Beef:
Correlation between Physical Properties and Quality

An Interactive Qualifying Project Report
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Degree of Bachelor of Science by

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Abstract

This study was conducted to correlate beef's physical properties to its quality. The water holding capability and tenderness of two different cuts of beef, filet mignon and eye round, were compared using thermogravimetric analysis, temperature testing and tensile strength testing. Each of these tests were successful in supporting past research and assumptions stating that filet mignon is a higher quality cut of beef than eye round. The paper was submitted to Nutrition & Food Science for publication.

Table of Contents

This IQP report is prepared as a journal article to be submitted to ***Nutrition and Food Science***. The paper is presented after a brief discussion of the goals of the project.

Introduction

The average American consumes 67 pounds of beef per year, making the U.S. the world leader in beef consumption with a total of 14 million short tons per year. Due to the vast consumption of beef, the characteristics involved in increasing the quality of beef are of great interest. In this study, the tenderness and water holding capability were the characteristics focused on to compare the quality of different cuts of beef.

For this project, two cuts of beef were chosen from opposite extremes to support the characteristics that define quality beef. Filet mignon was chosen for its tenderness and eye round was chosen for its high Warner-Bratzler shear force results. It was assumed that the filet mignon would exhibit characteristics that showed a greater quality than the eye round; however, it was an interest to determine how much each specific defined characteristic played a part in determining the quality of the different cuts. Three tests were conducted; thermogravimetric analysis, temperature testing, and tensile testing. Thermogravimetric analysis and temperature testing were used to realize the water holding capabilities of the different cuts of beef tested. The water holding capabilities were determined through the different transition temperatures in which water was lost. Other transition temperatures were found through temperature testing to compare the collagen and protein content in filet mignon and eye round. Tensile testing compared the strength of the collagen in filet mignon and eye round by applying a pulling force perpendicular to the face of the muscle fibers. It was assumed, and supported through the results, that the accumulation of these tests would show the filet mignon exhibiting characteristics of greater quality than the eye round.

Objectives

This study works to accomplish the following objectives:

1. Understand the importance of beef in the U.S.
    a. Gather information on the trends of beef consumption
    b. Understand why the trends exist and what affects them
2. Determine what affects the quality of beef
    a. Determine which cuts of beef correlate with higher and lower quality
    b. Determine which physical properties of beef affect its quality
3. Create an experimental approach to compare the physical properties of beef to its quality
    a. Determine which experimental tests to conduct
        i. Thermogravimetric analysis
        ii. Temperature testing
        iii. Mechanical testing
    b. Examine the results from the data collected
        i. Compare the results to previous research
        ii. Derive a conclusion based off of the results and the previous research

Results

The results of this IQP have been compiled as a journal paper to be submitted to ***Nutrition and Food Science*** for publication.

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ABSTRACT

The U.S. is the world leader in beef consumption, making the characteristics involved in increasing the quality of beef a topic of great interest. The quality of beef has commonly been determined by its tenderness and water-holding capabilities. In this study, experimentation was conducted to correlate the quality of beef with its physical properties. Thermogravimetric analysis, temperature testing, and tensile testing were done on filet mignon and eye round to compare these different characteristics believed to affect quality. It was assumed that filet mignon would exhibit greater water-holding capabilities and greater tenderness than eye round. From the testing, filet mignon was found to contain 73% water, while eye round only contained 68% water. Filet mignon also had a smaller breaking force, which ranged from 2N to 4N for the cooked samples, compared to the breaking force of the cooked eye round which ranged from 8N to 17N. The results from the testing appear to support the assumption that filet mignon contains characteristics which classify it as a higher quality beef than eye round.

INTRODUCTION

The average American consumes 67 pounds of beef per year, making the U.S. the world leader in beef consumption with a total of 14 million short tons per year (Davis & Biing-Hwan, 2005). Due to the vast consumption of beef, the characteristics involved in increasing the quality of beef are of great interest. When determining the quality of beef it is common to focus on the beef's tenderness and water-holding capability. The tenderness of the beef is greatly affected by a combination of the quantity of connective tissue and fat tissue (Purslow, 2001). The Warner-Bratzler shear test is a test to quantify the shear force necessary to break these tissues. The USDA Meat Animal Research Center has used the Warner-Bratzler shear test to compare the tenderness of different cuts of beef. Tensile testing has also been used to compare the tenderness of beef. In a study by Munro, the tensile strength was measured perpendicular to the face of the fibers (Munro, 1983). Both the Warner-Bratzler and tensile tests determine beef quality through tenderness. Temperature testing has been conducted to show the water-holding capability of the beef and also the solubility of the connective tissue and proteins. Dependent upon how much the connective tissue and proteins denature during cooking makes a difference on the tenderness of the beef. As beef is exposed to higher temperatures, it will experience a varying increase in water loss and protein loss (Garcia-Segovia et al., 2006). More advanced testing has been conducted to show the relation of water-loss, protein denaturation, and connective tissue denaturation. Martens & Vold used differential scanning calorimetry to determine key temperatures where these structural transitions occurred (Martens & Vold, 1976). Research by Ryland et al. used data from temperature testing and other material properties to determine the heat convection coefficient for ham (Ryland et al., 2006). The heat convection coefficient of beef could be used to give a cumulative representation of several physical properties that could affect the quality.

In the study conducted for this paper, two cuts of beef were chosen from opposite extremes to support the characteristics that define quality beef. Filet mignon was chosen for its tenderness and eye round was chosen for its high Warner-Bratzler shear force results (Savell, 2006). It was assumed that the filet mignon would exhibit characteristics that showed a greater quality than the eye round; however, it was an interest to determine how much each specific defined characteristic played a part in determining the quality of the different cuts.

METHODOLOGY

THERMOGRAVIMETRIC ANALYSIS

Thermogravimetric analysis is a method similar to differential scanning calorimetry and is used to study the mass loss patterns of a specimen due to steady temperature increases. This type of analysis was conducted on two small samples of uncooked USDA choice filet mignon and two small samples of uncooked USDA choice eye round to observe how each meat behaved due to high temperatures. The instrument used was the TGA Q50 V20.10 Build 36 programmed to use a ramp method to heat the samples 10°C/min until it reached 600°C in a Nitrogen atmosphere.

TEMPERATURE TESTING

LabVIEW, in conjunction with a NI-USB 6229 DAQ device, was used to monitor ambient oven temperature as well as the internal temperature of USDA choice eye round and filet mignon samples as they cooked. The samples were approximately 5 x 5 x 2 cm and a thermocouple was placed into the center of each sample at a depth of 1 cm as it was baked at 230 degrees Celsius for two hours (Garcia-Segovia et al., 2007). The temperature of each beef sample was graphed over time to explore protein change and water loss. It was assumed that the rate of change in the internal temperature of the sample would vary as key temperatures were approached (Raffael, 2003).

Fig. 1 shows before and after pictures of each sample and the location of the thermocouple insertion. During cooking, a temperature sample was generated every second and plotted over time using excel.

$$\frac{T-T_m}{T_i-T_m} = \exp(-Fo \cdot Bi) \qquad \text{Equation 1}$$

$$Bi = \frac{hL_c}{k} \qquad \text{Equation 2}$$

$$Fo = \frac{\propto t}{.01^2} \qquad \text{Equation 3}$$

$$\propto = \frac{k}{\rho C_p} \qquad \text{Equation 4}$$

$$k = 0.08 + 0.52X_w \qquad \text{(Hui, 2006)} \qquad \text{Equation 5}$$

Eq. 1-5 were used to calculate the heat convection coefficient, h, for both beef types at five points throughout the testing using the Lumped Capacitance method. In these equations, Bi is the Biot number, Fo is the Fourier number, $\propto$ is the found thermal diffusivity of the beef, and k is the thermal conductivity of the beef. A specific heat of $C_p = 3.579$ kJ/kg·°C (Heldman & Singh, 2009) and a density of $\rho = 1060$ kg/m^2·°C (Kraus & Bejan, 2003) were used in the calculations. The characteristic length, $L_c = 0.05$ m, and the temperatures obtained during testing were used in the above equations. L_c represents the length along the top face of the sample (Ryland et al., 2006).

MECHANICAL TESTING

Mechanical tensile testing was conducted on raw and cooked samples of USDA prime and select filet mignon and eye round using an Instron machine. The cooked samples were prepared in an oven until the internal temperature of each sample was 63°C. The purpose of the tensile testing was to determine if the strength of the collagen fibers of filet mignon was less than the strength of the collagen fibers of eye round.

Fig. 2 shows how each beef sample was positioned between the grips. The samples were oriented to measure the tensile strength of the connective tissue perpendicular to the face of the muscle fibers. Fine sand paper was placed between the sample and the grips to prevent slippage. The cross-sectional area and the distance between the grips for each sample were measured and collected with the machine set to a constant rate of 10mm/min. The software recorded the applied force of the machine and extension between the upper and the lower grips from the beginning of the test until the sample failed. The maximum force applied to each sample before failure was recorded with the corresponding extension. Representative plots were created to show the trends of applied force and extension between the different cuts of beef.

$$k = \frac{F_2 - F_1}{e_2 - e_1} \quad \text{(Equation 6)}$$

Eq. 6 was used to calculate the stiffness, k, of each sample. K is the slope of the linear region of the force-extension data measured in $\frac{N}{m}$. This equation uses two points, (e_2, F_2) and (e_1,F_1). The variable e represents extension and the variable F represents the applied force.

RESULTS AND DISCUSSION

Fig. 3 shows the results obtained using TGA. By looking at the derivatives of the weight % loss with time plotted versus the corresponding temperatures it is clear that there are four key transition temperatures; A, B, C, and D. The major transition points and previous research can be used to make assumptions about certain characteristics of beef, specifically its water-holding capability and protein content.

Beef contains three different types of water; free, immobilized, and bound water. Since bound water is trapped in the proteins and immobilized water is attached to the proteins in beef, free water is usually what is lost during cooking (Hui, 2006). Point A on the graph occurs around 100°C which happens to be the boiling temperature of water. It can therefore be inferred that the first major transition is attributed to water loss. By examining the graphs of weight % versus temperature it can be observed that by the time the beef samples reach a temperature of 175°C the filet mignon sample had lost about 73% of its original mass while the eye round sample had only lost about 67%. This observation suggests that filet mignon contains a higher percentage of free water than eye round and therefore has a higher water-holding capability. Although water makes up around 75% of meat, collagen and proteins such as myosin, actin, and titin are also important factors due to the fact that they account for approximately 20% of beef (Ranken, 1997). The second major transition, point B, can be attributed to the boiling point of collagen which is approximately 150°C in beef (Martens et al., 1982). At point C on the graph, which occurs at 300°C, there appears to be an additional 10% weight loss in both beef samples. This additional 10% occurs again at point D, 475°C, on the graph. It is reasonable to assume that 10% of the proteins are lost at a temperature of 300°C and the rest of the proteins are lost at a temperature of 475°C.

TGA is very useful in detecting the previously discussed weight loss transitions; however, the fast heating rate causes more subtle transitions to be overseen. Some of these transitions include the thermal denaturation of myosin which usually occurs between 54°C-58°C (Martens & Vold, 1976), the denaturation of actin around 80°C-83°C (Wright et al., 1977), and the denaturation of titin which occurs at 78.4°C (Pospiech et al., 2002). Although the denaturation of these proteins is too subtle for TGA to detect, the temperature testing conducted heated the samples at a slower rate and was able to detect some of these changes.

Temperature testing successfully captured thermal changes during cooking in the samples of filet mignon and eye round, as shown in Fig. 4. The dT/dt plot clearly shows several thermal transitions, found in Table 1. Transition A occurs at similar temperatures in both the eye round and filet mignon samples. This change correlates to the thermal denaturation of titin, around 78°C (Pospiech et al., 2002). Transition B shows the beginning of actin denaturing. Both eye round and filet mignon samples show a similar valley during this transition, approximately 80 to 83°C. Transition C occurs near 100°C and can be attributed to a loss in water. The transition in the eye round sample is more rapid than that of the filet mignon. This can be attributed to a greater amount of water loss in the filet mignon. Transition D occurs approximately at the collagen boiling temperature. The dT/dt plot shows that filet mignon has a more rapid transition than the eye round, this difference correlates to a higher collagen content in the eye round. The temperature testing and TGA indicate two similar transitions, that of the water loss and collagen boiling.

Using data from the previous two tests and Eq. 1-5, the resultant average h values for eye round and filet mignon were calculated to be 1.717 $W/m^2 \cdot °C$ and 1.845 $W/m^2 \cdot °C$, respectively. The calculated Bi are 0.2005 for eye round and 0.2007 for filet mignon. Both of these are greater than 0.1 making the Lumped Capacitance method invalid. Although h is not accurate, the higher value obtained for filet mignon can be attributed to the observed faster transition in Fig. 4. The filet mignon sample had reached a higher temperature than the eye round sample before the water boiling temperature of 100°C. This is due to the physical properties of the sample; such as, the water-holding capability that aids in determining beef tenderness and juiciness.

Typical force-elongation curves for filet mignon and eye round from the tensile testing are seen in Fig. 5 & 6. Fig. 5 shows representative plots from the raw sample tensile testing. The breaking force for the raw filet mignon representative samples was between 5N and 6N and the extension at the breaking force was seen to be about 35mm. The breaking force for the raw eye round representative samples ranged from 6N to 10N and had an extension of about 20mm. Fig. 6 shows representative samples from the cooked sample tensile testing. The breaking force for the cooked filet mignon ranged from 2N to 4N with an extension ranging from 25mm to 50mm. The breaking force for cooked eye round ranged from 8N to 17N with an extension ranging from 25mm to 40mm. The difference of the maximum breaking forces for filet mignon and eye round may be related to the amount of collagen and fat found in the different types of beef. The samples were pulled perpendicular to the face of the muscle fibers, this orientation of the beef enabled the test to record the forces applied on these intramuscular tissues. Experimentation by Dransfield shows that 2.24% of the fat free dry matter of the psosas major muscle, the muscle from which filet mignon originates, and 4.75% of the fat free dry matter of the semitendinosus muscle, the muscle from which eye round originates, is collagen. The fat content of the whole tissue weight was found to be 6.7% and 3.4%, respectively (Dransfield, 1977).

Table 2 shows the derived stiffness data that was calculated from the force-extension data using Eq. 6. Average k values were obtained for each type of beef. The average stiffness for the prime and select filet mignon was less than the average stiffness for the prime and select eye round. This may be due to the fact that eye round has more collagen and less fat marbling than filet mignon (Kerry, 2002), (Dransfield, 1977). The average stiffness of the filet mignon samples decreased after cooking for both the prime and the select grades. The average stiffness of the eye round samples only decreased after cooking for the prime grade, and increased after cooking for the select grade. The stiffness should not have increased for the select eye round sample. When the beef is cooked, it loses water and the proteins and the collagen begin to denature; although these transition temperatures were not met at the temperatures in which the beef was cooked, the stiffness would be more inclined to decrease than increase. The amount of collagen in filet mignon and eye round that has been found in previous research to be heat soluble collagen is 15.4% and 12.6%, respectively (Dransfield, 1977). It was expected to see a greater relative decrease in the stiffness of filet mignon than of eye round. The standard deviations for the average stiffness for each type of beef appear to be greater for the eye round samples than for the filet mignon samples. The variability observed in this data could have been decreased with a larger number of samples in each group.

CONCLUSION

Three experiments were conducted on filet mignon and eye round to correlate the quality of beef with its physical properties. Filet mignon and eye round are common representatives of higher and lower quality cuts of beef. Results were obtained from thermogravimetric analysis, temperature testing, and mechanical tensile testing to compare the water-holding capability and the tenderness of each of these cuts. Observations from TGA suggested that filet mignon has a higher water holding capability than eye round which was reinforced by the results found through temperature testing. Along with observing the water-holding capability of each cut, the temperature testing also revealed a lower collagen content in the filet mignon samples than in the eye round samples. Data collected during the mechanical tensile testing further supported the observation that filet mignon has a lower collagen content, and therefore a higher tenderness, since the filet mignon failed at a lower applied force than the eye round. The cumulative results from this study suggest that filet mignon has both a higher water-holding capability and a higher tenderness than eye round. This research supports the original assumption that these physical properties may play a role in determining the quality of beef.

TABLES

Table 1: Key transition temperatures obtained while cooking beef samples

Point	Eye round (°C)	Filet mignon (°C)
A	74	71
B	80	85
C	95	95
D	173	170

Table 2: Tensile stiffness of raw and cooked beef samples

Type of Beef	Raw samples (N/m)	Cooked samples (N/m)
Prime filet mignon	223 ± 49.4	127 ± 57.5
Select filet mignon	299 ± 109	214 ± 22.4
Prime eye round	572 ± 333	512 ± 158
Select eye round	552 ± 85.3	737 ± 161

FIGURES

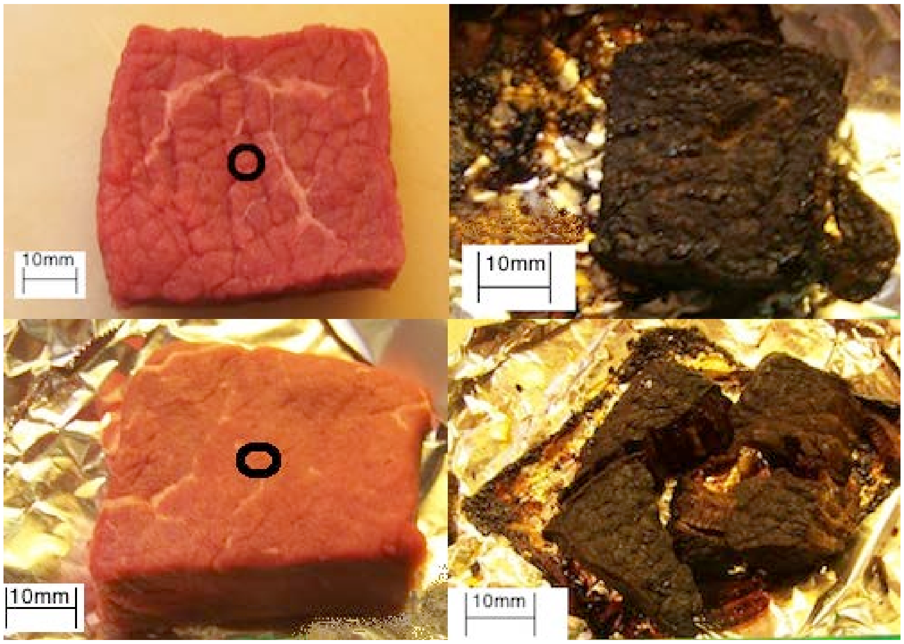

Figure 1: Before and after temperature testing (left side uncooked, right side cooked, top eye round, bottom filet mignon). Black circle indicates insertion location of thermocouple.

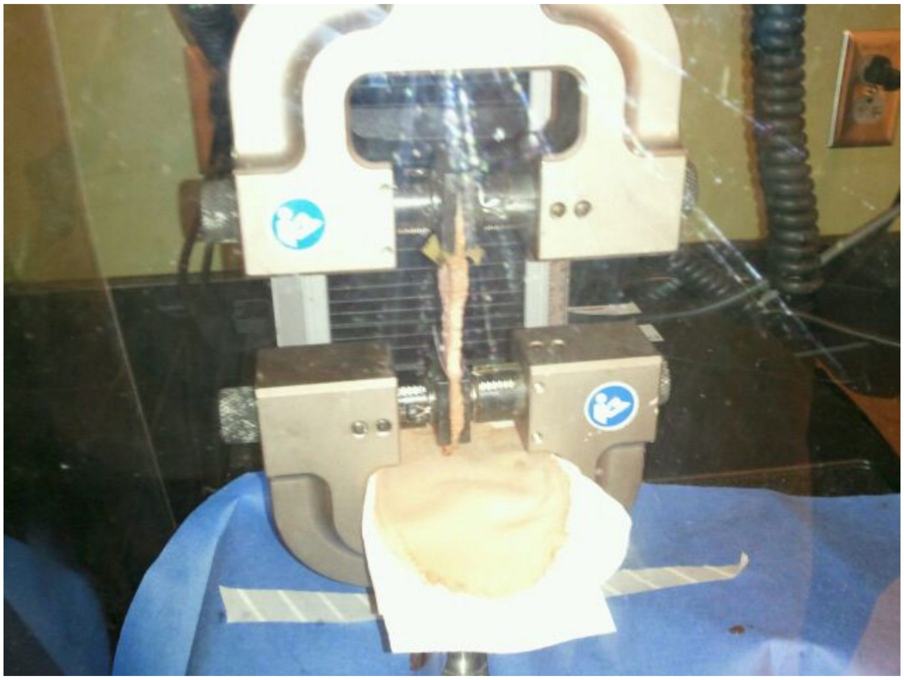

Figure 2: Instron machine set up.

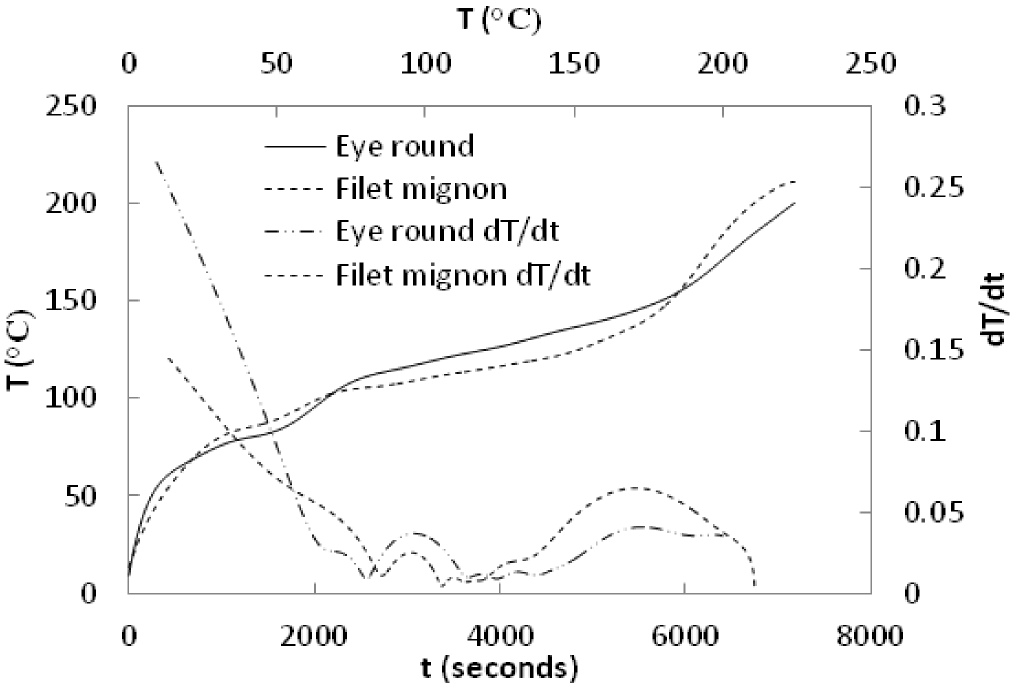

Figure 3: Cooking temperature data (heat at 225°C for 2 hours). The major axes correspond to T vs. t data. The minor axes correspond to dT/dt vs. T data.

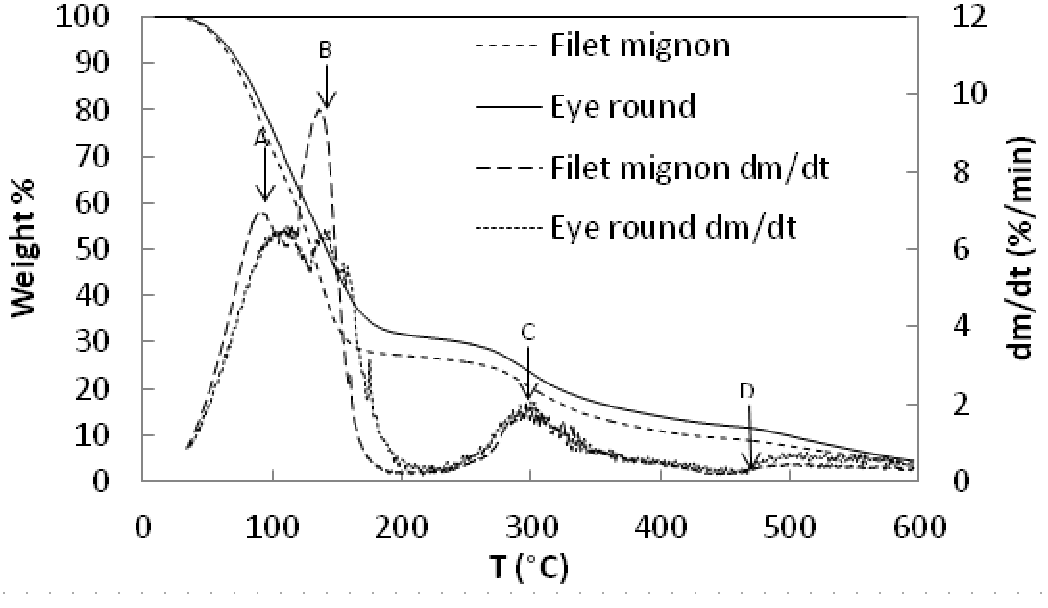

Figure 4: TGA data for filet mignon and eye round (heating rate = 10°C /min., Nitrogen atmosphere).

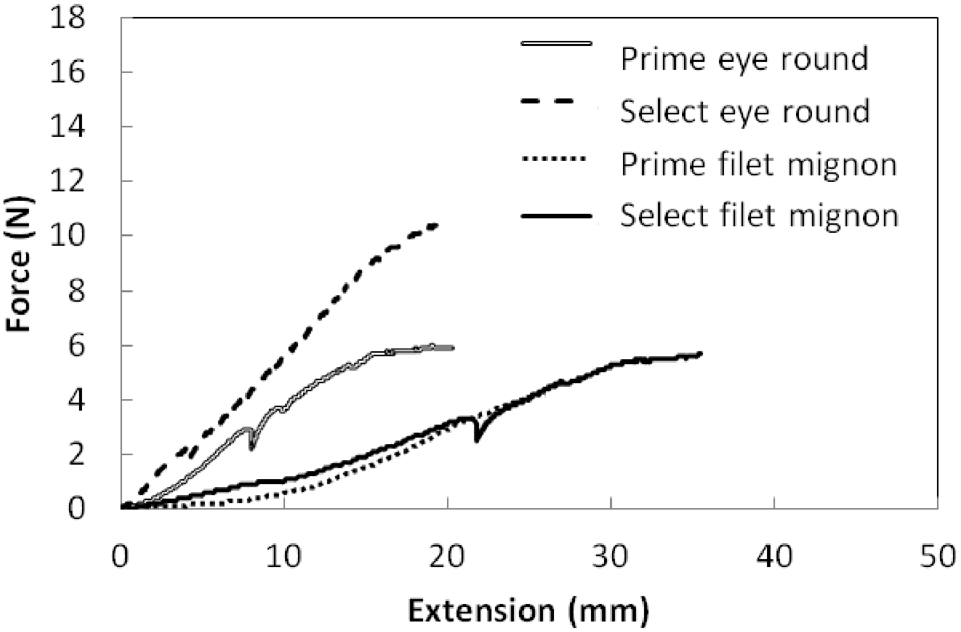

Figure 5: Representative tensile testing data for raw beef.

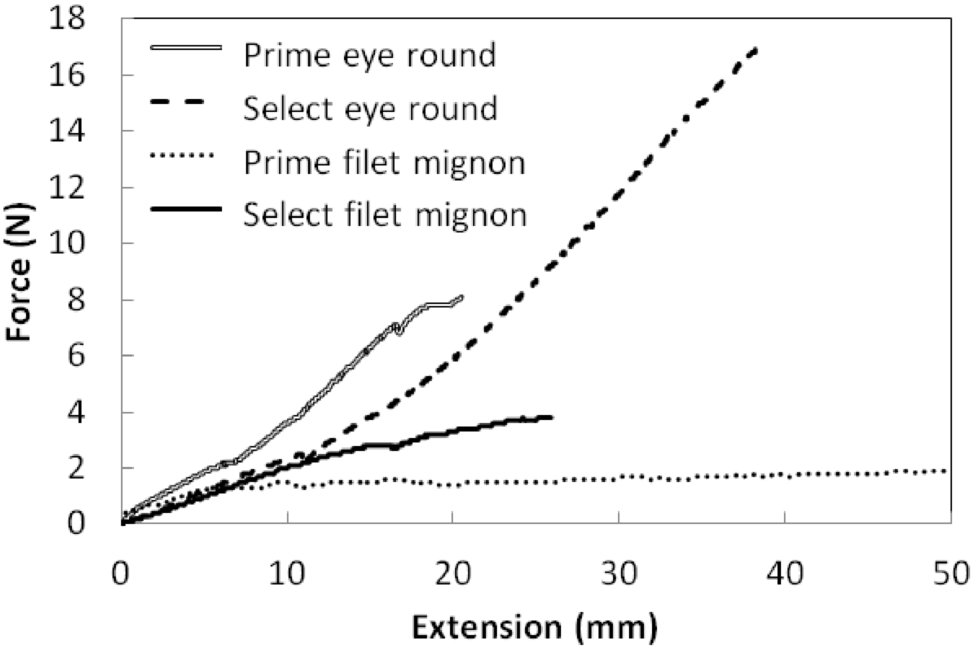

Figure 6: Representative tensile testing data for cooked beef.

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Appendix

Survey conducted to observe current meat consumption trends using Zoomerang.com

http://www.zoomerang.com/Survey/WEB22AXYPABX7D

What is your highest level of education?

1
Less than High School
GED/High School diploma
Some College
College degree +

Do you eat meat?

2
Yes
No

What types of meat do you most regularly eat?

3
Chicken
Turkey
Cattle
Pork
Lamb
Deer
Rabbit
Processed meats (Ham, sandwich meat, sausage, etc.)
Other, please specify

How do you buy your meat?

4
Fresh from the Butcher
Prepackaged

Is the way in which the animal is reared/raised a factor when choosing your meat?

5 Yes
No

Are you willing to sacrifice some of the flavor for a lower fat / sodium content in the meat?

6 Yes
No

How many servings of meat do you eat per day? (About 8oz per serving)

Less than 1
7 1
2
3
More than 3

How physically active are you?

Very active
8 Active
Moderately active
Not very active
Not active

Do you / have you had any of the following diseases/cancers:

Cardiovascular (heart) disease
Colon cancer
Bone health issues / osteoporosis
Overweight/obesity
9 Insulin sensitivity/diabetes
None
Other, please specify

When shopping for meat, what is of greatest importance to you?

Healthiness
Convenience (for cooking/preparation)
10 Animal welfare
Cost
Other, please specify

Does the fact that you may get sick from eating certain meat affect the quantity of meat that you eat?

11
Yes
No

Would you eat tissue engineered meat (meat that is grown in a lab outside the body of an animal using an animals cells as a base) if it looked and tasted the same?

12 Yes
No
Possibly, if I knew more about it.