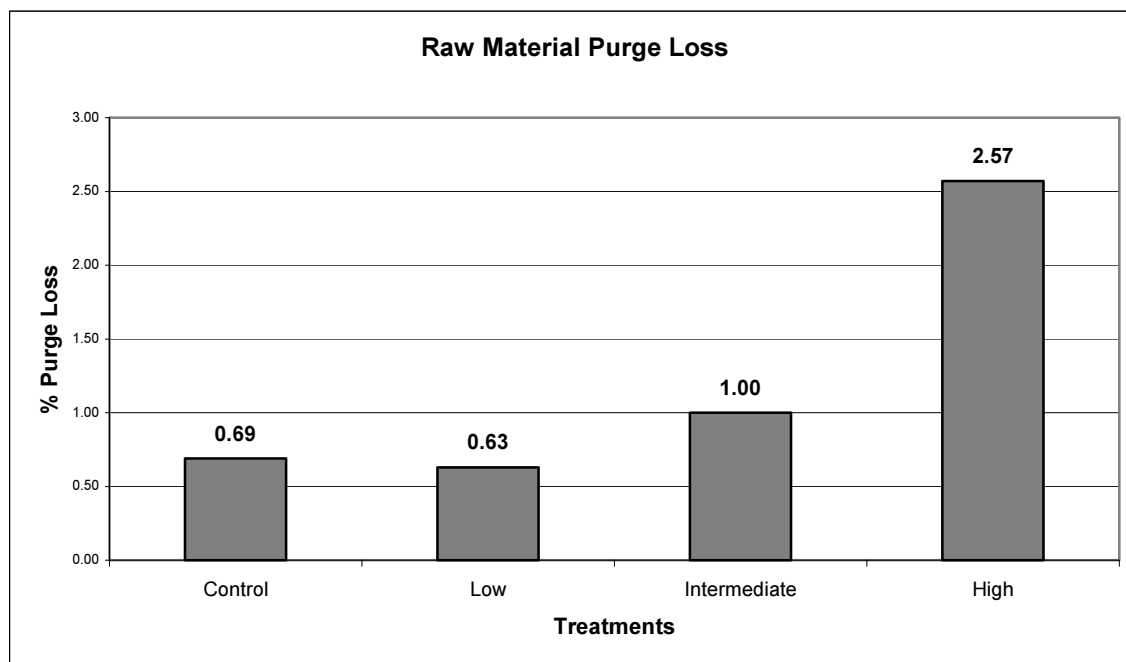


Figure 6. Post transportation purge loss data for boneless ham raw materials.

Table 5. Percentage slicing yield loss due to “normal” rework and “PSE-Outs” in each quality group

Group	Observed Defects		
	Normal Rework	PSE-Outs	Total Yield Loss
	-----%		
Control	2.28	4.31	6.59
Low PSE	1.01	1.35	2.36
Intermediate PSE	3.10	8.85	11.95
High PSE	2.14	7.14	9.28

Slicing Yields and Appearance Defects. Overall, the Intermediate group performed the worst during slicing, exhibiting the highest total yield loss at 11.95%, whereas the Low PSE group clearly had a lower total yield loss mostly due to distinct advantages found in the low percentage loss of “normal” rework (Table 5). When comparing the loss due to “PSE-Outs,” the High PSE group surprisingly matched up with the Control group, but had two times the loss when comparing their “normal” rework values resulting in a higher total yield loss.

After the rework and “PSE-Outs” had been sorted out, each 4x6 package was evaluated for appearance defects (Figures 7 to 9). Clearly, the Low PSE group outperformed the other treatments. It had the lowest percentages of minor and major appearance defects and, by far, the highest percentage of packages with no defects. The High PSE group had the most minor and major defects and least minor defects, however, the difference in major defect percentages were fairly small with the exception to the Low PSE group. As the amount of PSE muscle increases in the raw product, more consumer appeal issues could possibly be raised in the finished product.

Finished Product Objective Quality Measurements. Finished 4x6 boneless, sliced and packaged ham statistics are reported for color values recorded at slicing (Table 6) as well as color and purge values obtained during the storage period (Table 7). Objective color values taken at slicing, after the product was packaged, showed a difference ($P < 0.05$) in L^* values between each treatment with the Low PSE group exhibiting the lowest mean L^* values and the High PSE group having the highest L^* values. Although little

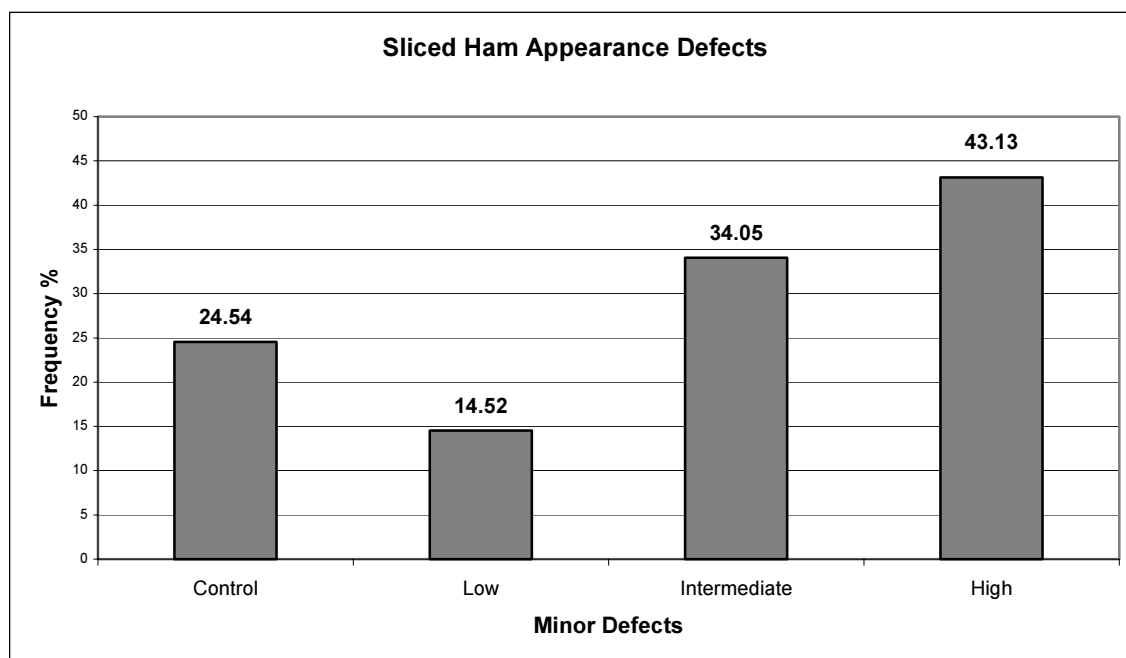


Figure 7. Sliced, boneless ham, 4x6 package visual appearance defects. Frequency of packages with minor defects.

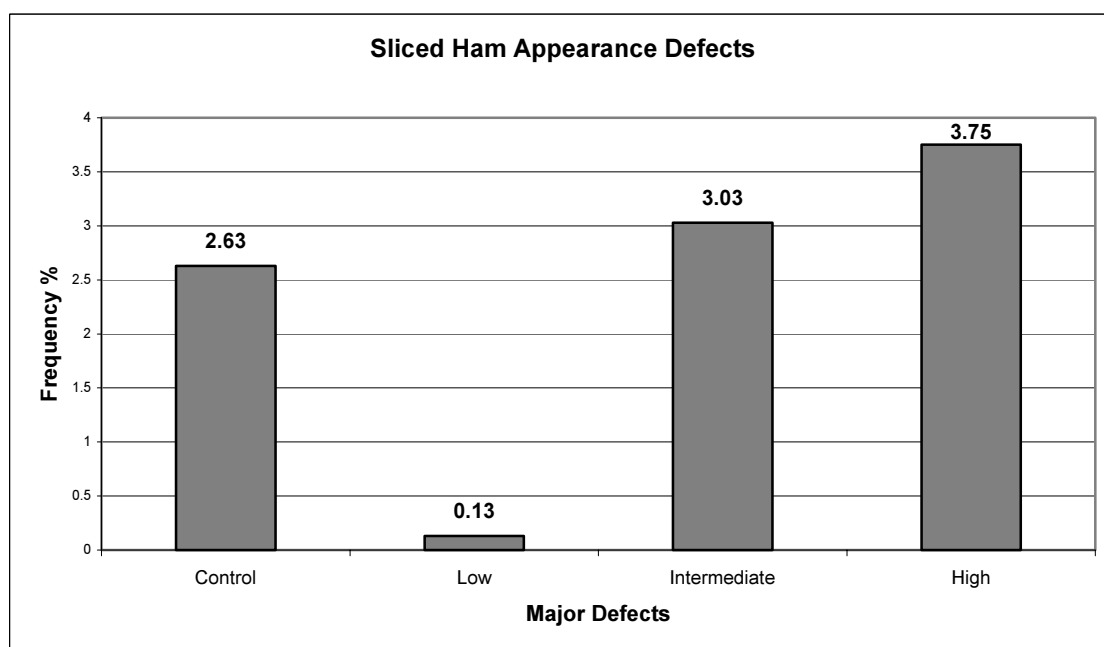


Figure 8. Sliced, boneless ham, 4x6 package visual appearance defects. Frequency of packages with major defects.

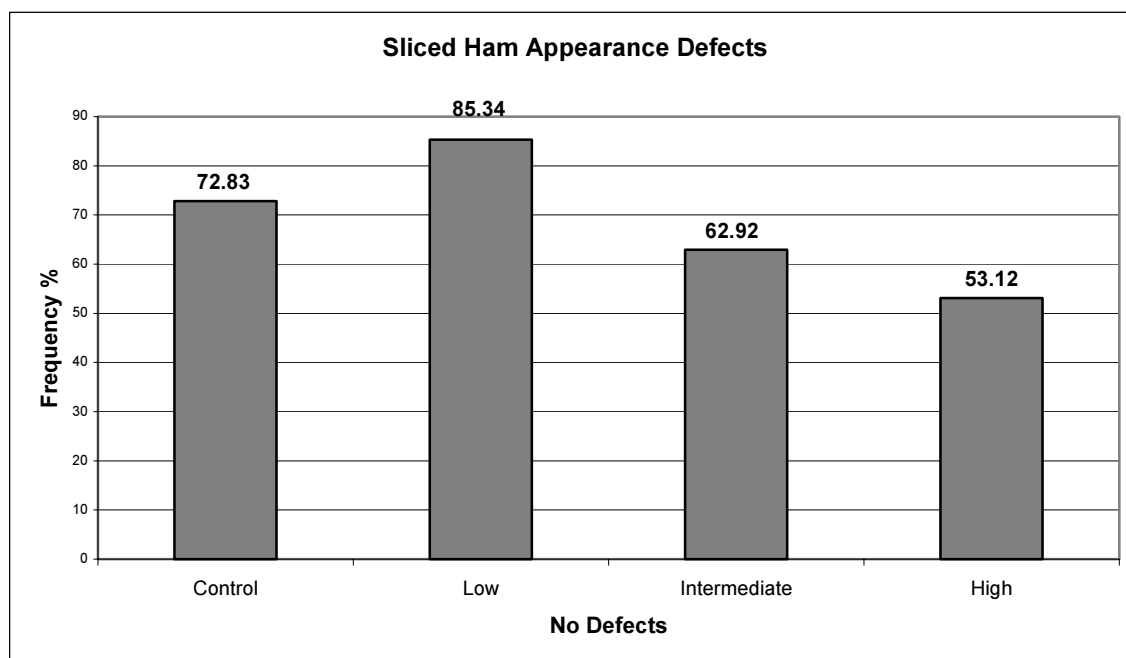


Figure 9. Sliced, boneless ham, 4x6 package visual appearance defects. Frequency of packages with no defects.

Table 6. Least squares means for color values for sliced ham packages manufactured from different quality groups taken post slicing

Group	Color parameter		
	L*	a*	b*
Control	63.57 ^c	12.63 ^b	9.52 ^c
Low PSE	63.05 ^d	12.98 ^a	9.77 ^b
Intermediate PSE	64.89 ^b	12.26 ^c	9.70 ^b
High PSE	65.78 ^a	12.12 ^c	10.06 ^a
SEM ^e	0.18	0.08	0.04

^{a,b,c,d} Least squares means within a column lacking a common superscript are different ($P < 0.05$).

^eSEM is the standard error of the least squares means

Table 7. Least squares means for color and purge measurements over storage time for each quality group of finished 4x6 ham packages

Parameter	Group	Storage day				
		15	30	45	60	75
L*	Control	63.91 ^{fg}	64.22 ^{fg}	65.01 ^{def}	63.61 ^g	65.44 ^{cde}
	Low PSE	63.11 ^g	63.46 ^g	63.12 ^g	63.91 ^{fg}	64.24 ^{efg}
	Intermediate PSE	65.43 ^{cde}	65.02 ^{def}	65.01 ^{def}	65.44 ^{cde}	66.69 ^{ab}
	High PSE	66.03 ^{bcd}	65.73 ^{bcd}	65.83 ^{bcd}	66.22 ^{bc}	67.44 ^a
	SEM ^j	0.43	0.43	0.43	0.43	0.44
a*	Control	12.42 ^{abcde}	12.23 ^{bcdef}	12.04 ^{defg}	12.50 ^{abc}	11.86 ^{fgh}
	Low PSE	12.82 ^a	12.65 ^{ab}	12.84 ^a	12.49 ^{abcd}	12.45 ^{abcde}
	Intermediate PSE	12.00 ^{efg}	12.04 ^{cdefg}	12.08 ^{cdefg}	11.88 ^{fg}	11.74 ^{gh}
	High PSE	11.84 ^{fgh}	11.88 ^{fg}	11.84 ^{fgh}	11.70 ^{gh}	11.40 ^h
	SEM ^j	0.17	0.17	0.17	0.17	0.17
b*	Control	9.80 ^{cde}	9.55 ^{efg}	9.76 ^{cdef}	9.03 ^j	9.09 ^{ij}
	Low PSE	9.96 ^{abcd}	9.92 ^{bcd}	10.01 ^{abc}	9.18 ^{ij}	9.23 ^{hij}
	Intermediate PSE	10.08 ^{ab}	9.73 ^{def}	10.15 ^{ab}	9.07 ^{ij}	9.30 ^{ghi}
	High PSE	10.00 ^{abc}	9.95 ^{abcd}	10.19 ^a	9.33 ^{ghi}	9.50 ^{fgh}
	SEM ^j	0.09	0.09	0.09	0.09	0.10
Purge loss (g)	Control	5.00 ^{hi}	5.45 ^{hi}	6.34 ^{efgh}	5.72 ^{ghi}	8.89 ^b
	Low PSE	3.24 ^j	4.44 ^{ij}	5.40 ^{hi}	5.25 ^{hi}	8.66 ^{bc}
	Intermediate PSE	5.73 ^{ghi}	7.56 ^{bcdef}	8.10 ^{bcd}	7.26 ^{cdefg}	12.74 ^a
	High PSE	6.05 ^{fgh}	7.91 ^{bcd}	7.06 ^{defg}	7.47 ^{bcd}	11.64 ^a
	SEM ^j	0.56	0.56	0.56	0.56	0.58
Purge loss (%)	Control	1.10 ^{hi}	1.20 ^{hi}	1.40 ^{efgh}	1.26 ^{ghi}	1.96 ^b
	Low PSE	0.71 ^j	0.98 ^{ij}	1.19 ^{hi}	1.16 ^{hi}	1.91 ^{bc}
	Intermediate PSE	1.26 ^{ghi}	1.67 ^{bcdef}	1.78 ^{bcd}	1.60 ^{cdefg}	2.81 ^a
	High PSE	1.33 ^{fgh}	1.74 ^{bcd}	1.56 ^{defg}	1.65 ^{bcd}	2.56 ^a
	SEM ^j	0.12	0.12	0.12	0.12	0.13

^{a,b,c,d,e,f,g,h,i,j}Least squares means within a parameter lacking common superscripts are different ($P < 0.05$).

^jSEM is the standard error of the least squares means.

difference is shown numerically between the a^* and b^* values, the Low PSE group did have higher ($P < 0.05$) a^* values when compared to the other treatments.

During the storage period, mean L^* values were lower ($P < 0.05$) for the Low PSE and Control groups compared to the other two treatments, with exception of day 45 where the Low PSE treatment was lower ($P < 0.05$) than all other treatments. This may signify that these two treatments were not losing as much color pigment during storage time. L^* values for the Low PSE group at day 75 were numerically lower than any of the day/treatment interactions for the Intermediate and High treatments and lower ($P < 0.05$) than any of the High PSE storage period measurements. There was no difference ($P > 0.05$) between the Low PSE mean L^* value at day 75 and the Control mean L^* value at day 15. In addition, the Low PSE treatment was the only group to show no significant increase in L^* value over the entire storage period. The mean a^* value for the Control treatment was the only value that showed a decrease ($P < 0.05$) when values for days 15 and 75 were compared (Table 7). The a^* value for the Low PSE treatment at day 75 is numerically higher, though not significant in some cases, than any other a^* value obtained indicating the Low PSE treatment maintained a more reddish-pink colored lean over the length of the storage period. There did not appear to be any worthy trends occurring with the b^* values.

During the storage period, the Low PSE and Control groups showed no significant difference in purge loss, except for lower ($P < 0.05$) purge loss values at day 15 for the Low PSE group compared to all groups (Table 7). The Low PSE group also displayed much lower ($P < 0.05$) purge values throughout the entire storage process when

compared to the Intermediate and High PSE treatments, especially evident at day 75. When coupled with the Low PSE treatments advantage's in color, the selection for higher quality raw materials has proven to be effective in terms of maintaining color and lowering purge loss during this storage period. The Low PSE treatment even indicates advantages, in some cases, of a higher quality product at extended storage days versus treatments of lower quality products at minimal storage days.

Sensory and Texture Evaluations. Although there were no significant differences found in the palatability characteristics between treatments, the High PSE group did display lower ($P < 0.05$) ratings for its visual characteristics compared to the other treatments (Table 8). Low scores in visual appeal for the High PSE group appear to be attributed mostly to color. The panelists confirmed this, as they stated “color uniformity” or lack thereof, to be the most decisive factor in visual appeal. Allo-Kramer shear values show small, but significant differences among treatments.

Purchase intent clearly indicates that panelists preferred the Low PSE packages two to three times more often than those from any other treatment (Table 9). The frequency distributions viewed in Figure 10 also show that the Intermediate group received more selections than either the Control or High PSE group, which were both similar. Again, when asked to defend their selections, product appearance, mostly due to a more desirable color, was the answer on 90% of the ballots.

Belly Data

Raw Material Selection. Although bellies were selected by subjective thickness evaluations, thickness data were compiled to validate this process. The results, found in Table 10, show that the selection process was effective as there is a significant difference

Table 8. Least squares means for consumer responses for visual and palatability characteristics and Allo-Kramer shear values for ham from different quality groups

Group	Characteristic				Allo-Kramer shear (kg/g)
	Visual appeal ^c	Color ^e	Flavor ^e	Overall like ^e	
Control	5.23 ^a	5.08 ^a	5.45 ^a	5.36 ^a	3.03 ^c
Low PSE	5.48 ^a	5.40 ^a	5.41 ^a	5.41 ^a	3.31 ^{ab}
Intermediate PSE	5.23 ^a	5.20 ^a	5.44 ^a	5.47 ^a	3.28 ^b
High PSE	4.63 ^b	4.40 ^b	5.37 ^a	5.35 ^a	3.40 ^a
SEM ^d	0.13	0.13	0.13	0.13	0.03

^{a,b,c}Least squares means within a column lacking a common superscript are different ($P < 0.05$).

^dSEM is the standard error of the least squares means.

^ePanelist rankings based on 8-point scale (1 = extremely dislike and 8 = extremely like)

Table 9. Purchase intent of consumers for ham manufactured from different quality groups

Group	Selection order			
	First ^a	Second ^a	Third ^a	Overall ^b
	-----%			
Control	6.09	6.09	9.57	7.25
Low PSE	64.35	54.78	54.78	57.97
Intermediate PSE	21.74	33.91	26.96	27.54
High PSE	7.83	5.22	8.70	7.25

^a n = 115.

^b n = 345.



Figure 10. Consumer purchase intent of finished, 4x6 ham product. Consumers were asked to select three packages, out of 12 packages that equally represented each treatment, and rank them in order of purchase preference.

Table 10. Least squares means of belly thickness measurements (mm) taken at selection.

Group	Thickness measurements		
	Dorsal edge ^a	Ventral edge ^a	Overall ^b
Thin	19.81 ^e	23.62 ^e	21.84 ^e
Average	25.40 ^d	26.67 ^d	25.91 ^d
Thick	27.69 ^c	33.53 ^c	30.73 ^c
SEM ^f	0.356	0.305	0.203

^aMeasurements taken at three equal points at the blade, center, and ham sections of the belly on both dorsal and ventral edges.

^bAverage of six measurements taken per belly.

^{c,d,e}Least squares means within a column without a common superscript are different ($P < 0.05$).

^fSEM is the standard error of the least squares means.

($P < 0.05$) between treatment groups in relation to thickness. Due to some variation in dorsal edge appearances, more focus was put on the ventral edges during selection.

Processing. Figure 11 shows differences in simple yields calculated between the three different treatment groups. The thin bellies had higher yields of skin, and the percentage of skin yield decreased as the bellies increased in thickness. Thinner bellies had higher percentage cook shrinks and lower overall final yield percentages when compared to thicker bellies. However, due to weight differences between the treatment groups and as mentioned before, statistics were performed using raw belly weight as a covariate. There was a difference ($P < 0.05$) in skin yield only between the thin and average treatments (Table 11). However, the thin bellies exhibited a higher ($P < 0.05$) cook shrink versus the average and thick treatments, while the thick treatment shows a higher ($P < 0.05$) final yield than the thin and average treatments. The thicker, fatter bellies tended to perform better over the thinner bellies when it came to processing yields, which is consistent with results found by Jabaay et al. (1976).

Slicing. Simple percentage mean yields were calculated for each treatment during slicing and Figure 12 shows the results for the yield of #1 slices. As seen during processing, the thicker bellies had higher yields at slicing for #1 slices and the thin treatment group was the lowest yielding of the three treatments. Figure 12 also shows an inverse relationship when calculating the yields of #2 slices as the thin bellies had higher yields of #2 slices. Within the #2 slices, some were a result of inadequate secondary lean (*M. cutaneous trunci*) and the others were too thin in profile to meet customer

specifications (Figure 13). Few differences were found in loss due to secondary lean specifications, however, the greatest difference between treatments was seen in the loss

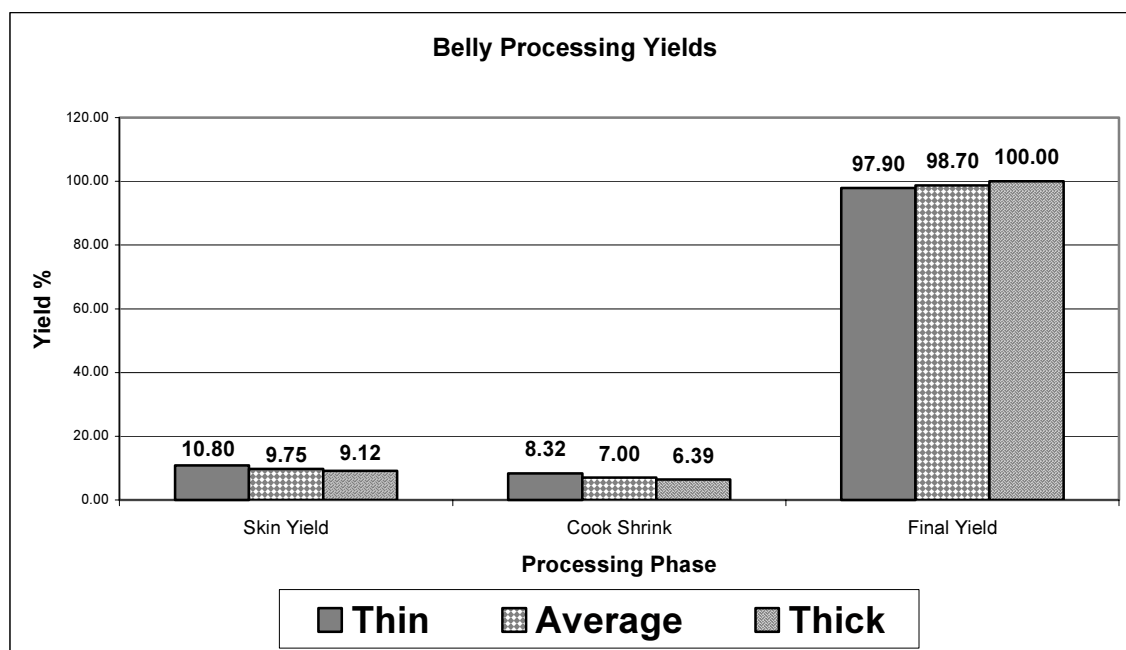


Figure 11. Processing yields for three belly treatments. Skin yield = yield of skin off raw belly, Cook Shrink = % shrink during cooking process, Final Yield = final weight of cooked belly compared to beginning raw weight.

Table 11. Least squares means of yield measurements using raw belly weight as a covariate.

Group	Yield measurements		
	Skin Yield ^a	Cook Shrink ^a	Final Yield ^a
Thin	10.57 ^b	8.13 ^b	96.85 ^b
Average	9.67 ^c	6.84 ^c	97.96 ^b
Thick	9.70 ^{bc}	6.06 ^c	103.68 ^c
SEM ^d	0.27	0.30	1.00
SEM ^e	0.23	0.24	0.85
SEM ^f	0.40	0.41	1.46

^aMean values are expressed as a percentage

^{b,c}Least squares means within a column without a common superscript are different ($P < 0.05$).

^dSEM is the standard error of the least squares means for the Thin group.

^eSEM is the standard error of the least squares means for the Average group.

^fSEM is the standard error of the least squares means for the Thick group.

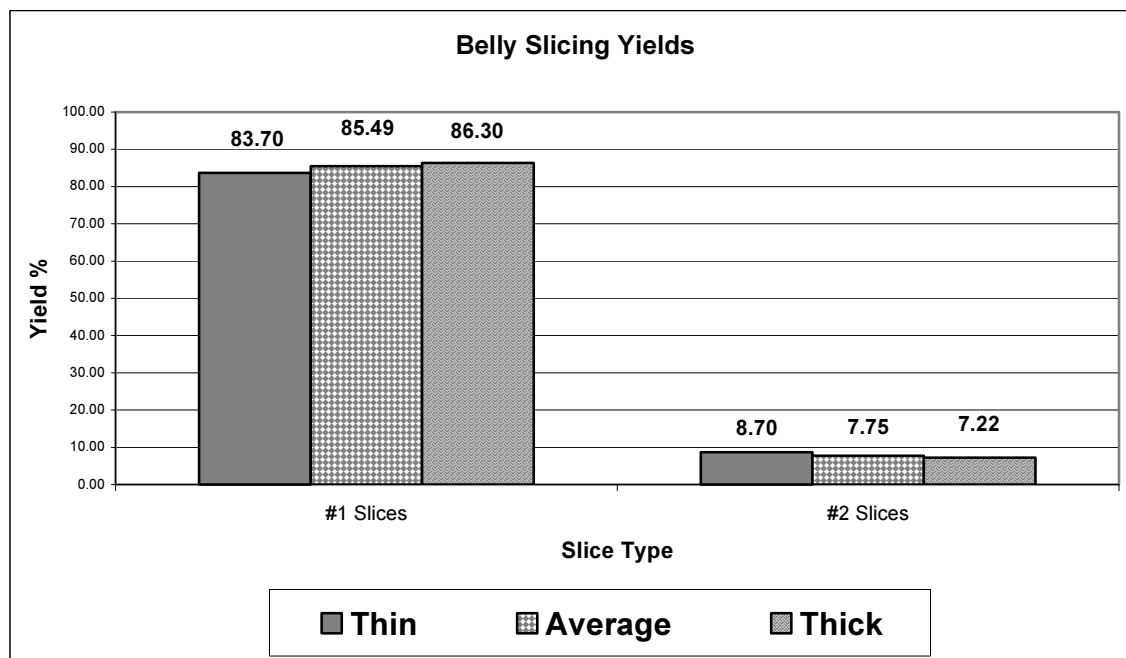


Figure 12. Yields of #1 and #2 slices for each belly treatment. #2 slices are discounted due to lack of sufficient secondary lean or slices do not meet specifications for thickness.

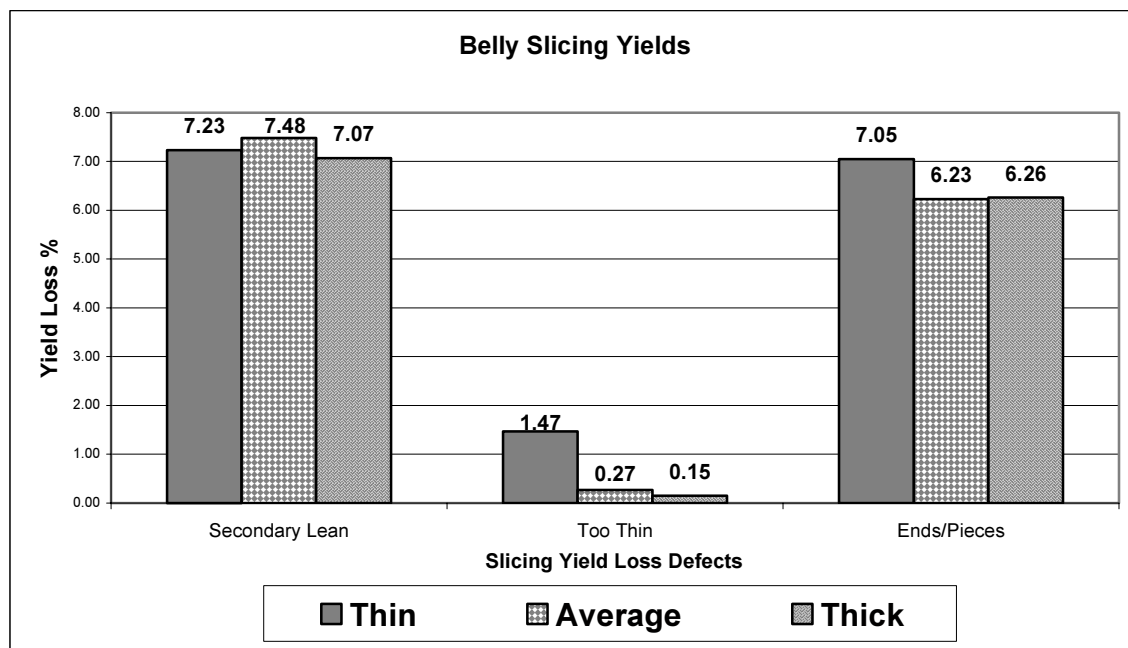


Figure 13. Yield losses incurred during slicing. Secondary Lean = slices sorted off for lack of sufficient secondary lean; Too Thin = slices sorted off due to lack of sufficient thickness of slice; Ends/Pieces = end slices and shattered pieces that would not qualify for sliced bacon.

due to slices being too thin. In addition, the thin bellies had a higher percentage yield loss due to a high percentage of ends and shattered pieces (Figure 13).

Consumer Panel Sensory and Visual Evaluation. Results from the consumer panel rankings and percentage distributions per score can be found in Figures 14 to 23. There were significant differences found between treatments for fattiness of the cooked bacon, overall taste acceptability, and purchase intent based on taste (Table 12). The thin treatment slices had a lower panel acceptability ranking ($P < 0.05$) for bacon flavor compared to the average and thick groups. Panelists preferred the thicker slices when evaluating the saltiness, and considered the thin slices less acceptable in crispiness ($P < 0.05$). When evaluating the visual lean to fat ratio and pink color characteristics, panelists preferred ($P < 0.05$) the thin and average groups to the thick slices due to the appearance of greater amounts of lean. Panelists also found the thin and average groups to be more acceptable visually and would be more apt to purchase bacon from these groups versus the thick treatment group ($P < 0.05$). Approximately 62% of the panelists said they would probably not or definitely not purchase the bacon from the thick treatment. These results are consistent to the findings of Jabaay et al. (1976) and West et al. (1973) where it was reported that fatter bacon slices were less acceptable visually to the consumer. Findings from this study indicate that consumers preferred the leaner bacon when evaluating and purchasing it visually, and experience very minimal differences in acceptability and purchase intent based on palatability.

Proximate Composition. Raw samples from the thin treatment had higher moisture and lower fat contents ($P < 0.05$) than the other two treatments (Table 13).

Furthermore, the cooked bacon samples from the average treatment were lower ($P < 0.05$) in moisture content, while the fat content was higher ($P < 0.05$) for the thick treatment.

Table 12. Least squares means for consumer responses for sensory palatability and visual characteristics of sliced bacon

Characteristic	Treatment		
	Thin	Average	Thick
Bacon Flavor ^{a*}	2.77 ^c	2.81 ^d	2.56 ^{cd}
Fattiness ^{a*}	3.43 ^c	3.31 ^d	3.41 ^c
Saltiness ^{a*}	3.26 ^c	3.32 ^c	3.04 ^d
Crispiness ^{a*}	2.32 ^c	2.80 ^d	2.59 ^d
Taste Acceptability ^{a**}	3.55 ^c	3.75 ^d	3.42 ^c
Purchase Intent ^{a***}	2.53 ^c	2.27 ^d	2.60 ^c
Lean to Fat Ratio ^{b*}	2.53 ^c	2.55 ^c	2.02 ^d
Pink Color ^{b*}	2.55 ^c	2.61 ^c	2.19 ^d
Appearance Acceptability ^{b**}	3.47 ^c	3.48 ^c	2.45 ^d
Purchase Intent ^{b***}	2.17 ^c	2.25 ^d	3.23 ^d

^aIndicates characteristics related to sensory palatability evaluation

^bIndicates characteristics related to visual evaluation

^{c,d,e}Least squares means within a row lacking a common superscript are different ($P < 0.05$).

*Panelist rankings based on 5-point scale (1 = much too little, 2 = somewhat too little, 3 = just right, 4 = somewhat too much, 5 = much too much)

**Panelist rankings based on 5-point scale (1 = extremely unacceptable, 2 = moderately unacceptable, 3 = neither, 4 = moderately acceptable, 5 = extremely acceptable)

***Panelist rankings based on 5-point scale (1 = definitely, 2 = probably, 3 = might, 4 = probably not, 5 = definitely not)

Table 13. Least squares means for proximate composition values for percentage of moisture and fat for raw and cooked bacon

Group	Raw Bacon		Cooked Bacon	
	Moisture	Fat	Moisture	Fat
Thin	47.86 ^a	36.17 ^a	14.49 ^a	34.69 ^a
Average	40.47 ^b	46.39 ^b	5.32 ^b	42.46 ^b
Thick	40.43 ^b	46.31 ^b	16.99 ^a	43.47 ^b
SEM ^d	1.2	1.70	1.70	1.82

^{a,b,c}Least squares means within a column without a common superscript are different ($P < 0.05$).

^dSEM is the standard error of the least squares means.

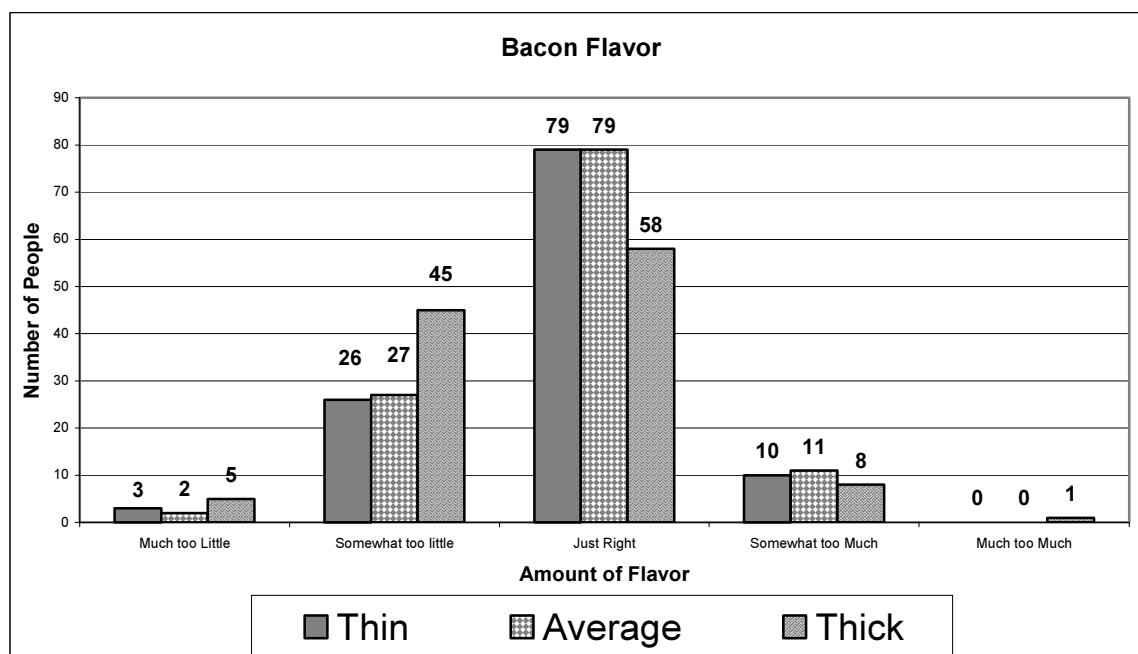


Figure 14. Consumer panel responses for bacon flavor characteristics with number of respondents per selection included.

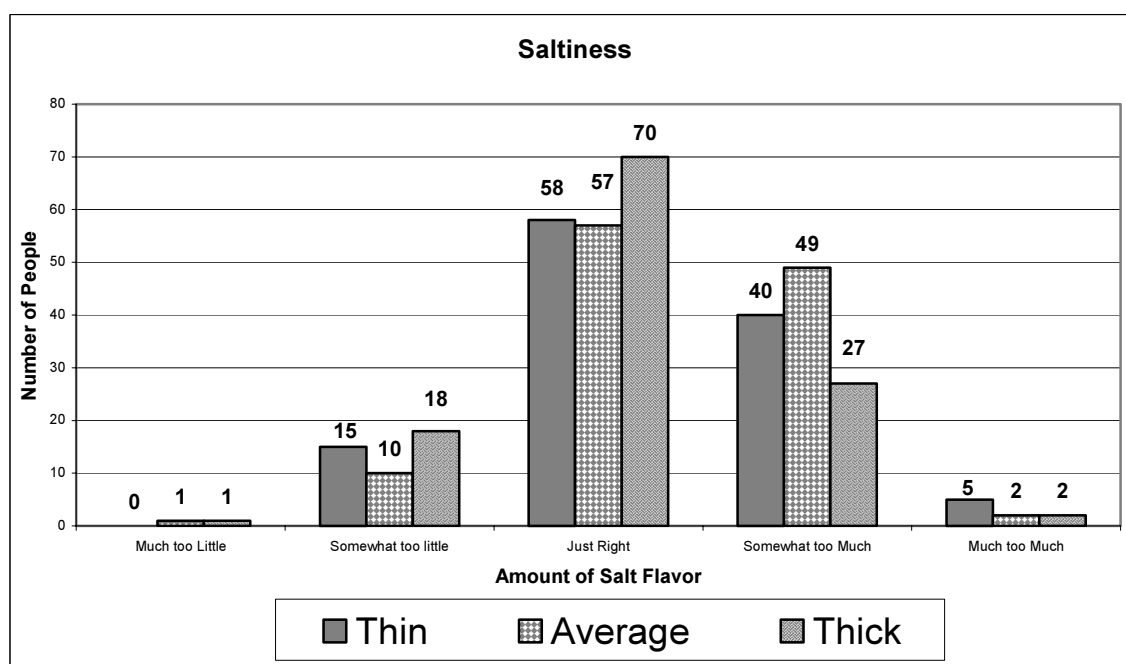


Figure 15. Consumer panel responses for bacon saltiness characteristics with number of respondents per selection included.

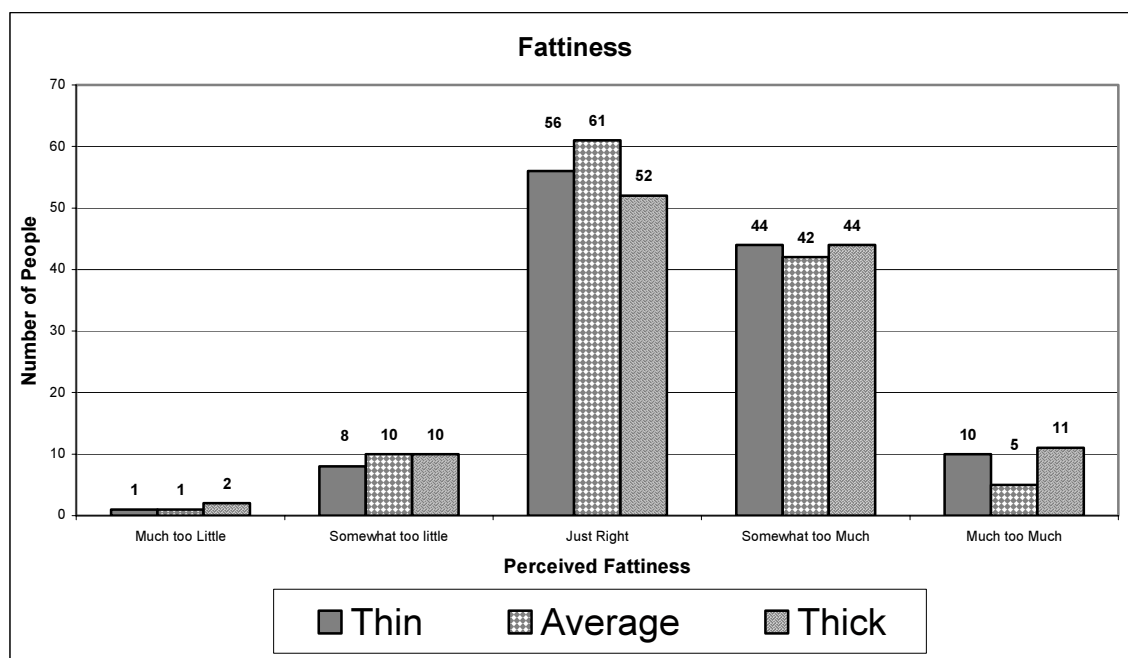


Figure 16. Consumer panel responses for bacon fattiness characteristics with number of respondents per selection included.

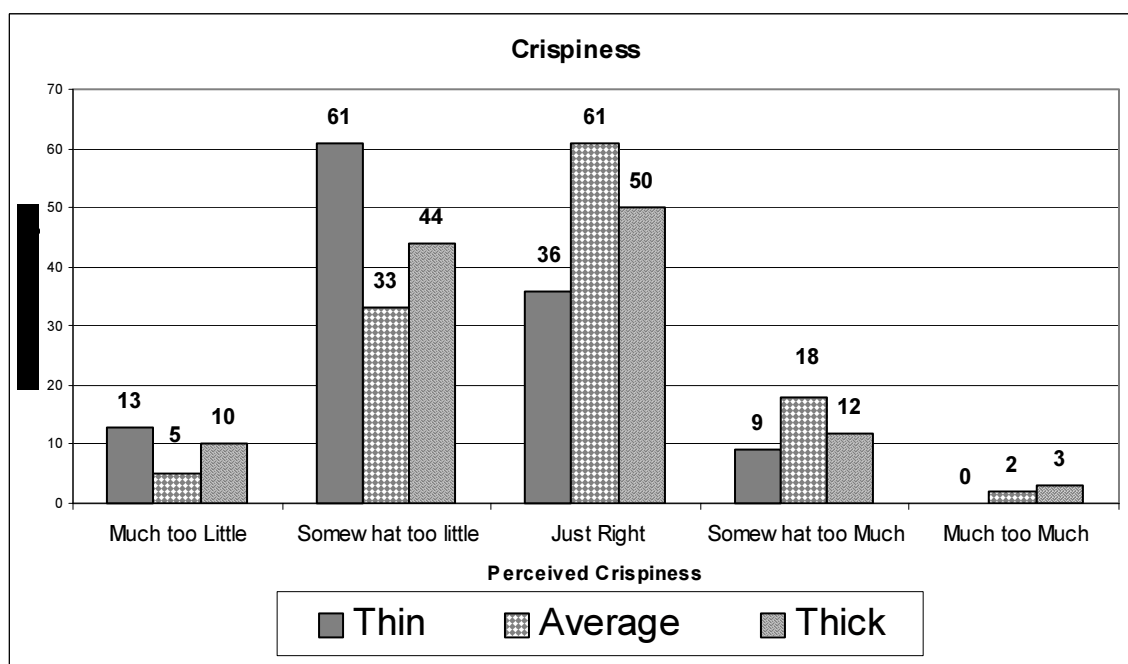


Figure 17. Consumer panel responses for bacon crispiness characteristics with number of respondents per selection included.

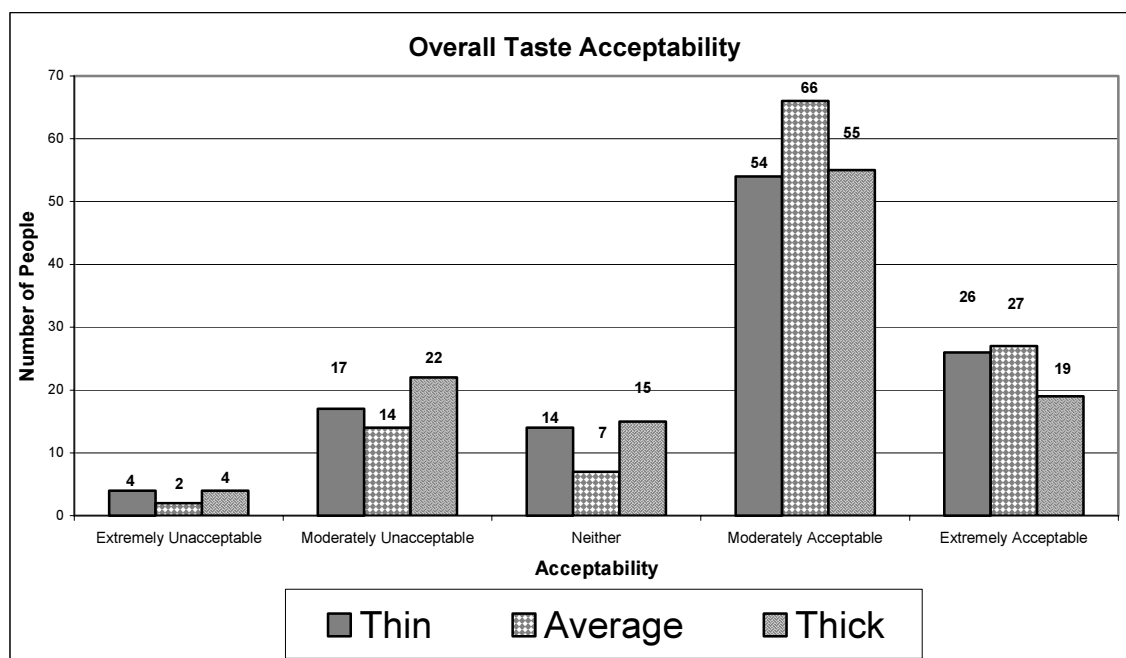


Figure 18. Consumer panel responses for overall bacon taste acceptability with number of respondents per selection included.

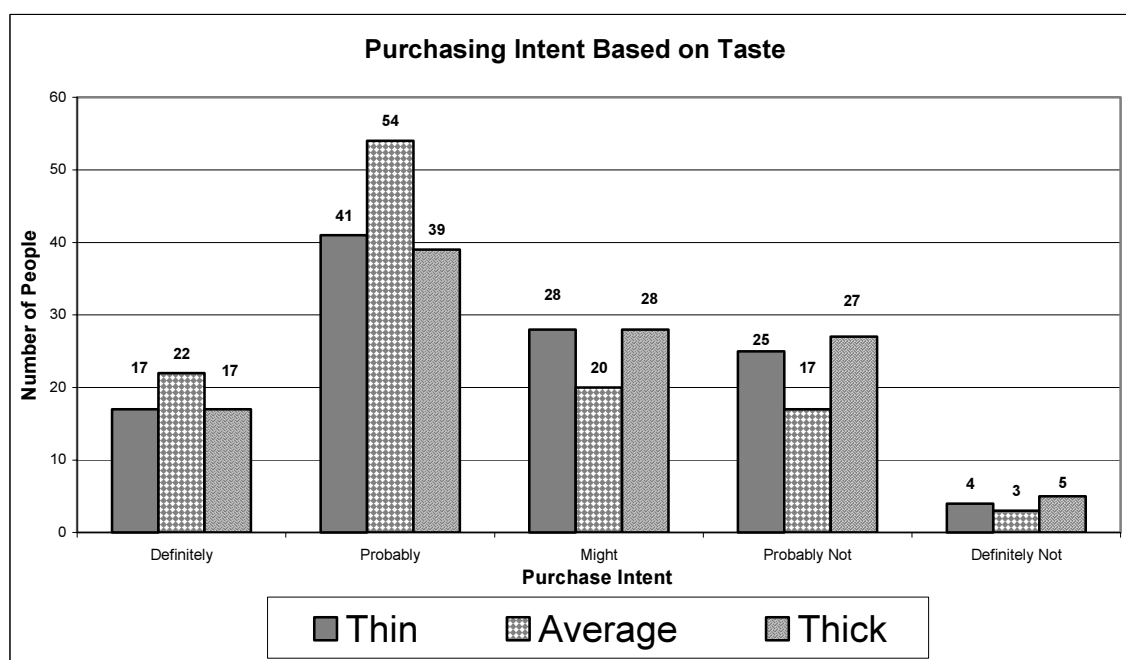


Figure 19. Consumer panel responses for purchase intent of bacon based on taste characteristics with number of respondents per selection included

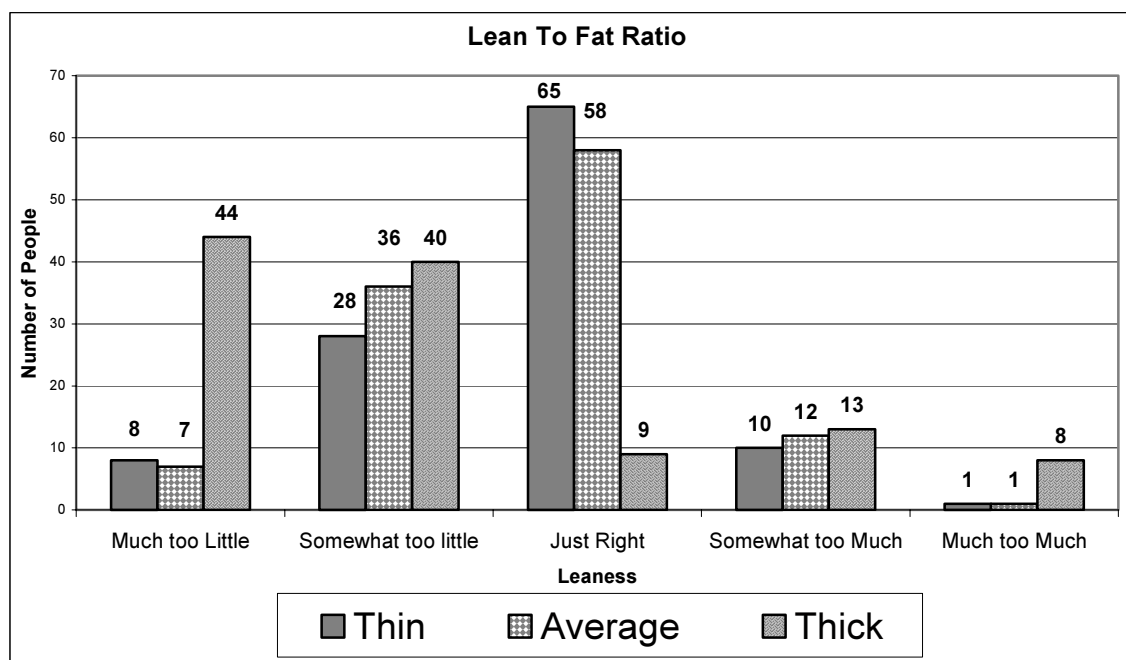


Figure 20. Consumer panel responses for visual lean to fat ratio characteristics of uncooked bacon, with number of respondents per selection included.

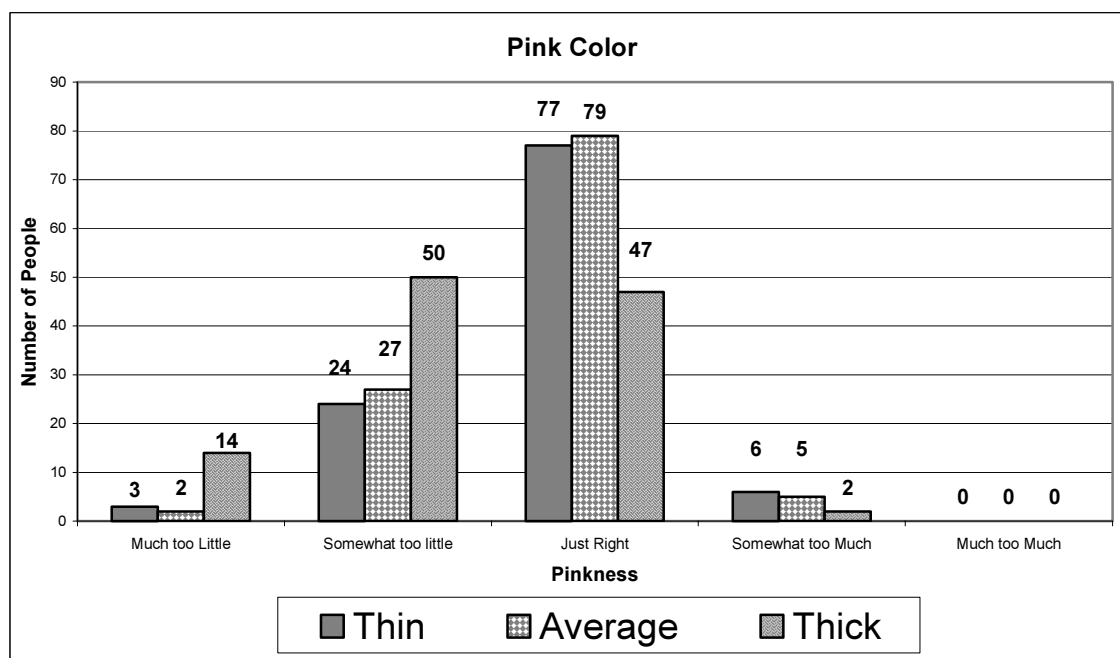


Figure 21. Consumer panel responses for visual pink color characteristics of uncooked bacon, with number of respondents per selection included.

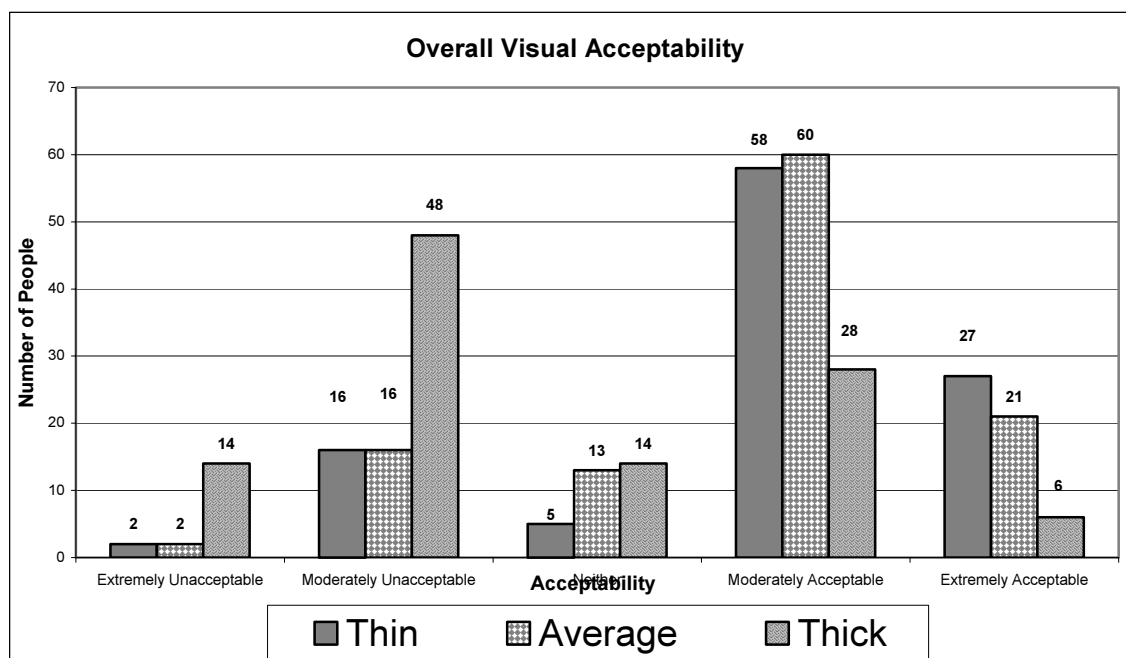


Figure 22. Consumer panel responses for overall visual acceptability of uncooked bacon, with number of respondents per selection included.

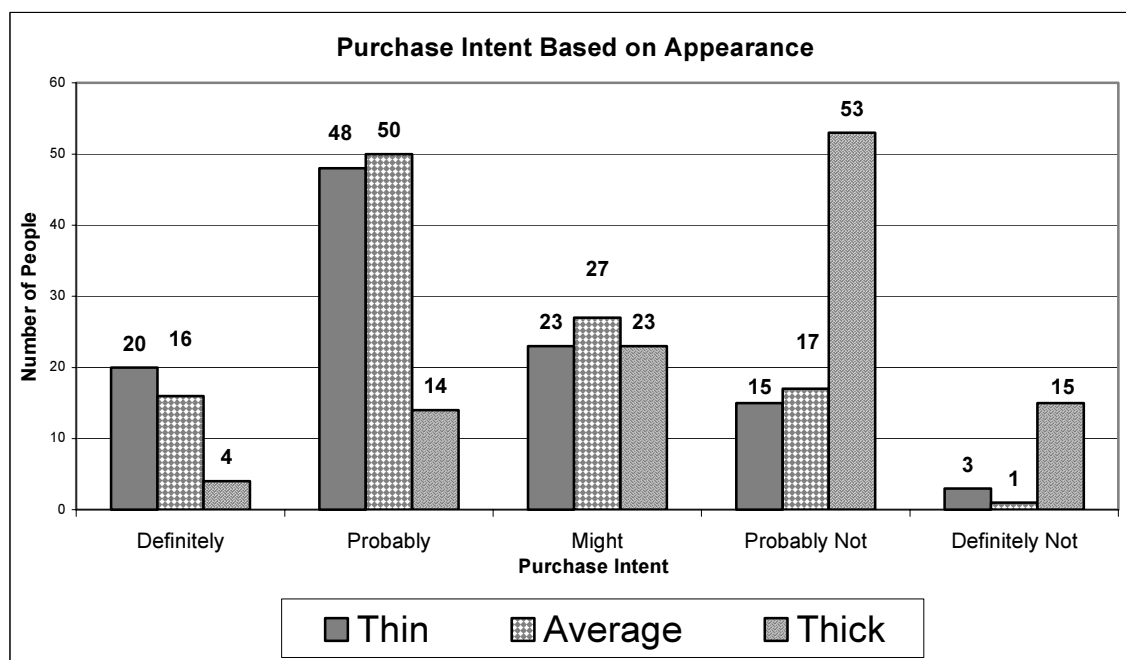


Figure 23. Consumer panel responses for purchase intent of uncooked bacon, based on visual appearance, with number of respondents per selection included.

CONCLUSIONS

Bone-in Hams

This study showed little difference in shelf life or storage quality attributes between the two treatment groups, except for those found during the holiday thaw period. This could indicate that some protein structural quality loss could have occurred during the freezing and thawing periods. There were some differences observed in the final yields of the two treatments, most noticeably favoring the “high pH” group, during processing. When comparing these results with the significant advantage the “high pH” group displayed in drip loss at bisection of the hams during slicing, there may be a significant loss of protein functionality. As a result, this is causing increased exudation and softer lean in the “low pH” group, in turn producing a product that loses more yield during slicing and packaging.

Boneless Ham Manufacturing

Results from this phase of the study imply that selection for higher quality raw materials can be advantageous in terms of processing yields, shelf-life attributes, and consumer appeal. It also shows that there is room for improvement in the quality of raw materials entering the boneless ham production chain. More research should be done to address the advantages and disadvantages (with regard to efficiency and value) of implementing a sorting process when compiling raw materials from the fabrication line. Further research in pork carcass chilling techniques and their effect on ham quality

should be conducted because it is believed that this factor alone could be playing a major role in some of the quality issues facing ham products, especially those of the inside cushion muscle.

Belly Processing

This phase of the study produced results that parallel past work that has been conducted with belly and bacon processing. We have seen an advantage to thicker bellies through the processing and slicing sequence, however, consumers clearly preferred the leaner, thinner bacon when selecting for consumption. With the change in the type of hog produced today versus those produced when past bacon research was conducted, further work should be done to indicate the percentage of “thin” bellies in the processing chain. Given these statistics, information could be gathered to determine if the value lost in the processing and slicing of thin bellies is significantly disadvantageous when compared to the added value found in consumer appeal and selection of bacon at the retail level.

LITERATURE CITED

- AMI. 1991. Meat and Poultry Facts. American Meat Institute, Washington, DC.
- AOAC. 1993. Official Methods of Analysis. 15th ed. Association of Official Analytical Chemists, Washington, DC.
- Berry, B. W. 1980. Update: Processed Meats Cookery and Sensory Evaluation. Proceedings 33rd Annual Reciprocal Meats Conference. pp. 169-175.
- Bligh, E.G. and W.J. Dyer. 1959. A rapid method of total lipid extraction and purification. Can. J. Biochem. Physiol. 37:911-917.
- Burke Marketing Research. 1987. Burke Marketing Research 1987 Consumer Climate for Meat. National Live Stock and Meat Board, Chicago, IL. Page 31.
- Cannon, J. E., J. B. Morgan, F. K. McKeith, G. C. Smith, S. Sonka, J. Heavner and D. L. Meeker. 1995. Pork chain quality audit survey: Quantification of pork quality characteristics. J. Muscle Foods. 7:29-44.
- Christian, L. L. 1997. Effect of stress gene on quality. Proc. Quality Summit, Des Moines, IA. Pages 37-48.
- Crenwelge, D. D., R.N. Terrell, T.R. Duston, G.C. Smith and Z.L. Carpenter. 1984. Effect of chilling method and electrical stimulation on pork quality. J. Anim. Sci. 59:697-704.
- Cross, H. R., G.C. Smith, and Z.L. Carpenter. 1971. Effect of quality attributes upon processing and palatability characteristics of commercially cured hams. J. Food Sci. 36:982-986.
- Dalrymple R. H. and R.F. Kelly. 1966. Processing, composition and organoleptic characteristics of normal and pale, soft, and exudative pork. J. Anim. Sci. 25:833.
- Fox, J. D., W.G. Moody, J.D. Kemp, and W. Henning. 1970. Physical, chemical and histological properties of low, medium and high quality hams at various intervals during curing and aging. J. Anim. Sci. 31:323-326.
- Gariépy C., D. Godbout, X. Fernandez, A. Talmant, A. Houde. 1999. The effect of RN gene on yields and quality of extended cooked cured hams. Meat Sci. 52:57-64.

- Grimes, G. and R. Plain. 2000. Hogs and Pigs Report. Agricultural Electronic Bulletin Board. Available: <http://agebb.missouri.edu/mkt/bull8c.htm>. University of Missouri, Colombia, MO.
- Hedrick, H. B., E.D. Aberle, J.C. Forrest, M.D. Judge, and R.A. Merkel. 1993. Principles of Meat Science. 3rd Edition. Kendall/Hunt Publishing Co., Dubuque, IA.
- Huff-Lonergan, E., J. Page, and R. Johnson. 2001. The Role of Carcass Chilling in the Development of Pork Quality. Pork Facts. National Pork Producers Council, Des Moines, IA. Pages 1-8.
- Jabaay, R. W., J.C. Forrest, E.D. Aberle, H.V. Courtenay, and M.D. Judge. 1976. Bacon quality criteria and associated carcass traits. J. Food Sci. 41:431-437.
- Jeremiah, L. E. and R. Wilson. 1987. The effects of PSE/DFD conditions and frozen storage upon the processing yields of pork cuts. Canadian Institute of Food Science and Technology. 20:25-30.
- Kauffman, R. G., G. Eikelenboom, P.G. van der Wal, G. Markus, and M. Zarr. 1986. The use of filter paper to estimate drip loss of porcine musculature. Meat Sci. 18:191-200.
- Kemp, J. D., J.D. Fox, W.G. Moody, and J.D. Crouse. 1971. Relationship of fresh ham traits to cured ham quality. J. Anim. Sci. 33:362-365.
- Mandigo, R. W. 2002. A New Look at Belly and Bacon Values. National Hog Farmer. Available: http://nationalhogfarmer.com/ar/farming_new_look_belly/index.htm. Accessed April 15, 2002.
- McKeith, F. K., M. Ellis, K.D. Miller, and D.S. Sutton. 1998. The effect of RN genotype on pork quality. 51st Annu. Recip. Meats Conf., Storrs, Connecticut. 51:119-125.
- Miller, R. K. 2002. Value of Ham Primals. National Hog Farmer. Available: http://nationalhogfarmer.com/ar/farming_value_ham_primals/index.htm. Accessed April 15, 2002.
- Miller, R. K. 2000. Meat Science and Technology 647 Notebook. Texas A&M University, College Station, TX.
- Monin, G., and P. Sellier. 1985. Pork of low technological quality with a normal rate of muscle pH fall in the immediate post-mortem period: The case of the Hampshire breed. Meat Sci. 13:49-63.

- Morgan, J. B., G.C. Smith, S.K. Fitzgerald, J.A. Sherbeck, C.C. Kukay, W.L. Radakovich, and S.W. Neel. 1995. International Pork Quality Audit: A Foreign Market Audit of U.S. Pork. Final Report to U.S. Meat Export Federation. pp 1-55.
- National Pork Board. 2000. Pork Composition and Quality Assessment Procedures. National Pork Board as implemented by the National Pork Producers Council, Des Moines, IA.
- NPPC. 1999. NPPC Official Color and Marbling Standards. National Pork Producers Council, Des Moines, IA.
- NPPC. 2000/2001. Pork Facts. National Pork Producers Council, Des Moines, IA.
- Offer, G., and P. Knight. 1988. The structural basis of water-holding in meat. Part 2: Drip losses. In: R. Lawrie Developments in Meat Science-4. p. 173. Elsevier Applied Science, London.
- Owen, B. L., J.L. Montgomery, C.B. Ramsey and M.F. Miller. 2000. Preslaughter resting and hot-fat trimming effects on the incidence of pale, soft and exudative (PSE) pork and ham processing characteristics. *Meat Sci.* 54:221-229.
- Plain, R. L. 2000. Structural Change in the Pork Industry: What it Means for Hog Prices, Meat Consumption and the Future of Family Farms. Agricultural Economics Report. Available: <http://www.ssu.missouri.edu/faculty/rplain/papers/Swsuminn.pdf>. University of Missouri, Columbia, MO.
- SAS. 2001. Statistical Analysis System (SAS). SAS Inst. Inc., Cary, NC
- Stites, C. R., F.K. McKeith, S.D. Singh, P.J. Bechtel, D.H. Mowrey, and D.J. Jones. 1991. The effect of ractopamine hydrochloride on the carcass cutting yields of finishing swine. *J. Anim. Sci.* 69:3094-3101.
- Topel, D. G., E.J. Bicknell, K.S. Preston, L.L. Christian, and C.Y. Matsuchima. 1968. Porcine stress syndrome. *Mod. Vet. Pract.* 49:40.
- USDA-AMS. 2000. Weekly National Carlot Meat Report, Week Ending December 9, 2000. United States Department of Agriculture, Agriculture Marketing Service, Washington DC.
- van Laack, Riette L.J.M., and R. G. Kauffman. 1999. Glycolytic potential of red, soft, and exudative pork longissimus muscle. *J. Anim. Sci.* 77:2971-2973.

- Warner, R.D., R.G. Kauffman, and M.L. Greaser. 1997. Muscle protein changes post mortem in relation to pork quality traits. *Meat Sci.* 45:339-352.
- West, R.L., W.L. Sawyer, G.W. Davis, G.C. Smith, and Z.L. Carpenter. 1973. Consumer response to lean-fat ratios in bacon. Abstracts of papers for presentation at the 65th Annual Meeting of the American Society of Animal Science. *J. Anim. Sci.* 37:273.

VITA

Ryan Christopher Person was born May 8, 1977, in Clovis, California, to parents Monte Person of Clovis, CA, and Nancee Fieguth of Fresno, CA. The author graduated from Clovis High School in 1995, where he was a member of a National Champion Meat Judging Team and a National Champion Livestock Judging Team. After high school, Ryan entered Reedly College in Reedly, CA, where he attended for one year. He then attended College of the Sequoias in Visalia, CA, for one year and was a member of their 1997 National Champion Meat Judging Team. In the fall of 1997, the author transferred to Texas A&M University, College Station, TX. While at Texas A&M, Ryan remained heavily involved on judging teams and in the Saddle and Sirloin Club. The author was a member of the 1998 National Champion Meat Judging Team, 1999 National Champion Livestock Judging Team, and 2000 National Champion Meat Animal Evaluation Team. In May 2000, Ryan received his Bachelor of Science degree in animal science. While doing his graduate work at Texas A&M, Ryan was the coach of the 2001 National Champion Meat Judging Team and the 2002 Meat Judging Team. Ryan received his Master of Science degree in Animal Science and graduated in August 2003.

Permanent address: 4690 N. Dewolf

Clovis, California 93611