QUALITATIVE ATTRIBUTES OF NATIONALLY AVAILABLE GRASS-FED BEEF

A Thesis in
Animal Science
by
Lindsay Nicole Eurich

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The thesis of Lindsay Nicole Eurich was reviewed and approved* by the following:

Christopher R. Raines  
Assistant Professor of Meat Science and Technology  
Thesis adviser

Edward W. Mills  
Associate Professor of Dairy and Animal Science

Catherine N. Cutter  
Associate Professor of Food Science

Daniel M. Kniffen  
Assistant Professor of Dairy and Animal Science

Terry D. Etherton  
Distinguished Professor of Animal Nutrition  
Head of the Department of Dairy and Animal Science

*Signatures are on file in the Graduate School.
Abstract

The objectives of this study were to assess the variability of qualitative attributes and microbiological profile associated with nationally available grass-fed beef, including: (1) product cost, (2) distance traveled, (3) potential distribution CO₂ emissions, (4) uncooked color for different bloom times, and (5) cooked color and tenderness at different endpoint temperatures. Frozen ground beef (GB, 1000 g per vendor) and longissimus lumborum steaks (LL, 4 per vendor) were purchased from online grass-fed beef vendors (n=15) in the United States and shipped to the Penn State Meats Laboratory via air freight. Only beef from vendors willing to provide animal age, breed type (bos taurus), and postmortem aging information (14-21 d) supplied beef for this study.

Sample cost per kg and shipping container dimensions were recorded, and samples were stored at -20°C until all samples were collected. The GB and LL steaks were thawed overnight at 2°C. The GB for use in microbiological profiling was separated and stored at -20°C until microbiological analysis. The GB patties (113.4 g) were made with a hand mold. Instrumental color (L*, a*, b*) was measured after GB patties and LL steaks bloomed for 0, 30, and 60 min at 22±2°C. GB patties and LL steaks were cooked using clamshell-style electric grills to 60°, 65.5°, 71.1°, and 76.6°C, rested for 10 min, then internal cooked color was measured. Warner-Bratzler shear force (WBSF) was conducted on four 1.27 cm cores taken parallel with the muscle fiber of each LL steak, and on two 2.5 cm thick strips from each cooked patty. The WBSF values for endpoint temperatures of 60°, 65.5°, 71.1°, and 76.6°C for LL steaks were 3.02±1.02, 3.6±1.43, 3.41±1.03, and 3.82±1.73 kg, and for GB patties were 4.64±1.6,
4.59±2.23, 4.33±1.3, and 4.16±1.41 kg, respectively. The $a^*$ values after 0, 30,
and 60 min of bloom time of uncooked LL steaks were 11.69±0.75, 15.62±1.38,
and 16.61±0.91, and of uncooked GB patties were 19.83±1.96, 22.65±1.84, and
21.85±1.29, respectively. The $a^*$ values after cooking to 60°, 65.5°, 71.1°, and
76.6°C for LL steaks were 13.35±2.07, 12.27±1.97, 9.71±1.74, and 7.81±0.76,
and for GB patties were 20.46±1.82, 19.96±1.61, 17.80±2.45, 16.51±1.51,
respectively.

Two, 25 g samples of ground beef were evaluated for aerobic plate count
(APC), total coliforms, generic and pathogenic *Escherichia coli*, *Salmonella spp.*, and
*Campylobacter spp.* *Salmonella spp.*, *Campylobacter spp.*, or pathogenic *E.
coli* were not detected in any of the samples.

Survey data indicate that online-purchased grass-fed LL steaks and GB
are considerably more expensive per kg than store-bought counterparts. The LL
steak retail price was $50.3±16.7/kg and GB retail price was $13.4±2.8/kg.
Standard cargo volume, fuel economy, and standardized emissions for trucks
and freight airplanes data were used to calculate potential CO$_2$ emissions
associated with product shipment. Beef was shipped 1904.5±1098.4 km with
potential CO$_2$ emissions of up to 9.9 kg CO$_2$/kg beef. CO$_2$ emissions per kg of
beef if shipped overnight can be ≥ 200% more than conventional counterparts
shipped by standard refrigerated truck. Proponents of grass-fed beef report that
it cooks differently than grain-fed beef; however, this survey reveals considerable
variation of cooked color and tenderness among grass-fed products. Food miles
and CO$_2$ emissions are emergent food qualities, neither of which are supported
for perishable products shipped via air. Grass-fed beef introduces more variation
into a beef system focused on improving product consistency and uniformity.
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Dedication

This thesis is dedicated to my parents, Mark and Ilona Eurich, and sister, Taylor. Your support throughout my educational endeavors has been incredible and this thesis would not have been completed without your encouragement.
Preface

This manuscript is written according to the style guideline of *Meat Science*, a scientific journal encompassing the many facets of meat science research. Some slight deviations from the journal format occur, with the intent of better communicating the contents of this thesis.

*Chapter I* is a literature review relating to grass-fed beef composition and safety as well as the development of the food movement. *Chapters II, III and IV* are research chapters. *Chapter II* is an evaluation of grass-fed beef color and tenderness (presented at the 2011 Reciprocal Meat Conference – Manhattan, Kansas). *Chapter III* investigates the potential environmental impact of different distribution models (presented at the International Conference of Meat Science and Technology – Brussels, Belgium). *Chapter IV* is a microbiological analysis of grass-fed beef products.
Statement of Research Needs

Grass-fed beef production is an emergent niche market in the United States that has developed because of popular press books, films, and related media associated with the “food movement.” Reasons for this market include perceived healthfulness for humans and animals and lessened environmental impact due to livestock production. In the Northeastern United States, including Pennsylvania, beef cattle farmers are seeking out value-added beef production opportunities, including grass-fed beef, by marketing beef directly to consumers through outlets such as farmers’ markets, community supported agriculture cooperatives (CSA), or simply by themselves directly to the consumer. The national beef industry continuously monitors beef quality through programs like the National Beef Tenderness Survey (NBTS) and the National Beef Quality Audit (NBQA). Interestingly, NBTS methodology (Penn State assisted research) excludes grass-fed beef, yet NBQA can include it. The United States Department of Agriculture (USDA) and other non-governmental organizations monitor and report beef prices and beef demand. However, this information is reported only for “commodity” feedlot beef and thus, there is a need for such information to be captured in order to answer questions and offer advice to farmers marketing grass-fed beef.
Animal and Human Subjects Use Note

This project originated as an independent addendum to the NBTS and some of the accepted methodologies for that project were applied in the following research. Beef was not purchased at traditional retail establishments because grass-fed is not commonly found at supermarkets, and when present, is usually imported. To identify grass-beef sources, various online beef vendors were found and only those offering detailed information about their products were included in this survey. Information including cattle breed and carcass aging time were posted publicly on their retail websites. Some vendors telephoned the research team to “follow-up” on their product and our eating experience; however, members of the team informed them that the beef was for research purposes and that a sensory panel was not a component of this project. All of the beef used in this study was slaughtered and processed under federal inspection. Upon receipt of meat, USDA inspection legends were checked.
CHAPTER I

Literature Review

1. Status of the U.S. Beef Industry

1.1 The U.S. Cow Herd

In 2011, the U.S. had its smallest cattle (beef and dairy) inventory since the 1950's. This issue can be attributed to a variety of factors impacting beef cattle production, including enhanced genetics and biotechnology resulting in the production of fed cattle at heavier slaughter weights while doing so more efficiently (USDA, 2012). The weak U.S. dollar limited the amount of imported beef, resulting in record high, cull cow prices. On December 20, 2010 the USDA Economic Research Service (ERS) reported that cow slaughter continued at a high rate, even with the low cow inventory. In 2011, ongoing drought in the Southwestern U.S. exacerbated the culling of the national beef cattle herd. Furthermore, there was a high ratio of heifer-to steer-slaughter. The combination of these factors implied continued liquidation of the national cow herd. Additionally, the rates of beef and dairy cow slaughter were higher that fall than they were for previous years, ensuring that U.S. cow inventories were lower on January 1, 2011 than they were on January 1, 2010.
In fall 2011, feeder cattle supplies outside of the feedlot were 4% less than in the fall of 2009, which is consistent with the increased placement of cattle into feedlots. As a result it was anticipated that feeder calf supplies for 2011 would be further reduced. The ERS projected that those feeders entering the feedlot in Spring 2012 would be lighter weight compared with their 2011 counterparts due to the low quality of winter wheat pastures overall, and the high corn prices, forcing producers to move feeders forward (USDA, 2012). There was an increase in the percentage of heifers entering the feedlot, with the total beef (excluding dairy) cow inventory the lowest since 1963. There was no expectation that the U.S. cow herd would begin to increase until calf prices rose. As a result of herd decline, the supply of feeder cattle and calves outside of the feedlot dropped 3% (USDA, 2012).

1.2 Beef Imports

Beef imports for 2010 were approximately 2.4 billion pounds representing a 10% decrease compared to previous years. The strong Australian dollar became a predominant factor in limiting U.S. imports from this top supplier because of the high prices importers were required to pay. Furthermore, imports from New Zealand decreased 6% from previous years and Brazil stopped exporting to the U.S in the second half of 2010. Because of the strength of the Australian dollar, beef exports to the U.S. declined 28% in 2010 (USDA, 2012).
Regardless of decreased imports from Australia and Brazil in 2010, there was a 4% increase forecasted for 2011 beef imports. Much of this growth did not take place until the second half of the year. Additionally, strengthening of the U.S. dollar would improve product flows into the U.S. (USDA, 2012).

Even so, imports of live cattle from Mexico were much larger than they were in many years – an increase of 31%. Additionally, there was a 6% increase in live cattle imports from Canada. Thus, total live cattle imports into the U.S. were up 16% from previous years. However, the expected smaller North American cow herd for 2011 resulted in a decreased percentage of live cattle traded. For 2011, live cattle imports were forecasted to be 9% lower than for 2010 (USDA, 2012).

1.3 Beef Exports

Even though the import market was down for 2010, there was a 16% increase in export markets, almost back to pre-bovine spongiform encephalopathy (BSE)-related export restriction levels. This export market recovery was expected to be accomplished by 2012 (USDA, 2012). Through October 2010, there was a 91% market recovery of exports pre- BSE levels. Prior to 2003, Korea and Japan shared about 60% of U.S. beef exports; and up until October 2010, they shared 28%, which does not fully explain the gain to almost pre-BSE export levels. Exports to Taiwan, Hong Kong, Egypt, Russia and
other countries helped boost 2010 export levels. October exports to Vietnam and Russia have constituted 23% of total U.S. beef exports. Fourth-quarter exports for 2010 were expected to undergo 25% growth. Because of this growth, ERS forecasted to end 2010 with exports being 19% higher than those years following the BSE outbreak. With few exceptions, exports have rarely exceeded imports, prior to December 2003. Additionally, the first half of 2011 expected to see a growth in U.S. exports (USDA, 2012).

1.4 Total U.S. Meat Supply

In 2011, the U.S. experienced a slight increase in meat production but a decrease in the Net Beef Supply (NBS), coinciding with elevated cattle prices. In 2010, the smallest NBS per capita since 1952 and the smallest per capita meat and poultry supply since 1997 (USDA, 2012) were observed. Worldwide, an increase in meat consumption has occurred as disposable income has increased. However, in 2011 a fourth straight year of beef production decline occurred. There has been a decline in beef cow numbers across the globe with the exception of Brazil, presumably because their cattle are grass-fed and they do not compete with 95% of the countries to which the U.S. exports beef (USDA, 2012).

In the retail market, there was a higher volume of proteins with more competition between them. In general, food service had less volume as
consumers traded down from steakhouses to family restaurants and even fast food chains (USDA, 2012).

There was a strong export market in 2011 which was met with challenges because of the low U.S. dollar and issues with accessibility. Import markets were limited by the U.S. dollar value and global supplies. Throughout 2011, a decrease in beef production and net supply was anticipated. An increase in imports and exports and stabilization of beef demand was expected, with the opportunity for it to improve (USDA, 2012).

2. Development of the Food Movement

2.1 Meat in Popular Culture

Books such as *The Omnivore’s Dilemma* by Michael Pollan and *Everything I Want to Do is Illegal* by Joe Salatin, have had consumers questioning where their food comes from. The popularity of books such as these has led to the development of many niche markets, including organic and grass-fed. It has steered individuals to shop local, question the sustainability of current agricultural processes, and ponder if the pork chop they are eating was raised humanely. Their questions have directed the development of “buzz words”, such as “locavore”, “certified humane”, “free range” and “All-Natural, Grass-fed…”, and the list goes on. For those producers looking for ways to maximize farm income, this food movement poses some promise for the small-scale farmer.
2.2 Popular Criticisms of Contemporary Meat Production

In *Food Politics*, by Marion Nestle, concern about the special interests funding lobbyists of politics on Capitol Hill is highlighted. The author is startled by the amount of money that the agricultural industry provides for lobbying and political action committees (PACs) and criticizes the regulations that are supported by officials given money by the industry. Nestle also speculates that the check-off programs are not really benefiting the producer themselves, but big industry; suggesting that the money is being used for more than just promotion of the chosen product.

In *The End of Food*, author Paul Roberts censures the beef industry declaring that even though they have become very efficient within concentrated animal feeding operations (CAFO) the industry has not been able to “…compensate for the inefficiency of the cows… and that cattle are raised in pens and fed rations …designed to produce rapid weight gain and marbling.” This, he believes, is not what the primary goal should be. Michael Pollan reasons that CAFOs are “… designed on seventeenth-century Cartesian principles…”, inferring that the industry treats animals simply as a machine working to support the backbone of big business. The proposed solution is to move towards a more sustainable and animal friendly systems, as seen with free range and grass-fed operators.
Food politician, Joel Salatin credits the industrial food system for emerging diseases that threaten public health and declares that these diseases were not known before 1900. He blames “industrial food” for the development of \textit{E. coli O157:H7}. Pollan defines O157:H7 as “… a relatively new strain of the common intestinal bacteria that thrives in feedlot cattle.” He specifies that it causes a serious, perhaps even fatal infection, which destroys kidneys in humans.

Roberts explains that even with the implementation of Hazard Analysis Critical Control Points (HACCP) in slaughterhouses improving the conditions in those facilities, they are “… one link in a much larger supply chain…” Informing the public that pathogens are in the supply chain “…long before they enter the slaughterhouse.” Roberts states that “…because of high corn diets and the realities of feedlot confinement, half of all feedlot cattle harbor the O157:H7 strain of \textit{E. coli}.” Cattlemen are not legally required to prevent pathogens from getting into the animals, even though slaughter facilities are required to control the pathogens. Roberts provides a solution: feeding cattle more grass or hay, which significantly reduces \textit{E. coli} early in the supply chain.

Pollan further explains that for producers, the main goal is to provide their animals with the “…cheapest, most convenient source of calories available.” The advantage of feeding cattle corn is that they gain quickly, but that the beef that originates from cows is unhealthy for human consumption because it is higher in
saturated fats and lower in omega-3 fatty acids. He further explains that growing grass-based meat products makes “…superb ecological sense: It is a sustainable, solar powered food chain that produces food by transforming sunlight into protein.” Salatin, agrees with Pollan on the free range, grass-fed front, declaring that meat from grass-fed animals is “… a whole different nutritional item than grain-based meat”. The issues raised by these authors have led researchers to question whether grass-fed beef is indeed healthier and a more sustainable feeding system.

2.3 Emergent Marketing Methods

The food movement has allowed for the development of more farmers’ markets, food cooperatives and opened the door for farmers to sell their products online, shipping anything from baked goods to steaks. Figures 1.1 and 1.2 display just two of many advertisements that are available to the consumer. The development of websites, such as EatWild.org, help the consumer locate the closest producer that sells the product they are looking for. The Know Your Farmer, Know Your Food program is the USDA effort to fulfill President Obama’s commitment to reinforce local and regional food systems. Additionally, organizations such as Pennsylvania Association for Sustainable Agriculture (PASA), strive for sustainable Pennsylvanian agriculture and food systems “…in a way that makes our farmers more viable, improves the land and restores the
health and wellbeing of all our citizens”. These books have raised the hackles of agriculture, making one wonder if what these authors are saying is actually true.

**Figure 1.1** Illustration of common advertisements promoting the local foods movement (http://www.fwi.co.uk/assets/getassetaspx?itemid=7534)
Figure 1.2 Popularized comparison between grain-fed and grass-fed beef used by an online grass-fed producer organization (http://www.texasgrassfedbeef.com/33ed5420.gif)

3. The USDA Grass-fed Standard

The grass-fed standard was developed in 2007 by the Agriculture Marketing Service (AMS), as a voluntary program. It is a verified program with the purpose of providing third party verification of an all forage diet, with the objective of market differentiation (USDA, 2007). The USDA grass-fed standard reads as follows:

"Grass and forage shall be the feed source consumed for the lifetime of the ruminant animal, with the exception of milk consumed prior to weaning. The diet shall be derived solely from forage consisting of grass (annual and perennial), forbs (e.g., legumes, Brassica), browse, or cereal grain crops in the vegetative (pre-
grain) state. Animals cannot be fed grain or grain byproducts and must have continuous access to pasture during the growing season. Hay, haylage, baleage, silage, crop residue without grain, and other roughage sources may also be included as acceptable feed sources. Routine mineral and vitamin supplementation may also be included in the feeding regimen. If incidental supplementation occurs due to inadvertent exposure to non-forage feedstuffs or to ensure the animal’s wellbeing at all times during adverse environmental or physical conditions, the producer must fully document (e.g., receipts, ingredients, and tear tags) the supplementation that occurs including the amount, the frequency, and the supplements provided.” (USDA, 2007)

It is important to note that the use of hormones and antibiotics is not prohibited for use in animals fed an all grass diet (USDA, 2007). Furthermore, because it is voluntary, products can still be labeled “grass-fed” without program participation.

4. Grass-fed Beef Composition

4.1 General Fatty Acid Composition

The assumed compositional and nutritional benefits of grass-fed beef have been marketed as a means to draws consumers to it. The lure of the supposed health benefits a consumer gets from switching to grass-fed beef from grain-fed beef is what has led researchers to investigate the potential in grass-fed beef. Nuernberg et al. (2005) and Leheska et al. (2008), established that compositionally, grass-fed animals have less fat than concentrate-fed animals.
Yet, the relative leanness of cattle can be controlled via nearly any diet formulation. Furthermore, concentrate-feeding has resulted in higher intramuscular fat levels than grass-based feeding (Nuernberg et al., 2005). Despite this observation, it was found that there are no differences in cholesterol content (Leheska et al., 2008). Although, Leheska and others (2008) noted that ground beef was higher in cholesterol than steaks.

Beef from pasture finished systems has less total saturated and monounsaturated fat content, as well as less total fatty acid content than grain-finished (Leheska et al., 2008; Duckett et al., 2009). Additionally, French and colleagues (2000) showed that an increase in grass intake provided a decrease in intramuscular fat, saturated fatty acid (SFA) concentrations. However, Noci et al. (2005) discovered no differences between treatments for total muscle fat or fatty acid content, while Leheska and colleagues (2008) observed higher concentrations of SFA for grass-fed beef.

It also was found that a decrease in concentrate intake causes an increase in conjugated linoleic acid (CLA) concentration (French et al, 2000; Duckett et al., 2009). Melton et al. (1982) learned that a grass diet causes beef lipid to have higher concentrations of C18:3 fatty acid. Also, grass-based feeding has resulted in a higher percentage of C18:1 trans isomers. The percentage of
CLA cis-9, trans-11 found in muscle was observed to be significantly higher in animals on a grass-based system (Noci et al., 2005).

Forage-fed beef appears to have a higher proportion of omega-3 polyunsaturated fatty acids (PUFA) than grain-fed beef (Mitchell et al. 1991). There was an increase in the n-3 fatty acid concentration in animals on a grass-based diet (French et al., 2000; Duckett et al., 2009; Noci et al., 2005; Leheska et al., 2008). Consequently, a beneficial decrease in the n-6: n-3 ratio occurred (French et al., 2000; Duckett et al., 2009; Noci et al., 2005; Leheska et al., 2008). In fact, it was discovered that the n-6: n-3 PUFA ratio was approximately half that of the treatment group on concentrate feed (French et al., 2000; Duckett et al., 2009). French et al. (2000) established that the concentration of PUFA in fat was higher for animals offered grass, than for those offered any other ration. Leheska et al. (2008) also observed that there were no differences in total PUFA concentration between grass-fed and concentrate fed animals.

4.2 Other Beef Components

Insani et al. (2008) demonstrated that at display time= 0, antioxidant vitamins, α-tocopherol and β-carotene, were in higher concentrations in pasture-fed steaks. Duckett and others (2009) also found that for the pasture-fed cattle in their study had higher concentrations of α-tocopherol, β-carotene, and antioxidants. This observation is believed to be due to the greater levels of
vitamins, such as β-carotene, in the forages fed to the cattle (Leheska, et al., 2008).

Higher concentrations of calcium, magnesium, and potassium also were observed in pasture-finished beef (Duckett et al, 2009). Leheska et al. (2008) found that ground beef samples in their study had significantly lower levels of magnesium, phosphorus, and potassium and significantly higher levels of sodium, and zinc than did the steak samples.

B-vitamins, thiamine, and riboflavin also are present in greater concentrations for grass-fed meat (Duckett et al., 2009). Ground beef has also been seen to have higher concentrations of vitamin B12 than steak (Leheska et al., 2008).

5. Grass-fed Quality Assessments

5.1 Cattle Performance and Carcass Characteristics

With the slight differences in composition between grass-fed beef and grain-fed beef, studies have been conducted to determine if these variances cause noticeable changes to the quality of the meat. Researchers have looked at carcass traits, color, protein and lipid oxidation, and sensory characteristics along with several other quality factors.
It was found that the daily gain of grass-fed bulls was significantly lower than that of concentrate-fed bulls, resulting in significantly older animals at slaughter (Nuernberg et al., 2005). Additionally, beef cattle finished on forages resulted in reduced carcass weights (Duckett et al., 2007). Crouse and Seideman (1984) observed trimmer, adjusted fat thicknesses and smaller *longissimus dorsi* areas for carcasses obtained from grass-fed heifers. Finishing beef cattle on pasture has resulted in higher percentages of lean and bone and a lower percentage of fat (Duckett et al., 2007).

Leander et al., (1978), discovered that carcass quality grades improved with grain feeding. Carcasses from grass-fed heifers have exhibited lower 12th-rib marbling scores (Crouse and Seideman, 1984). In the quality evaluation performed by Leheska et al. (2008), grass-fed beef had less marbling than did grain-fed beef.

Fat color was darker and yellower for pasture fed animals than for concentrate-fed animals (Duckett et al., 2007). Leheska and colleagues (2008) demonstrated that grass-fed beef had more yellow fat than did grain-fed beef. These authors speculated that the fat color could be altered as a result of the greater level of vitamins in the forages fed to the animals or because of the changes in the fatty acid profile.
5.2 Muscle and Lipid Quality Characteristics

Percent moisture declined and ether extractable constituents increased as the period of grain feeding increased (Leander et al., 1978). Leheska et al. (2008) validated the Leander and colleagues (1978) findings, in that grain-fed steak had a decreased percentage of moisture than grass-fed steak. A similar result was observed by Duckett et al., (2009), where finishing steers on high concentrate diets had decreased moisture content and increased lipid content. There were no differences in percent protein between grain fed and grass-fed meat (Leander et al., 1978). Duckett et al. (2009), observed that protein and ash did not differ between finishing systems.

Lipid and protein oxidation was higher in steaks from grain-based diets than in steaks from pasture diets (Insani et al., 2008). Additionally, after three days of display, Insani et al. (2008) observed an increase in lipid oxidation in meat obtained from grain-fed cattle, whereas meat from a grass-based diet did not display evidence of oxidation until after seven days of display. The authors further perceived that at day nine of display, protein oxidation was higher in meat from grain-fed cattle than in meat from pastured cattle. Insani and others (2008) speculate that the differences in the initial levels and consumption rate of α-tocopherol and β-carotene in the meat could explain the differences in the progress of lipid and protein oxidation observed between both treatments.
Furthermore, lipid oxidation results performed by Nuernberg et al. (2005) demonstrated that grass-based animals produced more oxidatively, stable meat. Luciano et al. (2009) found similar results in lambs fed herbage and believe that a grass-based diet could improve the oxidative stability of meat.

Crouse and Seideman (1984) found that lean from grass-fed heifers was decidedly darker and older in physiological maturity. A similar result was seen by Nuernberg et al. (2005) in that muscle color was darker in animals on a grass-based diet $L^*$ values were shown to be lower for samples from pasture diets (Insani et al., 2008). In a lamb study done by Luciano et al. (2009), meat lightness did not differ between lambs fed herbage or concentrate. The lack of difference could be partly due to the fact that lambs were allowed to grow at similar growth rates (Luciano et al., 2009). Duckett et al. (2007), also found that muscle color of pasture-fed meat was darker than concentrate-fed, which the authors believe may be due to lower muscle glycogen levels.

Insani and others (2008), reported that after 7 days of display, $a^*$ values were higher for steaks from pasture raised meat. However, longissimus muscle was less red for pasture-raised meat than for concentrate-fed (Duckett et al., 2007). No differences in $b^*$ values between both pasture-fed and grain-fed samples was observed (Insani et al., 2008). Insani et al. (2008) suggested that the higher levels of antioxidant vitamins could be the reason for the differences
observed between pasture and feedlot meat and the greater color stability seen in pasture meat. Duckett et al. (2007) speculated that this observation was due to the muscle having lower levels of glycogen.

5.3 Tenderness and Flavor

Measured muscle tenderness decreases with pasture feeding (Leander et al., 1978). A similar result was observed by Nuernberg et al. (2005) in that animals from a grass-based diet had tougher meat as measured by shear force. However, Duckett et al. (2007) found that shear force values did not differ between pasture-fed and concentrate-fed, however, collagen content was higher for pasture-fed than for concentrate-fed.

A trained sensory panel, in a study by Melton et al. (1982), observed that beef from grass-fed steers had a less desirable flavor than beef from grain-fed steers. In a study by Mitchell et al. (1991), a trained sensory panel rated steaks from grain-fed animals significantly more tender and more flavorful than those from forage-fed animals. Furthermore, beef flavor intensity was lower and off-flavor intensity was higher for pasture-braised meat than for concentrate-raised meat (Duckett et al., 2007).
6. Grass-fed Beef Safety

6.1 Beef Safety Background

With the grass-fed promotions practically shouting that their beef is safer because their cows don’t carry pathogenic *E. coli*, no wonder consumers are confused and influenced to purchase “safer” beef to protect their families. But the question remains, is it safer? Does it not shed pathogenic *E. coli*? *E. coli* is a bacterium that inhabits the gastrointestinal tract of mammals and while most strains of *E. coli* do not cause disease, some are pathogenic. *E. coli* O157:H7, isolated in 1982 (Riley et al., 1983), is one such pathogenic strain. It is a member of the enterohemorrhagic *E. coli* (EHEC) family, which are associated with Hemolytic Uremic Syndrome (HUS). *E. coli* O157:H7 is considered a major cause of HUS in North America. Additionally, Borczyk et al. (1987a) have frequently asserted that *E. coli* O157:H7 primarily harbors in cattle which are the reasons for the scrutiny focused on beef production and many suggest that it can be controlled by cattle diet. In 1994, the USDA classified *E. coli* O157:H7 as an adulterant when present in raw ground beef or beef trimmings intended for production of ground beef (USDA, 2004).

6.2 Conflicting Beef Cattle Feeding Research

It has been shown that grain-fed cattle have significantly higher concentrations of non-pathogenic *E. coli* in their feces than do grass-fed cattle.
(Barlow and Mellor, 2010). Diez-Gonzalez et al. (1998) determined that grain-feeding cattle increased both the number and acid-resistance of *E. coli*, concluding that this implicated significant food safety concerns. However, they did not investigate this approach with regards to pathogenic *E. coli*. In a study by Dargatz et al. (1997) cattle fed barley were more likely to be positive for *E. coli* O157:H7. Similar results were established by Buchko et al. (2000), in which the number of cattle shedding *E. coli* O157:H7 was significantly higher for the barley-fed group than for other diets. Also, Gilbert et al. (2005) found that cattle fed a grain diet had significantly higher numbers of fecal *E. coli* than cattle fed roughage diets. In an inoculation study, calves fed a high concentrate (grain) diet consistently shed the highest concentrations of *E. coli* O157:H7 (Tkalcic et al., 2000).

Conversely, Fegan et al. (2004) found that there were no differences in *E. coli* O157:H7 concentrations between grass-fed and concentrate-fed cattle. In a study by Kudva et al. (1997), similar results were observed in sheep that were inoculated with *E. coli* O157:H7 and then fed either all hay or a concentrate diet. Sheep fed an all hay diet shed the microorganism for twice as long as those fed a concentrate diet. It was also found that at 17 d post inoculation, 11 of the 14 hay-fed sheep were positive for the bacterium compared with only 3 of 13 in the concentrate group. Kudva et al. (1997) concluded that diet influenced the concentration of *E. coli* O157:H7 shed and the duration of shedding. In a similar
study by Hovde et al. (1999), hay-fed cattle shed *E. coli* O157:H7 for significantly longer periods of time than grain-fed cattle and that irrespective of diet, the bacteria were equally acid resistant. The authors concluded that “feeding cattle hay may increase *E. coli* O157:H7 infections in humans.” However, the authors’ in this case do not provide and supporting documentation or research to support this conclusion.

7. Emerging Questions about Food Production

7.1 Public Anxiety in a Global Food System

By 2050, it is predicted that the world population will be greater than 9 billion (UN, 2011) with most of the growth occurring in less developed regions of the world. With this in mind, it is important for agriculturalists to develop a sustainable, high quality food system that will be capable of serving a global scale.

While the development of a global food system is essential, it is also imperative to keep the consumers in the U.S. content. Their growing anxiety about food miles also must be addressed. Consumer concern with food miles, the distance a food item travels from farm to table, has increased over the last few years. It is driven by the desire of sustainable agriculturalists for consumers to be concerned about not only what they eat but the production practices of the farmer they are obtaining it from (Iles, 2005). There also is the aspiration to curb
global warming, one of the many reasons that have driven consumers to buy locally (Engelhaupt, 2008).

7.2 Eating “Green”

Weber and Matthews (2008) suggest that by replacing red meat and dairy intake once a week, a consumer can achieve about the same greenhouse gas reduction as buying locally. In a similar United Kingdom (UK) study in which consumer travel was evaluated, the finding suggested that if the consumer drove a round-trip distance of 6.7 km, with the goal of purchasing organic vegetables, their carbon emissions were likely to be higher than if they received home delivery from their local grocery (Coley et al., 2009). These results suggest that buying direct from the local grocery store may be more environmentally friendly than traveling to the local farmers’ market in a personal automobile.

Currently, there is no study that provides the carbon footprint for the beef industry as a whole. The only evaluation of the environmental impact of live production and processing, combined with the effects of packaging waste and distribution, was published by the Environmental Working Group in August 2011 (Figure 1.3). In this study, various false assumptions about livestock production were made. As an example, it was assumed in that model that the complete beef production cycle, including the cow-calf segment, occurs in a feedlot. Such
reports demonstrate the need for further, more comprehensive research regarding the impact of the food system and how it can be improved.

Figure 1.3 The Meat Eaters Guide published by the Environmental Working Group (http://static.ewg.org/reports/2011/meateaters/pdf/methodology_ewg_meat_eaters_guide_to_health_and_climate_2011.pdf)
CHAPTER II

SURVEY OF GRASS-FED BEEF COLOR AND TENDERNESS

L. N. Eurich

Department of Animal Science
The Pennsylvania State University
Abstract

The objective of this study was to assess the effect of bloom time on fresh lean color, and the effect of endpoint temperature on cooked color, and tenderness of grass-fed beef. Frozen ground beef (GB, 1000 g per vendor) and beef longissimus lumborum steaks (LL, 4 per vendor) were purchased from online grass-fed beef vendors (n=15) throughout the United States and shipped to the Penn State Meats Laboratory via air freight. Samples were stored at -20°C until all samples were collected. GB and LL steaks were thawed overnight at 2°C. GB patties (113.4 g) were made using a hand mold. Instrumental color ($L^*$, $a^*$, $b^*$) was measured after GB patties and LL steaks were allowed to bloom for 0, 30, and 60 min at 20°C. GB patties and LL steaks (4 per vendor) were cooked using clamshell-style grills to endpoint temperatures (ET) of 60, 65.5, 71, and 76.6°C, rested for 10 min. Steaks and patties were then cut in half for internal cooked color measurement. Warner-Bratzler shear force (WBSF) was measured on four, 1.27 cm cores taken parallel with the muscle fiber of each LL steak, and on two, 2.5 cm thick strips from each cooked patty. The $a^*$ values after 0, 30, and 60 min of bloom time of uncooked LL steaks were 11.69±0.75, 15.62±1.38, and 16.61±0.91, while $a^*$ values of uncooked GB patties were 19.83±1.96, 22.65±1.84, and 21.85±1.29, respectively. The $a^*$ values after cooking to ET of 60, 65.5, 71, and 76.6°C for LL steaks were 13.35±2.07, 12.27±1.97, 9.71±1.74, and 7.81±0.76, and for GB patties, were 20.46±1.82, 19.96±1.61, 17.80±2.45, 16.51±1.51, respectively. The WBSF values for ET of 60, 65.5, 71, and 76.6°C for LL steaks were 3.02±1.02, 3.6±1.43, 3.41±1.03, and 3.82±1.73 kg, while
WBSF for GB patties were 4.64±1.6, 4.59±2.23, 4.33±1.3, and 4.16±1.41 kg, respectively. Advocates of grass-fed beef report that it cooks differently than grain-fed beef. However, this study reveals considerable variation in cooked color and tenderness among grass-fed products.

1. Introduction

Quality attributes such as color and tenderness are what keep consumers purchasing beef (Garcia et al., 2008). However, these aspects in grass-fed beef can be highly variable because of the variety in genetics, forage source, and management practices (Steinberg et al., 2009).

Crouse and Seideman (1984) determined that meat from grass-fed heifers was darker in color as compared to meat from grain-fed heifers. Similarly, in a study evaluating stocker growth rate and finishing system effects on muscle color and palatability, longissimus color for pasture finished cattle was darker and less red than concentrate fed cattle (Duckett et al., 2007).

In a study evaluating the differences in beef from grass-fed or grain-fed cattle, results demonstrated that meat from grain-fed heifers tended to be more tender than meat from grass-fed beef (Crouse and Seideman, 1984). French et al. (2000) determined that concentrate-fed cattle had lower Warner-Bratzler shear force values (WBSF) than forage fed cattle. Similarly, Kerth et al. (2007)
found that steers fed a ryegrass forage diet had significantly lower WBSF values than steers on a high concentrate diet.

Therefore, the objective of this study was to analyze the variability of color and tenderness among steaks and ground beef from grass-fed vendors.

2. Materials and Methods

2.1 Sampling

Grass-fed suppliers were contacted and surveyed before product was ordered. Orders were placed with only those suppliers (n=15) able to provide slaughter age (24-32 months), breed (no *bos indicus* influence), post-mortem ageing time (14-28 days), and ground beef lean percentage (80-85%).

*Longissimus lumborum* steaks (4/supplier; derived from IMPS/NAMP 180 Beef Loin, Strip Loin) and ground beef (1000g/supplier) were collected from 15 grass-fed producers via online purchasing. Product was shipped to The Pennsylvania State University Meats Lab via overnight or two day shipping. Product was then stored at -20°C until sample preparation occurred.
2.2 Steaks

2.2.1 Thaw Loss

Steaks were removed from the freezer and weighed. They were allowed to thaw overnight at 3°C. They were removed from packaging and weighed. Packaging was rinsed clean and allowed to countertop-dry for a 24 hour period before being weighed. Thaw loss was calculated as a percentage of weight lost. Thaw loss percentages were recorded.

2.2.2 Color

After the thaw period, surface objective color values were taken with a HunterLab MiniScan EZ using illuminant A (Hunter Associates Laboratory, Inc., Reston, VA, USA). Readings were taken by placing the open orifice of the MiniScan against the surface of the sample then activating the automatic flash – detect sequence. Color measurements were recorded using the CIE (International Commission on Illumination) $L^*a^*b^*$ color space with $L^*$ representing lightness, $a^*$ representing the red to green continuum and $b^*$ representing the yellow to blue continuum. For color measurement steaks were removed from packaging and objective color was measured immediately, followed by 30 and 60 minute measurements at 3°C. Additionally, cooked objective color values were measured on the interior cut surface of the steak following cooking and holding as described below.
2.2.3 Cooking

Steaks were cut into halves and weighed, then randomly assigned to an internal endpoint cooking temperature of 60, 65.6, 71.1, or 76.7° C. Steaks were cooked in a clam-shell style grill (George Foreman Model GRP99, Madison, WI, USA) at 148.8° C until the designated temperature was reached. Temperatures were taken using a digital instant read thermometer (Wayfair, Boston, MA, USA), by inserting the tip of the thermometer into the center portion of the steak. Cook loss percentage was calculated as 
\[
\frac{\text{Final Weight} - \text{Initial Weight}}{\text{Initial Weight}} \times 100
\]
x 100. Steaks were rested for ten minutes prior cutting in half for internal objective color measurements, as described previously. Cooked steaks were then refrigerated overnight at 3° C for texture analysis. Cook loss percentages were recorded.

2.2.4 Texture analysis

After overnight refrigeration at 3° C, 6 round cores using a 1.27 cm corer were obtained. Each core was sheared perpendicular to the direction of the muscle fibers using a Warner-Bratzler V-shaped blunt blade (Texturecorder Model TMS-90, Food Technology Corp, Rockville, MD). Peak shear forces were recorded in kg.
2.3 Ground Beef

2.3.1 Thaw Loss

Ground beef removed from the freezer and weighed. It was allowed to thaw overnight at around 3°C. It was removed from the packaging and weighed. Packaging was rinsed clean and allowed to countertop dry for a 24 hour period before being weighed. Thaw loss percentages were recorded.

2.3.2 Color

Fresh lean objective color values were taken as described above for steaks, immediately following removal from the package and at 30 and 60 minute intervals at 3°C. Additionally, cooked objective color values were measured.

2.3.3 Cooking

Ground beef was formed in to 7.6 cm wide, 0.63 cm thick, 113 g patties, and then randomly assigned to an internal endpoint cooking temperature of 60, 65.6, 71.1, or 76.7°C. Patties were cooked on a clam-shell style grill (George Foreman Model GRP99, Madison, WI, USA) at 148.8°C until the designated temperature was reached. Temperatures were taken using a digital instant read thermometer (Wayfair, Boston, MA, USA), by inserting the tip of the thermometer into the center portion of the patty. Cook loss percentage was calculated as

\[
\text{Cook loss percentage} = \left( \frac{\text{Final Weight} - \text{Initial Weight}}{\text{Initial Weight}} \right) \times 100
\]

Patties were rested for
ten minutes prior to objective color measurements, as described previously for steaks. Patties were then refrigerated overnight at 3° C to be used for texture analysis. Cook loss percentages were recorded.

2.3.4 Texture analysis

After overnight refrigeration at 3° C, two 2.5 cm wide strips were removed from the center of each patty. Each section was sheared in three separate locations with a straight edge, unsharpened, blade attached to a texture analyzer ((Texturecorder Model TMS-90, Food Technology Corp, Rockville, MD)). Peak Shear force values were recorded as kg.

2.4 Statistical Analysis

Simple statistics were used to describe the mean values and variability of results obtained for color and tenderness. Data were analyzed using the repeated measures option of PROC GLM in SAS (SAS Institute Inc., Cary, NC, USA).

3. Results and Discussion

3.1 Steak

Steak $L^*$ values for 60 minute bloom time had a smaller range of variation than 0 and 30 minute $L^*$ values, with 0 and 30 minute $L^*$ values having the widest
range of $L^*$ color variation (Table 2.1). Bloom time presented $L^*$ values of 38.25 ± 1.58, 38.70 ± 1.65, and 36.37 ± 1.15, respectively (Table 2.1). O'Neill et al. (2004), reported a mean $L^*$ value for *longissiumus dorsi* muscles of 30.34 ± 0.81 after an hour bloom time. Those researchers observed less variation in lightness than in the current study. Their standard deviation was 0.81 versus 1.15 for an hour of bloom time for the current study. $L^*$ values for 65.5°C had the smallest range of variation amongst endpoint cooking temperatures with 71.1 °C having the largest range of $L^*$ color variation between endpoint cooking temperatures (Figure 2.1). The $L^*$ values for endpoint cooking temperatures of 60, 65.5, 71.1 and 76.7 °C were 49.85 ± 2.56, 48.54 ± 2.72, 48.95 ± 3.13, and 48.72 ± 2.73, respectively (Table 2.1).

The $a^*$ values for 0, 30, and 60 minute bloom times were 11.69 ± 0.75, 15.62 ± 1.38, and 16.61 ± 0.91 (Table 2.1), respectively, with 30 minute bloom time having the widest range of $a^*$ value variation among bloom times (Figure 2.2). O'Neill et al. (2004), reported a mean $a^*$ value of 22.26 ± 0.48. Those authors observed more red color than in the current study after an hour of bloom time and less variation in $a^*$ values. Their standard deviation was 0.48 versus 0.91. This indicates that grass-fed beef steaks are less red than commercial steaks. The $a^*$ values for 60, 65.5, 71.1, and 76.7 °C were 13.35 ± 2.07, 12.27 ± 1.97, 9.71 ± 1.74, and 7.81 ± 0.76 (Table 2.1), respectively. The 65.5 °C endpoint cooking temperature had the widest range of $a^*$ color variation and the
endpoint cooking temperature of 76.7 °C had the smallest range of $a^*$ color variation (Figure 2.2).

Initial bloom time appeared to have a lower range of $b^*$ values than did 30 or 60 minute bloom times (Figure 2.3). The $b^*$ values for 0, 30, and 60 minute bloom time were 10.75 ± 0.58, 14.08 ± 0.77, and 14.07 ± 0.70 (Table 2.1), respectively. In a study by O'Neill et al. (2004), the mean $b^*$ value was reported as 19.59 ± 0.53. Those authors observed a lower range of variation than the current study. Their standard deviation was 0.53 versus 0.70, indicating that grass-fed steaks in the current study are less yellow than commercial steaks. 71.1 and 76.7° C endpoint temperatures had wider ranges of $b^*$ color variation than did 60 and 65.5° C endpoint temperatures (Figure 2.3), with the $b^*$ values of 60, 65.5, 71.1, and 76.7° C endpoint temperatures being 18.38 ± 0.88, 18.21 ± 0.97, 18.14 ± 1.79, and 17.49 ± 0.89 (Table 2.1), correspondingly.

3.2 Ground beef

Ground beef bloom times 0, 30, and 60 minutes appear to have a wider range of $L^*$ color variation (Figure 2.4), with bloom time $L^*$ values of 47.21 ± 3.19, 47.79 ± 2.03, and 47.67 ± 1.81, respectively, than do endpoint cooking temperatures 60, 65.5, 71.1, and 76.7° C, with $L^*$ values of 54.84 ± 2.06, 55.60 ±
2.18, 56.48 ± 1.98, and 56.87 ± 2.72 (Table 2.2), respectively. Hague et al. (1994), perceived raw ground mean L* values of 50.5-52.2 with no differences in means observed. Those values demonstrate more lightness in raw ground beef than in the current study. Additionally, L* values for ground beef patties cooked to 60, 66, 71, and 77 °C, were reported as 51.9, 52.6, 52.6, 52.2, respectively (Hague et al., 1994), which is similar to the results of the current study, indicating that lightness values are similar for both grass-fed and commercial beef.

The a* values for bloom times of 0, 30, and 60 minutes were 19.83 ± 1.96, 22.65 ± 1.84, and 21.85 ± 1.29 (Table 2.2), respectively. Bloom time a* color variation appeared to have a wider range of variation than did cooked color with 60° C endpoint cooking temperature having the smallest range of a* variation (Figure 2.5). The a* values for endpoint cooking temperatures 60, 65.5, 71.1, and 76.7 °C were 20.46 ± 1.82, 19.96 ± 1.61, 17.80 ± 2.45, and 16.51 ± 1.51 (Table 2.2), correspondingly. Hague et al. (1994) reported raw mean a* values ranging from 12.1-13.3, which are much lower than the a* values observed for the current study indicating that raw ground beef grass-fed beef for the current study is more red than commercial ground beef. Internal a* values of patties cooked to 60, 66, 71, and 77 °C were reported as 13.9, 12.6, 11.4, and 11.0, respectively (Hague et al., 1994). These values are lower than those presented in the current study which indicates that cooked internal color is not a reliable way to determine doneness.

Initial and 60 minute bloom time appeared to have the widest range of b* color variation amongst bloom times with 30 minutes having the smallest range
of variation (Figure 2.6). The $b^*$ values for 0, 30, and 60 minute bloom times were $17.26 \pm 1.57$, $19.71 \pm 1.42$, and $19.29 \pm 0.90$ (Table 2.2), correspondingly. Hague et al. (1994), reported mean $b^*$ values for raw ground beef ranging from 16.6-17.2, with no significant differences observed. These values are lower than the current study indicating that raw ground grass-fed beef is more yellow than raw ground commercial beef. 60° C endpoint temperature has the widest range of $b^*$ color variation amongst all temperatures with the other temperatures having similar ranges of variation (Figure 2.6). The $b^*$ values for endpoint cooking temperatures 60, 65.5, 71.1, and 76.7° C were $18.99 \pm 1.03$, $18.68 \pm 1.11$, $18.20 \pm 1.06$, and $18.02 \pm 0.83$ (Table 2.2), respectively. Hague et al. (1994), reported mean $b^*$ values, for endpoint cooking temperatures of 60, 66, 71, and 77 °C, of 17.7, 16.7, 16.0, and 15.9, respectively. These values are lower than those reported for the current study, indicating that cooked grass-fed beef patties are more yellow than cooked commercial patties.

### 3.3 Warner-Bratzler Shear Force

Steak WBSF values for endpoint temperatures of 60, 65.5, 71.1, and 76.7° C, were $3.02 \pm 0.91$, $3.59 \pm 1.09$, $3.41 \pm 0.8$, and $3.82 \pm 0.91$ (Table 2.3), respectively. Endpoint temperatures 60 and 76.7 °C appeared to have a wider range of WBSF values than did the other temperatures with 65.5° C appearing to have the smallest range of variation (Figure 2.7). The NBTS (2010) found a mean WBSF value for *longissimus dorsi* steaks (originally reported in newton’s
but for the purpose of this survey converted to kg) of 2.47 ± 0.07. This is considerably less than the averages found in this survey. The results of this survey compare more with the WBSF values found for bottom round steaks in NBTS, 3.18 ± 0.1, respectively. The investigators of NBTS concluded that all of the steaks were tender (Raines C.R., 2011).

The ground beef WBSF values for endpoint cooking temperatures of 60, 65.5, 71.1, and 76.7°C were 4.64 ± 1.25, 4.59 ± 1.48, 4.33 ± 0.84, and 4.16 ± 1.09 (Table 2.3), respectively. Endpoint cooking temperature of 65.5°C had the widest range of WBSF value variation while endpoint temperature of 71.1°C appeared to have the smallest range of WBSF value variation (Figure 2.7). These results could be due to the amount of restructuring that goes into ground beef patty creation, which would make the patties tougher than steaks. This could also be a result of the type of raw material used for the ground beef samples. Meaning that it is more likely that muscles that are generally recognized as tougher were most likely used to produce ground beef samples.

4. Conclusions

1. No major differences were found for grass-fed color
2. There was a wide variation in color among bloom times and endpoint cooking temperatures
3. Ground beef appeared to be less tender than steaks when cooked to endpoint temperatures of 60.0, 65.6, 71.1, and 76.7°C.
5. Implications

This study demonstrated that grass-fed beef products are highly variable across color and tenderness evaluations. The producer desiring to market their product as ‘grass-fed’ is left to do the research and comparisons to others on their own. Because of this observation grass-fed beef as a category, ought to be included in more national beef surveys, thus allowing for easier access to niche-specific information.
<table>
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Table 2.1. Mean raw and cooked color ($L^*$, $a^*$, $b^*$) of *longissimus lumborum* steaks
Figure 2.1 Steak $L^*$ (lightness)\textsuperscript{a} variation during 60 min of bloom\textsuperscript{b} or cooking\textsuperscript{c} to 76.7\textdegree C.

\textsuperscript{a}CIE Lightness value was measured on the cut surface of the steak using a HunterLab MiniScan EZ unit (Hunter Associates Laboratory, Inc., Reston, VA, USA)

\textsuperscript{b}Fresh steak was allowed to bloom at ca. 20\textdegree C for 0, 30 and 60 min before color measurement.

\textsuperscript{c}Color measurements were made after cooking to 60.0 (140), 65.5 (150), 71.1 (160) and 76.7 (170) \textdegree C (\textdegree F) internal temperature in a clamshell type grill (George Foreman, Model GRP99) then resting at room temperature for 10 minutes.
Figure 2.2 Steak $a^*$ (redness)\textsuperscript{a} variation during 60 min of bloom\textsuperscript{b} or cooking\textsuperscript{c} to 76.7°C.

\textsuperscript{a}CIE redness value was measured on the cut surface of the steak using a HunterLab MiniScan EZ unit (Hunter Associates Laboratory, Inc., Reston, VA, USA).

\textsuperscript{b}Fresh steak was allowed to bloom at ca. 20°C for 0, 30 and 60 min before color measurement.

\textsuperscript{c}Color measurements were made after cooking to 60.0, 65.5, 71.1 and 76.7 °C internal temperature in a clamshell type grill (George Foreman, Model GRP99) then resting at room temperature for 10 minutes.
Figure 2.3 Steak $b^*$ (yellowness)$^a$ variation during 60 min of bloom$^b$ or cooking$^c$ to 76.7°C.

$^a$CIE yellowness value was measured on the cut surface of the steak using a HunterLab MiniScan EZ unit (Hunter Associates Laboratory, Inc., Reston, VA, USA).

$^b$Fresh steak was allowed to bloom at ca. 20°C for 0, 30 and 60 min before color measurement.

$^c$Color measurements were made after cooking to 60.0, 65.5, 71.1 and 76.7 °C internal temperature in a clamshell type grill (George Foreman, Model GRP99) then resting at room temperature for 10 minutes.
<table>
<thead>
<tr>
<th>Assessment Point</th>
<th>$L^*$</th>
<th>$a^*$</th>
<th>$b^*$</th>
</tr>
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<tr>
<td>Time (minutes)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>47.21±3.19</td>
<td>19.83±1.96</td>
<td>17.26±1.57</td>
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<td>30</td>
<td>47.79±2.03</td>
<td>22.65±1.84</td>
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<td>60</td>
<td>47.67±1.81</td>
<td>21.85±1.29</td>
<td>19.29±0.90</td>
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<tr>
<td>Temperature (°C)</td>
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<td></td>
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<tr>
<td>60</td>
<td>54.84±2.06</td>
<td>20.46±1.82</td>
<td>18.99±1.03</td>
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<tr>
<td>65.6</td>
<td>55.60±2.18</td>
<td>19.96±1.61</td>
<td>18.68±1.11</td>
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<tr>
<td>71.1</td>
<td>56.48±1.98</td>
<td>17.80±2.45</td>
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<tr>
<td>76.7</td>
<td>56.87±2.72</td>
<td>16.51±1.51</td>
<td>18.02±0.83</td>
</tr>
</tbody>
</table>

**Table 2.2** Mean raw and cooked color ($L^*$, $a^*$, $b^*$) of ground beef patties
Figure 2.4 Ground beef $L^*$ (Lightness)$^a$ variation during 60 min of bloom$^b$ or cooking$^c$ to 76.7°C.

$^a$CIE Lightness value was measured on the cut surface of the ground beef patty using a HunterLab MiniScan EZ unit (Hunter Associates Laboratory, Inc., Reston, VA, USA)

$^b$Fresh ground beef was allowed to bloom at ca. 20°C for 0, 30 and 60 min before color measurement.

$^c$Color measurements were made after cooking to 60.0, 65.5, 71.1 and 76.7 °C internal temperature in a clamshell type grill (George Foreman, Model GRP99) then resting at room temperature for 10 minutes.
**Figure 2.5** Ground beef $a^*$ (redness)$^a$ variation during 60 min of bloom$^b$ or cooking$^c$ to 76.7°C.

$^a$CIE redness value was measured on the cut surface of the ground beef patty using a HunterLab MiniScan EZ unit (Hunter Associates Laboratory, Inc., Reston, VA, USA).

$^b$Fresh ground beef was allowed to bloom at ca. 20°C for 0, 30 and 60 min before color measurement.

$^c$Color measurements were made after cooking to 60.0, 65.5, 71.1 and 76.7 °C internal temperature in a clamshell type grill (George Foreman, Model GRP99) then resting at room temperature for 10 minutes.
Figure 2.6 Ground beef $b^*$ (yellowness)$^a$ variation during 60 min of bloom$^b$ or cooking$^c$ to 76.7°C.

$^a$CIE yellowness value was measured on the cut surface of the ground beef patty using a HunterLab MiniScan EZ unit (Hunter Associates Laboratory, Inc., Reston, VA, USA)

$^b$Fresh ground beef was allowed to bloom at ca. 20°C for 0, 30 and 60 min before color measurement.

$^c$Color measurements were made after cooking to 60.0, 65.5, 71.1 and 76.7 °C internal temperature in a clamshell type grill (George Foreman, Model GRP99) then resting at room temperature for 10 minutes.
<table>
<thead>
<tr>
<th>Endpoint Temperatures (°C)</th>
<th>Means</th>
<th>MSE</th>
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<td></td>
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</tr>
<tr>
<td>60.0</td>
<td>3.02</td>
<td>0.91</td>
</tr>
<tr>
<td>65.5</td>
<td>3.59</td>
<td>1.09</td>
</tr>
<tr>
<td>71.1</td>
<td>3.41</td>
<td>0.8</td>
</tr>
<tr>
<td>76.6</td>
<td>3.82</td>
<td>0.91</td>
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<tr>
<td><strong>Ground Beef</strong></td>
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<td></td>
</tr>
<tr>
<td>60.0</td>
<td>4.64</td>
<td>1.25</td>
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<td>65.5</td>
<td>4.59</td>
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<td>0.84</td>
</tr>
<tr>
<td>76.6</td>
<td>4.16</td>
<td>1.09</td>
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</table>

**Table 2.3** Average Warner Bratzler Shear Force values for each endpoint cooking temperature per each supplier for *longissimus lumborum* steaks and ground beef
Figure 2.7 Steak and ground beef Warner-Bratzler shear force value (kg) variation for different endpoint cooking temperatures
CHAPTER III

POTENTIAL ENVIRONMENTAL IMPACT OF GRASS-FED BEEF USING DIFFERENT DISTRIBUTION MODELS

L. N. Eurich

Department of Animal Science

The Pennsylvania State University
Abstract

The objective of this study was to assess emerging qualitative attributes of nationally available grass-fed beef including: product cost, distance traveled, and post-production beef distribution systems for Carbon Dioxide (CO₂) emissions. Frozen ground beef (GB) and beef longissimus lumborum steaks (LL) were purchased from online grass-fed beef vendors (n=15) from the United States, willing to provide postmortem aging information (14-21 d), and shipped to the Penn State Meats Laboratory via air freight. Sample cost per kg and shipping container dimensions were recorded upon arrival. Nine distribution scenarios were developed for grass-fed beef sold to consumers in the Northeastern United States: (1) 2.3-kg from farmers’ market (FM); (2) bulk share (25-kg) from community supported agriculture (CSA) program; (3) bulk carcass (181-kg) from farmer; (4) 2.3-kg from a supermarket distributed within Pennsylvania by truck; (5) 2.3-kg from supermarket shipped to Pennsylvania from Midwestern U.S. (MWUS) by truck; (6) 4.5-kg from online retailer (OR) shipped from MWUS by overnight air (OA); (7) 6.8-kg from OR shipped from MWUS by OA; (8) 4.5-kg shipped coast-to-coast by OA; and (9) 6.8-kg shipped coast-to-coast by OA. Standard cargo volume, fuel economy, and emissions data were used to calculate possible CO₂ emissions associated with product shipment per kg of beef for each distribution scenario. Among ground transportation, bulk purchasing beef had the least emissions (0.1-0.3 kg CO₂/kg beef); bulk truck distribution was intermediate (1.1-1.2 kg CO₂/kg beef); and FM had the greatest
(2.8 kg CO₂/kg beef) possible emissions. Scenario 7 (1.68 kg CO₂/kg beef), OA shipping can generate far greater (3.4-9.9 kg CO₂/kg beef) emissions for beef distribution than ground shipping. LL steak retail price was $50.28±4.04/kg and GB retail price was $13.44±0.74/kg. Beef was shipped 1905.27±283.72km. Survey data indicate that online-purchased grass-fed LL steaks and GB are considerably more expensive per kg than conventional counterparts. CO₂ emissions per kg of beef if shipped overnight can be ≥200% more than conventional counterparts shipped by truck. Beef products are marketed increasingly by OR and FM for their perceived sustainability advantages, which can be negated by associated shipping costs. Bulk purchasing and bulk shipping contribute positively to the sustainability of meat consumption. Food miles and CO₂ emissions are emerging food qualities, neither of which are supported by products shipped via air. These findings are among the first to demonstrate that.

1. Introduction

Agriculture has received increased scrutiny for its impact on the environment, especially live animal production. It is important to produce high-quality food items with a minimal environmental effect. While most studies focus on the environmental impact in cattle production, there are currently few reports that identify the impact of animal processing and distribution of animal products on the environment. There is an increased need for these studies, due to the increased interest in sustainable agriculture.
With the world population predicted to grow to over 9 billion people by 2050 (UN, 2011), agriculturists need to ascertain methods that best utilize resources to minimize its environmental impact and achieve a sustainable food supply (Capper, JL et al., 2009). While focusing on live animal production is important, focusing on animal processing and product distribution also is essential as improvements in these areas should be more achievable in a shorter period of time. Focus on reducing packaging waste as well as delivery methods would help put the meat industry on the right track to becoming more sustainable. The objective of this study was to develop a distribution model of beef based on distance shipped, packaging size, and distribution type.

2. Materials and Methods

2.1 Sampling

Grass-fed suppliers were contacted and surveyed before product was ordered. Orders were placed only with those suppliers (n=15) able to provide slaughter age (24-32 months), breed (no bos indicus influence), post-mortem ageing time (14-28 days), and ground beef lean percentage (80-85%). Longissimus lumborum steaks (4/supplier; derived from IMPS/NAMP 180 Beef Loin, Strip Loin) and ground beef (1000g/supplier) were collected from grass-fed producers via online purchasing. Product was shipped to The Pennsylvania
State University Meats Lab via overnight or two day shipping (Figure 8). Product was then stored at 0°C until sample preparation occurred. Upon receipt, distance shipped, packaging dimensions to determine average package size, and distribution system was recorded. Furthermore, fuel efficiency was calculated for each vehicle that was assumed to be used.

2.2 Model Development

2.2.1 Model 1: Local Distribution

The first model evaluated three local distribution systems: 1) Farmers’ Market (FM), 2) Community Supported Agriculture (CSA), and 3) Whole-Animal Purchase (WA). For FM, it was assumed that vendors traveled 80.5 km in a pick-up truck with 226.8 kg of beef per vendor. Additionally, it was assumed that the average consumer purchased 2.3 kg of beef and traveled an average distance of 24.1 km to and from the FM. Consumers buying through a CSA were assumed to travel 80.5 km to and from the CSA and purchased 22.7 kg of beef. For WA, consumers were assumed to have traveled 80.5 km and purchased 181.4 kg of beef. Assumptions of distance and amount purchased were based off of the purchasing experiences of the researchers for the current study, though it is clear that actual distance traveled and amount purchased vary by region.

Total carbon emissions per kg of beef were calculated using data from a)
Environmental Protection Agency (EPA), b) Bureau of Transportation Statistics (BTS), Aviation and Climate Change (ACC), and d) Boeing. These values were recorded.

2.2.2 Model 2: Commodity Distribution

Model 2 evaluated two commodity distribution systems: 4) PA Commodity (PC) and 5) Midwest to PA Commodity (MC) (Figure 3.1). For PC, it was assumed that the distance shipped was 321.9 km with an 18,140 kg load and that the average consumer traveled 8 km to and from the grocery store and purchased 2.3 kg of beef. For MC, it was assumed that the distance shipped was 2415 km with an 18,140 kg load and that the average consumer purchased 2.3 kg of beef and traveled 8 km to and from the grocery store. Assumptions of distance and amount purchased were based off of the purchasing experiences of the researchers for the current study, though it is clear that actual distance traveled and amount purchased vary by region. Total carbon emissions per kg of beef were calculated and recorded, as previously described.

2.2.3 Model 3: Overnight Air Distribution

The third and final model evaluated four overnight air distribution systems: 6) 2.3 kg Midwest to PA shipping (MWA1), 7) 6.8 kg Midwest to PA shipping...
(MWA2), 8) 2.3 kg West Coast to PA shipping (WCA1), and 9) 6.8 kg West Coast to PA shipping (WCA2) (Figure 3.1). For each of the overnight air shipping scenarios carrying capacity was based on box weight and size (0.03 m³). For MWA1 and MWA2, it was assumed that the plane flew 2415 km and then the delivery truck traveled 32.2 km. For WCA1 and WCA2, it was assumed that the plane flew 4000 km and then delivery truck traveled 32.2 km. Assumptions of distance and amount purchased were based off of the purchasing experiences of the researchers for the current study, though it is clear that actual distance traveled and amount purchased vary by region. Total carbon emissions per kg of beef were calculated and recorded, as previously described.

3. Results and Discussion

When evaluated, CSA and whole-animal purchase had the lowest CO₂ equivalent emissions as compared to Farmers’ Markets, Commodity distribution, and Overnight Air Shipping (Figure 3.2). This observation could be due to the fact that when consumers purchase through Farmers’ Markets, Commodity distribution, and Overnight Air Shipping, they buy small quantities which amounts to higher concentrations of CO₂ per kg of beef than if purchased in bulk as would be the case with a CSA or whole-animal purchases. In a study by the Environmental Working Group (2011), transportation of commodity beef accounted for less than one percent of beef’s total carbon emissions and buying locally only reduced beef’s carbon footprint from 1-3 percent. In the current study
it was demonstrated that buying locally accounted for the higher carbon emissions than buying bulk or commodity. It was observed that emissions were much higher for airfreighted meat (EPA, 2011). This was consistent with the results of the current study.

When compared with contemporary, conventional beef, grass-fed beef was sold at considerably higher prices per kg (Table 3.1). In fact, grass-fed beef purchased for this survey cost greater than 200% more per kg than commodity beef that could be purchased at the supermarket. This observation could be attributed to extra shipping costs as well as the added costs of producing and processing grass-fed cattle.

4. Conclusions

1. The bulk purchasing of grass-fed beef had the least CO₂ emissions (0.1-0.3 kg CO₂/kg beef) of any other system

2. Bulk truck distribution was intermediate in CO₂ emissions (1.1-1.2 kg CO₂/kg beef)

3. FM had the greatest (2.8 kg CO₂/kg beef) possible emissions of any of the local distribution systems for grass-fed beef

4. OA shipping can generate far greater (3.4-9.9 kg CO₂/kg beef) emissions for beef distribution than ground shipping and can almost double the carbon footprint of the entire beef system (Figure 3.3).

5. Implications

The bulk purchase of grass-fed beef minimizes the CO₂ emissions associated with meat purchasing and can, in general, be applied to other food
products (for example eggs and dairy)(Figure 3.3); however is only accountable for less than 5% of all sales of beef. The commodity distribution system shows little differences between regional and national systems. Finally, depending on the purchase volume, overnight air shipping can essentially double the carbon footprint of meat production and consumption.
Figure 3.1 Origin points used in the distribution to Penn State Meat Lab
Figure 3.2 Illustration of potential CO$_2$ emission equivalents for different beef distribution systems
<table>
<thead>
<tr>
<th>Product</th>
<th>CleanMetrics Estimates of GHG Emissions kg CO\textsubscript{2}e/kg of product at farmgate</th>
<th>GHG Emissions kg CO\textsubscript{2}e/kg of product (other references) at farmgate</th>
<th>Peer-Reviewed, Independent, and Government Sources</th>
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<td></td>
<td></td>
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<td>Phetteplace, et al (US)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>15.32</td>
<td>Subak, 1999</td>
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<td>Lamb</td>
<td>20.44</td>
<td>17.6</td>
<td>Williams 2005 (DEFRA, UK)</td>
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<td></td>
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<td></td>
<td></td>
<td>31.35</td>
<td>Barber 2007 (New Zealand)</td>
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<td>Pork</td>
<td>4.62</td>
<td>6.4</td>
<td>Williams 2005 (UK)</td>
</tr>
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<td></td>
<td></td>
<td>3.4-4.2</td>
<td>Pelletier 2010 (US)</td>
</tr>
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<td></td>
<td></td>
<td>5.5</td>
<td>Wiltshire 2006 (DEFRA, UK)</td>
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<td>Chicken (broiler)</td>
<td>2.33</td>
<td>4.6</td>
<td>Williams 2005 (UK)</td>
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<td></td>
<td>2.36</td>
<td>Pelletier 2008 (US)</td>
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<td>3.1</td>
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<td>Eggs</td>
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<td>1.8 (kg/dozen)</td>
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<td></td>
<td>1.68</td>
<td>Nielsen 2003</td>
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<td>9.8</td>
<td>Wiltshire 2006 (DEFRA, UK)</td>
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**Figure 3.3** Estimated total CO2 equivalents per kg of beef produced as published in the EWG’s Meat Eater’s Guide http://static.ewg.org/reports/2011/meateaters/pdf/methodology_ewg_meat_eaters_guide_to_health_and_climate_2011.pdf
<table>
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<th>Supplier</th>
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<th>GB ($/kg)</th>
<th>Distance Shipped (km)</th>
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<td>15</td>
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<td>13.19</td>
<td>1511.79</td>
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</table>

Mean±SEM 50.28±4.04 13.44±0.74 1905.27±283.72

Table 3.1: Price ($) per kilogram (kg) and distance shipped (km) of LL steaks and GB for each supplier
CHAPTER IV

MICROBIOLOGICAL ANALYSIS OF GRASS-FED GROUND BEEF

L. N. Eurich

Department of Animal Science

The Pennsylvania State University
Abstract

The objective of this study was to assess the microbiological profile of nationally available, grass-fed beef. Frozen ground beef (GB) was purchased from online grass-fed beef vendors (n=15) from the United States and shipped to the Penn State Meats Laboratory via air freight. Samples were stored at -20°C until all samples were collected. Two, 25 g samples of ground beef, per supplier, were stomached with 225-ml buffered peptone water (BPW). Each sample was serially diluted (5-fold) and enumerated for Aerobic Plate Count (APC) and Escherichia coli/coliform (EC/CF), as well as presence or absence of Salmonella spp., Campylobacter spp., and pathogenic Escherichia coli. APC counts ranged from 6.03 to 8.97 log_{10} CFU/g and EC/CF counts ranged from 2.95 to 8.72 log_{10} CFU/g. Salmonella spp., Campylobacter spp., and pathogenic Escherichia coli were not isolated from any of the ground beef samples. These findings suggest that while no pathogens were isolated, grass-fed ground beef has highly variable microbial profiles, which appear to be dependent upon the supplier.

1. Introduction

Grass-fed beef is promoted frequently as safer than grain-fed beef (McCluskey et al., 2005). Furthermore, cattle diet can influence the microbial populations of the rumen and digestive tract (Callaway et al., 2003; Depenbusch
et al., 2008; Jacob et al., 2009). Diez-Gonzalez et al. (1998) found that high starch/grain diets can cause a decrease in rumen pH, which can support the growth of acid-tolerant bacteria. The decrease in pH is frequently cited as a reason for an increase in shedding of *Escherichia coli* (*E. coli*) O157:H7. However, studies that focus on differences in *E. coli* O157:H7 shedding between grain-fed and grass-fed cattle report inconsistent findings (Hovde et al., 1999; Berg et al., 2004; Jacob et al., 2009).

The purpose of this research was to determine the microbiological profiles of grass-fed ground beef from online suppliers in the United States.

2. Materials and Methods

On-line suppliers of grass-fed beef were identified through a brief over the phone survey, which included questions regarding age at slaughter, breed, and ageing post-mortem, those suppliers that provided answers to all questions were selected for purchase. Samples were shipped directly to the Penn State Meats Lab by overnight courier. Insulated shipping containers, with ice packs or dry ice were provided by the vendor. Upon arrival that the Meat Lab, shipping containers were opened and products were noted to be cool, though actual product temperatures were not recorded. Samples were catalogued with an identifying letter and date of receipt and frozen (ca. -18°C) until all samples
were received and microbial sampling could be performed. Samples were thawed at ca. 3°C for 24 hours before microbial sampling. Two, 25-gram samples of ground beef from each supplier were added to 225 ml each of sterile buffered peptone water (BPW). Each sample was homogenized for 2 minutes at 230 rotations per minute (rpms) using a Stomacher 400 Blender (Seward, UK) in a sterile, filtered stomacher bag (Interscience, Rockland, MA).

2.1 APC and EC/Coliform Enumeration

Samples were serially diluted (5-fold) in BPW. Dilutions were plated on Petrifilm™ Aerobic Plate Count plate (APC) and E. coli/coliform plates (3M Microbiology, St Paul, MN, USA) in duplicate and incubated at 37°C for 48 hours. Aerobic bacteria, E. coli, and coliforms were enumerated using the 3M™ Petrifilm™ Plate Reader (3M Microbiology, St Paul, MN, USA) and results recorded.

2.2 Salmonella Isolation

Using methods adapted from the Microbiology Laboratory Guidebook (MLG; USDA-FSIS), pathogen prevalence was determined as follows. One milliliter from each stomached sample was added to 9 ml of lactose broth (Difco Laboratories, Detroit, MI) for enrichment and then incubated at 37°C for 24
hours. After incubation, 1 ml of the lactose broth was added to 9 ml of both tetrathionate (TT) broth (Oxoid Ltd., Basingstoke, Hampshire, UK) and selenite cysteine (SC) broth (Oxoid Ltd., Basingstoke, Hampshire, UK) and incubated for 24 hours at 37°C. Ten µl of each enriched sample were plated in duplicate on Xylose Lysine Deoxycholate agar (XLD) (Oxoid Ltd., Basingstoke, Hampshire, UK) and incubated at 37°C for 24 hours. Each plate was photographed and assessed for distinctive black salmonellae colonies. A latex agglutination test (Oxoid Ltd., Basingstoke, Hampshire, UK) was used to confirm *Salmonella* spp. from isolated black colonies. Test results were recorded.

2.3 *Campylobacter Isolation*

One milliliter from each stomached sample was added to 9 ml of Bolton broth (Oxoid Ltd., Basingstoke, Hampshire, UK) for enrichment, then incubated at 42°C for 48 hours under microaerophilic conditions (5.0% O₂, 10% CO₂, 85% N₂) using a CO₂ incubator (VWR International, West Chester, PA) supplied with a constant infusion of bone dry CO₂ gas. Ten µl was plated on Modified Charcoal Cefoperazone Deoxycholate Agar (mCCDA; Remel Microbiology, Lenexa, KS, USA) and then incubated at 42°C for 48 hours under microaerophilic conditions as described above. Each plate was assessed for *Campylobacter* spp. colonies.
which were confirmed using a latex agglutination test (Microbiology International, Frederick, MD, USA). Results were recorded.

2.4 Pathogenic E. coli Isolation

One milliliter from each stomached sample was added to 9 ml of tryptic soy broth (TSB) with novobiocin (8 mg/L ; VWR International, Radnor, PA) for enrichment and incubated at 37°C for 24 hours. Ten µl was plated on Rainbow agar (Biolog, Modesto, CA, USA) and incubated at 37°C for 24 hours. Each plate was assessed for six Shiga toxin-producing *Escherichia coli* colonies, which were confirmed using a latex agglutination test (Dryspot *E. coli* Seroscreen (Oxoid Microbiology, Hampshire, UK). Results were recorded.

2.5 Statistical Analysis

Bacterial populations of APC and *Escherichia coli* /Coliform duplicate counts were averaged and transformed to log$_{10}$ colony forming units per gram (CFU/g) of ground meat. Descriptive statistics (average and standard deviation) were calculated for APC and *Escherichia coli* /Coliform counts using an Excel spreadsheet (Microsoft Corp., Redmond WA) Samples exhibiting pathogens on selective agars or after enrichment procedures were indicated by counts or presence (+) or absence (-), respectively.
3. Results and Discussion

3.1 APC and EC/Coliform

APC results were highly variable among all suppliers, with counts ranging from 5.94 to 8.96 log\(_{10}\) CFU/g (Table 4.1). Eisel et al. (1997) reported an APC range of 4.1-5.6 log\(_{10}\) CFU/g in frozen ground beef. Additionally, they reported an average of 4.7 log\(_{10}\) CFU/g for fresh ground product. The current study observed a much larger range of counts. Generic E. coli and coliform counts also resulted in a large range of counts among suppliers from 2.95 to 8.72 log\(_{10}\) CFU/g and 2.95 to 8.63 log\(_{10}\) CFU/g, respectively. Eisel et al. (1997) observed coliform counts ranging from 1.4-3.2 log\(_{10}\) CFU/g for fresh product and an average of < 3.0 log\(_{10}\) CFU/g for frozen ground product. Additionally, researchers indicated that EC counts ranged from 1-2 log\(_{10}\) CFU/g for fresh product and averaged < 2.0 log\(_{10}\) CFU/g for frozen ground product. The current study demonstrated a much larger range of counts for both generic E. coli and coliforms. These results may be due to the wide variation of suppliers and processors, since most suppliers allowed for post-mortem ageing of at least 2 weeks, with some allowing up to 4 weeks. Furthermore, the low levels of external fat generally found in grass-fed cattle most likely allowed for increased surface growth (Eisel and Muriana, 1997).
3.2 *Salmonella* spp.

*Salmonella* spp. was not isolated from ground beef samples (Table 4.2). These results could be due to small sample size, or the sensitivity of the detection protocol or a combination of both issues. Bosilevac et al. (2009), observed a level of 4.2% of *Salmonella enterica* in commercial ground beef samples collected from seven regions within the U.S., signifying that levels of *Salmonella* spp. is low in ground beef. This observation could be a contributing factor to the lack of isolation of the organism from the samples for the current study.

3.3 *Campylobacter* spp.

*Campylobacter* spp. was not identified in any of the ground beef samples (Table 4.2). These results could also be due to small sample size or the length of storage at frozen temperatures. Eideh et al. (2010) determined that freezing rendered *Campylobacter jejuni* survivors undetectable in 70% of chicken breast inoculated with 50 CFU/g and 92.5% of chicken breast inoculated with 500 CFU/g after 20 days of frozen storage. Additionally, Georgsson et al. (2006) observed more than a one log reduction in naturally contaminated whole chickens after a seven month storage time at -20°C. In the current study, samples were stored for more than one year, suggesting that the length of storage may have reduced natural contamination to undetectable levels.
3.4 Pathogenic *E. coli* spp.

Ground beef samples did not test positive for any Shiga-toxin producing *E. coli* (Table 4.2). Uttendaele et al. (2001) observed one log reductions in frozen ground beef inoculated with low levels of *E. coli* O157:H7 and stored for a 14-day period. However, the authors noted that there was no further reduction after a 35-day storage period. It is likely that the product, in the current study, was not contaminated by Shiga-toxin producing *E. coli* or it was present at much lower levels than inoculation levels used by Uttendaele et al. (2001). Additionally, the product in the current study was stored at frozen temperatures for at least one year. Ansay et al. (1999) observed that frozen storage (-20°C) of ground-beef patties that had been inoculated with a single strain of *E. coli* resulted in approximately a 1 to 2 log reduction in the numbers of the control strain and individual serotype O157:H7 strains after 1 year, indicating that the product from the current study could have levels of Shiga-toxin producing *E. coli* that are undetectable by the methods used for isolation in this study. However, generic *Escherichia coli* strains were observed (Table 4.1). Block 1 counts appeared to be higher than counts from block 2. This observation could be due to small sample size, or the sensitivity of the detection protocol, or a combination of both issues.

4. Conclusions

1. Grass-fed beef has highly variable microbial counts, which could be dependent upon supplier
2. Pathogens were not detected in this study
5. Implications

Microbial analyses indicated that ground beef from various suppliers provided highly variable results. Further actions should be taken to reduce microbial counts across the system, including beef processing and production. A more comprehensive study of microbiological profiles, including a detailed comparison between conventionally-raised and pastured-raised beef, needs to be executed.
<table>
<thead>
<tr>
<th>Supplier</th>
<th>Coliforms</th>
<th>Generic <em>E. coli</em></th>
<th>APC</th>
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</thead>
<tbody>
<tr>
<td>A</td>
<td>5.74</td>
<td>5.96</td>
<td>8.10</td>
</tr>
<tr>
<td>B</td>
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<td>8.79</td>
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<tr>
<td>C</td>
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<td>8.96</td>
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<td>2.95</td>
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<tr>
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<td>2.95</td>
<td>5.94</td>
</tr>
<tr>
<td>G</td>
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<td>8.90</td>
</tr>
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<td>H</td>
<td>2.95</td>
<td>2.95</td>
<td>6.03</td>
</tr>
<tr>
<td>I</td>
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<td>6.98</td>
</tr>
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<tr>
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</tr>
<tr>
<td>O</td>
<td>2.95</td>
<td>2.95</td>
<td>6.06</td>
</tr>
</tbody>
</table>

*Table 4.1.* Aerobic plate counts and generic *Escherichia coli* / coliform plate counts in grass-fed ground beef (log_{10} CFU/g) from 15 online suppliers.
<table>
<thead>
<tr>
<th>Pathogen</th>
<th>Isolate numbers</th>
<th>% positive</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Salmonella spp.</em></td>
<td>0/15</td>
<td>0%</td>
</tr>
<tr>
<td><em>Campylobacter spp.</em></td>
<td>0/15</td>
<td>0%</td>
</tr>
<tr>
<td>Pathogenic <em>Escherichia coli</em></td>
<td>0/15</td>
<td>0%</td>
</tr>
</tbody>
</table>

**Table 4.2.** Prevalence of *Salmonella spp.*, *Campylobacter spp.*, and pathogenic *Escherichia coli* spp. in grass-fed ground beef from 15 online suppliers.
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Lindsay N Eurich

Department of Animal Science
324 Henning Bldg
The Pennsylvania State University
University Park, PA 16802

Cell: (303) 915-5830
demail: lneurich@gmail.com

EDUCATION

Master of Science, Animal Science (Meat Science)
The Pennsylvania State University, University Park, Pennsylvania, U.S.A.
Dr. C. R. Raines, advisor | Anticipated Graduation: August 2012
Working Thesis Title: Assessment of Qualitative Attributes and Microbiological Profiles of Nationally Available Grass-fed Beef

Bachelor of Science, Animal Science
Colorado State University, Fort Collins, Colorado, U.S.A.
Graduated: May 2009