THE EFFECTS OF FORAGE LEVEL IN WHOLE OR DRY-ROLLED CORN BASED DIETS ON CARCASS CHARACTERISTICS, MEAT TENDERNESS, AND MEAT COLOR

A Thesis
Submitted to the Graduate Faculty
of the
North Dakota State University
of Agriculture and Applied Science

By

Tyler James Frick

In Partial Fulfillment of the Requirements
for the Degree of
MASTER OF SCIENCE

Major Department:
Animal Sciences

April 2016

Fargo, North Dakota

North Dakota State University
Graduate School

Title

THE EFFECTS OF FORAGE LEVEL IN WHOLE OR DRY-ROLLED CORN BASED DIETS ON CARCASS CHARACTERISTICS, MEAT TENDERNESS, AND MEAT COLOR

By

Tyler James Frick

The Supervisory Committee certifies that this ***disquisition*** complies with North Dakota State University's regulations and meets the accepted standards for the degree of

MASTER OF SCIENCE

SUPERVISORY COMMITTEE:

Dr. Robert Maddock
Chair

Dr. Kasey Maddock-Carlin

Dr. Kendall Swanson

Dr. Kevin Sedivec

Approved:

4/15/2016
Date

Dr. Greg Lardy
Department Chair

ABSTRACT

The objective of this study was to determine if increasing the forage level and feeding grain whole as opposed to dry-rolled is a feasible alternative to high energy rations with a similar age at time of slaughter. Steers were fed either twenty or forty percent forage, with whole or dry-rolled corn. There were no differences in fat thickness, longissimus area, KPH, marbling, USDA quality grade, Warner-Bratzler shear force, or cook loss. Cattle fed high forage and whole corn tended to have lower hot carcass weights. Additionally, the forty percent forage treatment tended to have lower USDA yield grades, and had darker colored steak. Also, steaks from the dry-rolled corn treatment had steaks that were redder, and more yellow. Results from this study suggest that increasing forage level, and corn processing might not result in significant differences in carcass characteristics or meat tenderness, but could negatively impact meat color.

ACKNOWLEDGEMENTS

I would like to start by thanking my advisor, Dr. Robert Maddock for giving me this great opportunity to learn from you, as well as continue coaching a meat judging team. I am certain I have learned more on the road or in your office than in a classroom. I would also like to thank my committee, Drs. Kasey Maddock-Carlin, Kendall Swanson, and Kevin Sedivec. Thank you for all of your guidance and advice throughout the last couple of years. Additionally, I would like to thank all of the other graduate students that have either helped with the project, provided comic relief, or any other kind of stress relief.

I would also like to thank the meat judging programs both here at NDSU and down at Iowa State. Without these programs I would not be where I am today. I would especially like to thank "aunt" Sherry Olsen who introduced me to the world of meat science, and for the many conversations during breakfast after dropping the kids off at a contest. I would also like to thank my undergraduate meat judgers, both for assisting with my project and putting up with me for a whole year.

Last but not least, I would like to thank my family who has always provided me with support and believed in me when many others might not have.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

^{o}C..Degrees Celcius

CP...crude protein

cm...centimeter

DM ....dry matter

Fe2+ ....Ferrous Iron

Fe3+ ....Ferric Iron

HCW ....Hot Carcass Weight

KPH..Kidney, Pelvic, and Heart Fat

KG...Kilogram

Mcal ....megacalorie

MDGS ....modified wet distillers grains

mm ....millimeter

N...number

Neg...net energy gain

REA..Longissimus Muscle area

SAS ....Statistical Analysis Software

Sq. cm ....square centimeters

U.S. ....United States of America

USDA...United State Department of Agriculture

CHAPTER 1. LITERATURE REVIEW

Introduction

Typical beef finishing diets have high levels of concentrate, usually corn, which greatly increases the energy level of these diets (Vasconcelos and Galyean, 2007). The price of corn is highly volatile, and can impact the cost of gain tremendously (Berthiaume et al., 2006). The interest in feeding high levels of forage in a finishing diet tends to follow grain prices. As grain prices increase, so does the interest in feeding higher levels of forages (Harrison et al., 1978). These price increases may be due to many factors, including development of new technologies that use grains as a raw material source, the increasing demand of grain sources for human consumption, (Young and Kauffman, 1978) and weather (Harrison et al., 1978) among other things. During these times of high corn prices, increasing the forage level or different types of corn processing may be a viable option to reduce feed costs. However, these changes may have negative effects on carcass characteristics, meat tenderness, and meat color. Significant changes in forage level can result in a slower growth rate and a lower gain to feed ratio, and may contribute to differences in animal age or carcass fatness at the time of slaughter (Steen and Kilpatrick, 2000). Studies comparing grazing versus feedlot animals tend to have significant differences in animal age or weight at the time of slaughter due to the significant decrease in energy availability of the diet. These differences may confound any differences observed in carcass and meat quality.

There have been many different grain processing methods developed, including steam flaking, high moisture grain, dry rolling and many others (Theurer, 1986). The main goal of processing concentrates is to increase the starch availability of the grains (Owens et al., 1997). Processing may also allow for easier management and handling of the grains through more even mixing (Ensminger and Olentine, 1978). Increased starch availability achieved through processing may impact rate of gain prior to slaughter, carcass fatness, and subsequent meat quality. The objective of this chapter is to review literature relevant to the effects of forage level and concentrate processing on carcass characteristics, meat tenderness, and meat color.

Carcass Characteristics

USDA yield and quality grades are two main measures of beef carcass characteristics (USDA, 1997). Yield grade is an estimate of the percentage of lean retail cuts from a carcass, and is expressed numerically from 1 to 5, with 1 yielding the highest amount of lean cuts, and 5 the lowest. Yield grade increases as back fat, KPH% and HCW increase, and decreases as REA increases, USDA yield grade can be calculated using the equation of 2.5 + (2.5 * adjusted fat thickness in inches) + (0.2 * KPH fat %) + (0.0038 * HCW) – (0.32 * REA in square inches) (USDA, 1997). Back fat typically measured opposite the ribeye three fourths of the way from the backbone, and can be adjusted depending on how much fat has been deposited in other places. KPH% is a visual estimation of the internal fat and is typically expressed as a percentage of the hot carcass weight. Quality grade is an indicator of the potential eating quality of steaks from that carcass.

Maturity and marbling are two factors in quality grades. Maturity refers to the physiological maturity of that carcass and determined through the ossification of the vertebral column balanced with the lean maturity. As the animal ages, the sacral vertebra begin to fuse and the cartilaginous tips of the thoracic and lumbar vertebra become ossified. Maturity can also be assessed through the texture and color of the ribeye, with older animals tending to have a coarser, darker red colored ribeye, and younger animals a bright cherry-red fine textured ribeye. Maturity is a scale of A through E, with the approximate ages equal to or less than 30, 30 to 42, 42 to 72, 72 to 96, and greater than 96 months of age for groups A through E respectively (Shackelford, Koohmaraie, and Wheeler, 1995). As these maturity scores increase, the quality grade generally decreases. The line between B and C maturity carcasses occur when carcasses with C or greater do not qualify for grades of Prime, Choice, Select, or Standard. Additionally, for a carcass to have a UDSA quality grade of Select, the carcass must be A maturity. Within the B and greater maturities, the amount of marbling required to maintain a specific grade increases proportionally to the degree of maturity. For example a carcass with a maturity score E will require two additional degrees of marbling to be a similar grade as one in the C maturity classification (USDA, 1997; Figure 1).

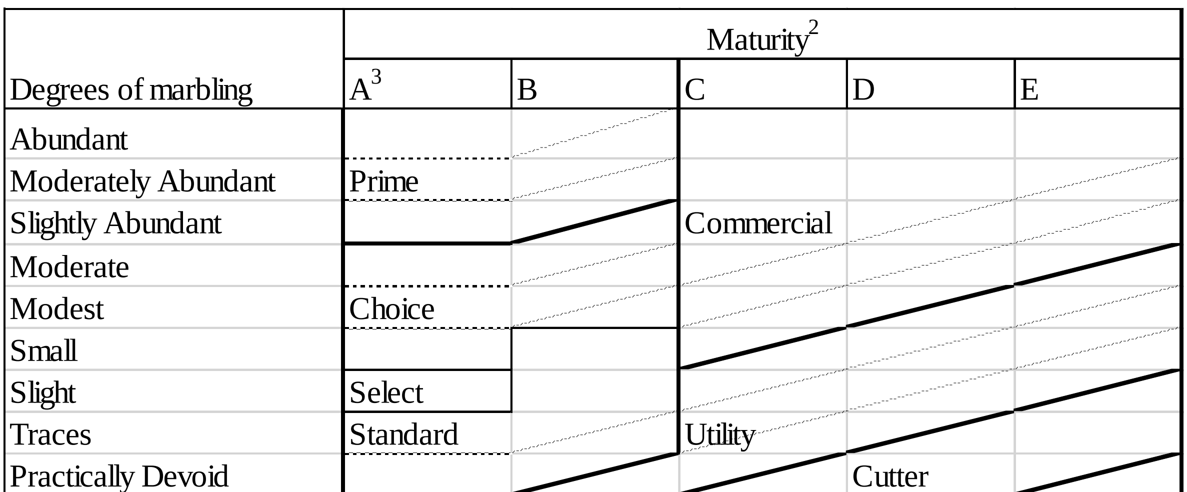

Figure 1.1 The relationship between marbling, maturity and carcass quality grade[1]

[1]Assumes that firmness of lean is completely developed with the degree of marbling and that the carcass is not a "dark cutter."

[2]Maturity increases from left to right (A through E).

[3]The A maturity portion of the figure is the only portion applicable to bullock carcasses.

Figure 1.1. The relationship between marbling, maturity and carcass quality grade.[1]

Effects of forage level on carcass characteristics

Differences in carcass characteristics attributed to forage level may be more linked to management system (i.e. grazing vs. feedlot) or the magnitude of difference in forage level

(Mandell et al., 1997). When compared to a typical finishing diet, grazing typically results in no difference (Bowling et al., 1977; Bidner et al., 1981) or lower yield and quality grades (Bidner et al., 1986; Bowling et al., 1978; Harrison et al., 1978; Hedrick et al., 1983) of carcasses. However, these changes in carcass characteristics are also dependent upon when these animals are slaughtered. For example, if the cattle are slaughtered at a constant back fat thickness, the grazing group will take much longer to finish, resulting in differences related to maturity at the time of slaughter. Conversely, if the time on feed is the determining factor for slaughter, the higher forage treatment typically has less fat deposited in most depots, resulting in a lower USDA yield grade, as well as marbling and USDA Quality Grade (Mandell et al., 1997; Arnett et al., 2012). Studies involving smaller differences in forage level typically avoid the problem of large differences in animal age and back fat at the time of slaughter, have smaller differences in carcass and meat quality characteristics, or no differences at all.

Arnett et al. (2012) studied a difference in forage level of 12 vs 24% using jersey steers and found the low forage level treatment had a greater amount of back fat and marbling, and a higher average USDA quality grade. However, there was no differences in hot carcass weight, kidney, pelvic and heart fat percentage, longissimus muscle area or final yield grade. The authors attributed these differences in carcass fatness to the higher energy density of the low forage diet. In a higher forage level diet, Marino et al. (2006) used treatments of 60 or 70% forage diets in a drylot setting with access to pasture and found no differences in carcass weight or carcass fatness.

Kerth et al. (2007) compared grazing cattle on ryegrass to cattle fed a typical grain finishing ration in a feedlot setting, and cattle that were started on the grazing ration then moved to the feedlot. Comparing the grain fed finishing ration treatment to the grazing treatment, the feedlot cattle had heavier hot carcass weights, more actual and adjusted fat thickness, larger longissimus muscle area, a greater KPH %, more youthful carcasses, and a higher USDA yield grade, with no differences in marbling or final quality grade. Bidner et al. (1986) used Brahman-Angus-Hereford, and Angus-Hereford steers in another grazing vs. feedlot trial with slaughter weights being held the same, resulting in the grazing cattle being 10 months older than the grain finished cattle at the time of slaughter. The grain finished cattle had a greater amount of back fat, KPH%, marbling, and a higher quality and yield grade, with hot carcass weight and longissimus muscle area being similar.

The effect of forage level on carcass characteristics appears to become more pronounced as the magnitude of difference in forage level increases, such as comparing grazing without supplementation to a typical feedlot finishing diet. Additionally, if total forage level is high and the difference between treatments small, the difference in carcass characteristics between treatments may be small (Marino et al. 2006).

Effect of grain processing on carcass characteristics

Processing corn breaks the outer shell, and performed with or without heating the grain. Heat impacts the starch within the grain to change chemically making it more available to the rumen microbes (Zinn et al., 2002). Grain processing is used to increase how efficiently the starch in the grain is used by the animal. Usually the more a grain is processed the more readily available that starch is to the rumen and can increase the efficiency of starch digestion by the rumen microbes. When particle size decreases, surface area increases, creating a conformational change in the starch that is more available to the rumen microbes. This conformational change usually occurs through the disruption of the protein matrix surrounding the starch granules (Hale, 1973). Additionally, grain processing may improve efficiencies through the destruction of mycotoxins that could have a negative impact on animal health (Owens et al., 1997). Processing grain, specifically corn, is often utilized by larger feedlots and in areas where less corn is produced. Thus, in finishing drylots that utilize grain processing usually feed large quantities of grain, and will transport grain over longer distances. This process also increases feed costs, so the increased efficiency must offset the increased cost of transportation and processing.

One of the more commonly used methods to process grain with heat is steam flaking, which consists of processing the grain through rollers that are set smaller than the whole grain after steam is applied. Steam rolling is similar to steam flaking, with the difference being the length of time the steam is applied. The steam rolling process occurs any time after one to eight minutes of steam whereas steam flaking could occur anywhere from 30 to 40 minutes of heating (Richards and Hicks, 2007). Steam rolling and flaking is costly and usually used in the southern parts of the United States. Since corn is more readily available across the northern regions of the U.S. where corn is more readily available, and transporting the grain less costly, it is mainly fed in either the whole, unprocessed, or dry-rolled. Dry rolling is similar to steam-flaking without the application of heat, resulting in smaller particle size compared to whole corn (Ensminger and Olentine, 1978). The availability of starch from these three different types of processing methods, from least to most available, is whole, dry-rolled, and steam-flaked corn (Richards and Hicks, 2007).

Carcasses from cattle fed tallow with steam-flaked corn tended to have heavier hot carcass weights, more back fat, and a higher yield grade than dry-rolled corn in a study conducted by LaBrune et al. (2008). The longissimus muscle size, KPH%, marbling, and percentage of carcasses grading USDA Choice were all similar in this study. Leibovich et al. (2009) also compared steam-flaked and dry-rolled corn, and found the carcasses from the steam-flaked corn treatments had a greater amount of back fat and a higher USDA yield grade, a tendency to have a smaller longissimus muscle area, while the hot carcass weight, KPH%, marbling, and percentage of cattle grading USDA choice all similar across treatments.

Meat Tenderness

Tenderness is a major factor in consumer satisfaction. According to Boleman et al. (1997) consumers can detect the difference between tough, intermediate, and tender steaks with shear force values of 2.27 to 3.58 kg, 4.08 to 5.4 kg, and 5.9 to 7.21 kg respectively. The authors (Boleman et al., 1997) also determined consumers are willing to pay a premium for guaranteed tender beef. The tenderness of steaks is usually determined through the use of Warner-Bratzler shear force. This involves cooking the steak to an internal temperature of around 71^{o}C, then cooled followed by removal of multiple cores parallel to the muscle fibers. The force required to shear the cores in half is then measured.

Another way to measure tenderness involves the use of sensory panels, with the panels either trained or untrained. Trained panels usually involve intensive screening and trials to find appropriate panelists that can accurately detect small differences in flavor, juiciness, and tenderness among other attributes. However, descriptions from trained panels may not always accurately represent consumer preferences (Lorenzen et al., 2002). Untrained panels usually involve consumers that are asked simpler questions, which may only apply to one area or location (Neely et al., 1998).

Reports of the effect of forage level in the diet on tenderness in beef vary. Some have found no difference in tenderness (Arnett et al., 2012; Bidner et al., 1986), while others have found steaks from forage-fed cattle to have higher shear force values (Kerth et al., 2007; Hedrick et al., 1983). These results may be confounded by animal age (maturity) when slaughtered at similar weights or fatness in diets composed of large differences in forage level or grazing compared to feedlot. Cattle on high forage diets could result in carcasses with lighter carcass weights and lower amounts of back fat. These decreases in hot carcass weights may result in an increase in the chilling rate of those carcasses, therefore at risk of cold shortening. Chilling rate may also be linked to differences in tenderness since carcasses with faster chilling rates tend to have less tender steaks (Bowling et al., 1977). If the chilling rate is extremely high, cold shortening may occur.

Cold shortening causes a decrease in tenderness by two main mechanisms. First, the temperature drops below the optimal temperature for postmortem proteolysis to occur. Cold shortening is defined by a rapid decline in muscle temperature to 14 – 19^{o}C before the onset of rigor mortis (Savell et al., 2005). This shortening results in decreased breakdown of proteins in the muscle. The second reason for decreased tenderness is the muscles become shorter. Cold shortening results in more overlapping myofilaments, increasing the toughness of the meat. Differences in chilling rate are only partially responsible for any differences in tenderness between forage and grain finished beef (Savell et al., 2005). Additionally, as an animal ages, the connective tissue tends to become more insoluble through the forming of collagen cross links. This decrease in solubility results in less breakdown of the connective tissues during the cooking process, therefore creating a less tender steak (McCormick, 1994). The growth rate pre-slaughter has been linked to meat tenderness (Fishell et al., 1985). As growth rate increases, so does meat tenderness. These differences in tenderness can be partially accounted for by variations in the amount of crosslinking (McCormick, 1994).

There have been few recent reports on the effect of corn processing on meat tenderness. Galyean et al. (1979) found as ground corn particle size decreased, total starch digestion increased. In contrast, Gorocica-Buenfil and Loerch (2005) found no difference in the digestibility and similar feedlot growth and feed:gain between cattle fed whole or rolled corn in corn silage-based diets. The authors stated there may be a greater proportion of the starch digested in the rumen, but did not change total tract digestion. Whole corn-based diets are typically fed with lower forage diets when compared to dry-rolled (Owens et al., 1997). This difference in forage level could account for the differences in feedlot gains and feed:gain of cattle in the feedlot. If there is little difference in energy, cattle will be of similar age and fatness at the time of slaughter. Additionally, there would be no difference in the growth rate of cattle directly prior to slaughter, which has been postulated to have an effect on meat tenderness (Steen and Kilpatrick, 2000). When comparing these diets, little to no difference in meat tenderness would be expected.

Meat Color

The color of meat is the most important meat quality characteristic when consumers are making purchasing decisions (Daniel et al., 2009). Steaks with a bright cherry-red color will tend to be purchased more often, while steaks that are darker, brown or purplish less likely to be purchased. It is also of economic importance that steaks retain color over a period of time. Steaks that become discolored are less likely to be purchased as compared to steaks that retain color over longer periods of time (Kim et al., 2009). The color of meat is mostly dependent upon the state of the myoglobin within the muscle. There are two main factors that influence the state of myoglobin, the bound ligand and the oxidation state of the iron within the heme ring. When myoglobin is bound to oxygen, iron is in the ferrous ($Fe2+$) state and in the oxymyoglobin form, which has a bright cherry-red color. Deoxymyoglobin has no bound ligand and iron is in the ferrous state, having a purplish color. When the iron undergoes oxidation and enters the ferric

(Fe^{+3}) state, the myoglobin is in the metmyoglobin form, which has a brown muddy color (Mancini and Hunt, 2005).

Color is also affected by ultimate pH. As pH decreases, the meat becomes lighter however, as pH increases meat is darker in color. The pH of meat is dependent on muscle glycogen at the time of slaughter. The glycogen is converted into lactic acid, resulting in decreased pH. The pH of the meat greatly influences the amount of light scatter at the cut surface. As the pH decreases, the water holding capacity of the muscle decreases and the free water causing more scattered light, resulting in meat that appears lighter in color (Brewer et al., 2001).

The color of meat can be measured visually using a sensory panel or instrumentally using a Chromameter. Panels could be used to evaluate both overall color of the steaks and surface discoloration. One end of the scale usually represents the best, most desirable, and least discolored steaks while the other end represents the worst, least desirable, and greatest amount of discoloration. Chromameters or colorimeters are an objective measurement of meat color. This involves a machine that reads the hue of the meat in three different planes, L*, a*, and b*. L* represents the lightness of the meat, with a value of 100 being completely white and a value of 0 as black. The a* value is a measure along the red and green plane, with a negative value representing green and a positive value representing more red. The b* value measures the yellowness or blueness of a color, with a negative value more blue and a positive value more yellow.

Increasing forage level has been shown to produce steaks that have a darker lean color (Bidner et al., 1981; Bidner et al., 1986; Schroeder et al., 1980; Duckett et al., 2007). Bidner et al. (1986) attributed the darker color of lean to the increase in myoglobin content associated with a higher forage diet. Whereas, Schroeder et al. (1980) related the differences in lean color to the glycogen content of muscle at the time of slaughter. The lower glycogen content of muscle at the time of slaughter would result in a higher ultimate pH, causing a darker color. Duckett et al. (2007) attributed the difference in lightness to the amount of light scatter and thickness of the oxymyoglobin layer at the cut surface. Hedrick et al. (1983) also found lower a* and b* values for grain fed beef, indicating that the higher forage diet resulted in an increase in the redness and yellowness of the steaks. The authors stated that color differences were likely due to the differences in intramuscular fat and moisture content. In contrast, Marino et al. (2006) and Arnett et al. (2012) found no difference in instrumental L*, a* or b* between the higher and lower forage diets. The smaller differences in forage level found in the previous studies could result in smaller differences in muscle glycogen content at the time of slaughter, ultimate pH, and moisture and fat content of the muscle.

The effects of grain processing on meat color have been of little focus in recent literature. However, higher levels of grain processing may result in higher digestibility of starches within the grain (Galyean et al., 1979). A higher digestibility may result in an increase in the amount of glycogen in the muscle at time of slaughter (Mounier et al., 2006). This increase in glycogen may lead to a decrease in the ultimate pH of the meat, causing steaks to be lighter and redder in color.

Literature Cited

Arnett E. J., F. L. Fluharty, S. C. Loerch, H. N. Zerby, R. A. Zinn, and P. S. Kuber. 2012. Effects of forage level in feedlot finishing diets on carcass characteristics and palatability of jersey beef. J. Anim. Sci. 90:960-972.

Berthiaume R., I. Mandell, L. Faucitano, and C. Lafreniere. 2006. Comparison of alternative beef production systems based on forage finishing or grain-forage diets with or without growth promotants: 1. Feedlot performance, carcass quality, and production costs. J. Anim. Sci. 84:2168-2177.

Bidner T. D., A. R. Schupp, R. E. Montgomery, and J. C. Carpenter, Jr. 1981. Acceptability of Beef Finished on All-Forage, Forage-Plus-Grain, or High Energy Diets. J. Anim. Sci. 53:1181-1187.

Bidner T. D., A. R. Schupp, A. B. Mohamad, N. C. Rumore, R. E. Montgomery, C. P. Bagley, and K. W. McMillin. 1986. Acceptability of Beef from Angus-Hereford or Angus-Hereford-Brahman Steers Finished on All-Forage or a High-Energy Diet. J. Anim. Sci. 62:381-387.

Boleman S. J., S. L. Boleman, R. K. Miller, J. F. Taylor, H. R. Cross, T. L. Wheeler, M. Koohmaraie, S. D. Shackelford, M. F. Miller, R. L. West, D. D. Johnson, and J. W. Savell. 1997. Consumer Evaluation of Beef of Known Categories of Tenderness. J. Anim. Sci. 75:1521-1524.

Bowling R. A. J. K. Riggs, G. C. Smith, Z. L. Carpenter, R. L. Reddish, and O. D. Butler. 1978. Production, Carcass and Palatability Characteristics of Steers produced by Different Management Systems. 46:333-340.

Bowling R. A., G. C. Smith, Z. L. Carpenter, T. R. Dutson, and W. M. Oliver W. M. 1977. Comparison of forage-finished and grain-finished beef carcasses. J. Anim. Sci. 45:209.

Brewer M. S., L. G. Zhu, B. Bidner, D. J. Meisinger and F. K. McKeith. 2001. Measuring pork color: effects of bloom time, muscle, pH and relationship to instrumental parameters. Meat Sci. 57:169-176.

Daniel M. J., M. E. Dikeman, A. M. Arnett, and M. C. Hunt. 2009. Effects of dietary vitamin A restriction during finishing on color display life, lipid oxidation, and sensory traits of longissimus and triceps brachii steaks from early and traditionally weaned steers. Meat Sci. 81:15-21.

Duckett, S. K., J. P. S. Neel, R. N. Sonon Jr., J. P. Fontenot, W. M. Clapham, and G. Scaglia. 2007. Effects of winter stocker growth rate and finishing system on: II. Ninth-tenth-eleventh-rib composition, muscle color and palatability. J. Anim. Sci. 85:2691-2698.

Ensminger M. E. and C. G. Olentine Jr. 1978. Feed processing. Pages 437-467 in: *Feeds & nutrition – complete*, The Ensminger Publishing Company, Clovis, California, USA. (Chapter 14).

Fishell V. K., E. D. Aberle, M. D. Judge and T. W. Perry. 1985. Palatability and muscle properties of beef as influenced by preslaughter growth rate. J. Anim. Sci. 61:151-157.

Galyean M. L., D. G. Wagner and F. N. Owens. 1979. Corn particle size and site and extent of digestion by steers. J. Anim. Sci. 49:204-210.

Gorocica-Buenfil M. A. and S. C. Loerch. 2005. Effect of cattle age, forage level, and corn processing on diet digestibility and feedlot performance. J. Anim. Sci. 83:705-714.

Hale W. H. 1973. Influence of Processing on the Utilization of Grains (Starch) by Ruminants. J. Anim. Sci. 37:1075-1080.

Harrison A. R., M. E. Smith, D. M. Allen, M. C. Hunt, C. L. Kastner, and D. H. Kropf. 1978. Nutritional Regime Effects on Quality and Yield Characteristics of Beef. J. Anim. Sci. 47:383-388.

Hedrick H. B. J. A. Paterson, A. G. Matches, J. D. Thomas, R. E. Morrow, W. C. Stringer, and R. J. Lipsey. 1983. Carcass and Palatability Characteristics of Beef Produced on Pasture, Corn Silage and Corn Grain. J. Anim. Sci. 57:791-801.

Kerth C. R., K. W. Braden, R. Cox, L. K. Kerth, and D. L. Rankins Jr. 2007. Carcass, Sensory, fat color, and consumer acceptance characteristics of Angus-cross steers finished on ryegrass (Lolium multiflorum) forage or on a high-concentrate diet. Meat Science. 75:324-331.

Kim Y. H., J. T. Keeton, S. B. Smith, L. R. Berghman, and J. W. Savell. 2009. Role of lactate dehydrogenase in metmyoglobin reduction and color stability of different bovine muscles. Meat Sci. 83:376-382.

Mancini R. A., and M. C. Hunt. 2005. Current research in meat color. Meat Science. 71:100-121.

Mandell I. B., E. A. Gullett, J. G. Buchanan-Smith, and C. P. Campbell. 1997. Effects of diet and slaughter endpoint on carcass composition and beef quality in Charolais cross steers. Can. J. Anim. Sci. 77:403-414.

Marino R., M. Albenzio, A. Girolami, A. Muscio, A. Sevi, and A. Braghieri 2006. Effect of forage to concentrate ratio on growth performance, and on carcass and meat quality of Podolian young bulls. Meat Science. 72:415-424.

Mounier L. H. Dubroeucq, S. Andanson, and I. Veissier. 2006. Variations in meat pH of beef bulls in relation to conditions of transfer to slaughter and previous history of the animals. J. Anim. Sci. 84:1567-1576.

LaBrune H.J., C. D. Reinhardt, M. E. Dikeman, and J. S. Drouillard. 2007. Effects of grain processing and dietary lipid source on performance, carcass characteristics, plasma fatty acids, and sensory properties of steaks from finishing cattle. J. Anim. Sci. 86:167-172.

Leibovich J., J. T. Vasconcelos, and M. L. Galyean. 2009. Effects of corn processing method in diets containing sorghum wet distillers grain plus solubles on performance and carcass characteristics of finishing beef cattle and on in vitro fermentation of diets. J. Anim. Sci. 87:2124-2132.

Lorenzen C. L., R. K. Miller, J. F. Taylor, T. R. Neely, J. D. Tatum, J. W. Wise, M. J. Buyck, J. O. Reagan, and J. W. Savell. 2002. Beef customer satisfaction: trained sensory panel ratings and Warner-Bratzler shear force values. J. Anim. Sci. 81:143-149.

McCormick R. J. 1994. The flexibility of the collagen compartment of muscle. Meat Sci. 36:79-91.

Neely T. R., C. L. Lorenzen, R. K. Miller, J. D. Tatum, J. W. Wise, J. F. Taylor, M. J. Buyck, J. O. Reagan, and J. W. Savell. 1998. Beef customer satisfaction: role of cut, USDA quality grade, and city on in-home consumer ratings. J. Anim. Sci. 76:1027-1033.

Owens F. N., D. S. Secrist, W. J. Hill, and D. R. Gill. 1997. The effect of grain source and grain processing on performance of feedlot cattle: a review. J. Anim. Sci. 75:868-879.

Richards C. J. and B. Hicks. 2007. Processing of corn and sorghum for feedlot cattle. Vet. Clin. Food anim. 23:207-221.

Savell J. W., S. L. Mueller, and B. E. Baird. 2005. The chilling of carcasses. Meat Sci. 70:449-459.

Schroeder J. W., D. A. Cramer, R. A. Bowling, and C. W. Cook. 1980. Palatability, shelflife and chemical differences between forage-and grain-finished beef. J. Anim. Sci. 50:852-859.

Shackelford S. D., M. Koohmaraie, and T. L. Wheeler. 1995. Effects of slaughter age on meat tenderness and USDA maturity scores of beef females. J. Anim. Sci. 73:3304-3309.

Steen R. W. J., and D. J. Kilpatrick. 2000. The effects of the ratio of grass silage to concentrates in the diet and restricted dry matter intake on the performance and carcass composition of beef cattle. Livest. Prod. Sci. 62:181-192.

Theurer C. B. 1986. Grain processing effects on starch utilization by ruminants. J. Anim. Sci. 63:1649-1662.

USDA, 1997. United States standards for grades of carcass beef. USDA agricultural marketing service.

Vasconcelos J. T. and M. L. Galyean. 2007. Nutritional recommendations of feedlot consulting nutritionists: The 2007 Texas Tech University surveyl. J. Anim. Sci. 85:2772-2781.

Young A. W., and R. G. Kauffman. 1978. Evaluation of beef from steers fed grain, corn silage or haylage-corn silage diets. J. Anim. Sci. 46:41-47.

Zinn R. A., F. N. Owens, and R. A. Ware. 2002. Flaking corn: Processing mechanics, quality standards, and impacts on energy availability and performance of feedlot cattle. J. Anim. Sci. 80:1145-1156.

CHAPTER 2. THE EFFECTS OF FORAGE LEVEL IN WHOLE OR DRY-ROLLED CORN BASED DIETS ON CARCASS CHARACTERISTICS, MEAT TENDERNESS, AND MEAT COLOR

Abstract

Interest in finishing cattle on high-forage diets and the use of grain processing tends to increase with increasing grain prices. Our hypothesis was that forage level and grain processing would have no effect on carcass characteristics, meat tenderness, or meat color when fed for a similar time on feed. The objective of this study was to determine if increasing the forage level and feeding corn whole as opposed to dry-rolled is a feasible alternative to high energy rations with a similar age at time of slaughter. Steers (n = 106) were fed either 20 or 40 percent forage, with whole or dry-rolled corn in a 2 x 2 factorial design. Data were analyzed using the general linear model of SAS (SAS institute, Cary, NC). There were no differences in fat thickness, longissimus area, KPH, marbling, or USDA quality grade ($P \geq 0.11$). Cattle fed high forage and whole corn tended to have lower hot carcass weights ($P = 0.07$). Additionally, the forty percent forage treatment tended to have lower USDA yield grades, ($P \leq 0.06$) and had darker colored steaks ($P \leq 0.001$). We found no difference in Warner-Bratzler shear force or cook loss ($P \geq 0.17$). Additionally, steaks from the dry-rolled corn treatment had redder and more yellow colored steaks ($P < 0.001$). Results from this study suggest that increasing forage level and corn processing do not result in differences in carcass characteristics or meat tenderness, but could negatively impact meat color.

Introduction

Typical finishing diets contain a source of high energy concentrates and a low level of forage. The grain, usually corn, might be processed to increase the efficiency of starch utilization. Previous research has shown differing results of the effect of forage level on carcass characteristics, meat tenderness, and meat color (Harrison et al., 1978; Bidner et al., 1981; Kerth et al, 2007; Arnett et al., 2012). Studies where cattle were slaughtered at a similar time point have found either no differences in carcass characteristics, or the forage-fed carcasses had lighter hot carcass weights, less back fat, KPH, marbling, lower USDA quality and yield grades, and a darker lean color, with no differences in longissimus muscle area, tenderness, redness or yellowness of lean (Harrison et al., 1978; Arnett et al., 2012). When cattle have been slaughtered at a similar final weight, previous researchers have generally found no difference in carcass traits (Hedrick et al., 1983). However, the steaks of forage fed carcasses were darker, redder, more yellow, and less tender than steaks of grain finished beef (Hedrick et al., 1983; Kerth et al. 2007). A majority of these past studies have been confounded by weight or animal age at the time of slaughter (Mandell et al., 1997).

Grain processing, through steam-flaking or high moisture ensiling, has been shown to cause a tendency towards carcasses with a greater amount of back fat, higher USDA yield grades, and no difference in KPH, marbling, or USDA quality grades when compared to dry-rolled (LaBrune et al., 2008; Leibovich et al., 2009). Leibovich et al. (2009) found no difference in carcass weights and a tendency toward larger longissimus muscle areas for high moisture corn as opposed to dry rolling. LaBrune et al. (2008) found a tendency toward heavier carcass weights with steam flaked when compared to dry rolled corn and no difference in ribeye area.

The diets in the current study utilize a higher forage level than typical finishing diets in order to evaluate a low input beef production system. We hypothesized that there would be no differences in carcass characteristics, meat tenderness, or meat color due to forage level or grain processing. The objective of this study was to determine if increasing the forage level and feeding corn whole as opposed to dry-rolled is a feasible alternative to high energy finishing rations with similar animal ages at time of slaughter.

Materials and Methods

All methods and procedures were approved by the North Dakota State University Institutional Animal Care and Use Committee.

Animals, experimental design and carcass measurements

Table 2.1. Diets and nutrient composition for steers fed whole or dry-rolled corn and 20 or 40 percent grass hay.[1]

Corn Treatment	Whole		Rolled	
Forage Level	20	40	20	40
Corn, %[2]	51.47	32.54	52.39	33.48
MDGS, %[3]	25.65	25.67	25.07	25.27
Hay, %[4]	20.73	39.75	20.32	39.15
Supplement, %[5]	2.20	2.04	2.21	2.10
Nutrient Composition[6]				
CP, %	14.51	14.29	14.17	14.07
Neg, Mcal/Kg	1.23	1.03	1.23	1.06
DM, %	72.91	74.10	74.59	73.02
Diet Concentrate, %	79.27	60.25	79.68	60.85
Diet Forage, %	20.73	39.75	20.32	39.15

[1]Componets measured on a dry matter-basis.

[2]Mean particle size for the whole and dry-rolled corn was 5,516 ± 1.15 and 2,824 ± 1.45 mm, respectively.

[3]Modified corn distillers grains, 52 percent dry matter.

[4]Cool season grass hay (9.44% CP and 1.45 mcal/kg NEg).

[5]Supplement included vitamins, minerals, calcium carbonate, and an ionophore (Rumensin).

[6]Samples were taken every 28 days analyzed, and then compiled.

From a larger study concerned with low input beef production one hundred six Angus-based crossbred yearling steers (417 ± 1.1 kg) were allotted to a 2 x 2 factorial experimental design with diets consisting of: 1) 20% grass hay with whole corn, 2) 20% grass hay with dry-rolled corn, 3) 40% grass hay with whole corn, and 4) 40% grass hay with dry-rolled corn (table 2.1). Steers were fed for a total of 141 days, as reported by Engel et al. (2015) which provides a more detailed description of the feedlot performance of this study.

Steers were transported to a commercial slaughter facility (Dakota City, NE) after finishing and slaughtered the following day. Following a 24-hour chill at 2 ± 2^{o}C, carcasses were ribbed, and Longissimus muscle area (LMA), 12th rib fat thickness (FT), KPH %, marbling (MARB), USDA Quality (QG) and Yield grades (YG) measured. Measurements of LMA, FT, MARB, and KPH were all obtained using the instrument grading system. Yield grade was calculated according to the following equation, YG = 2.5 + (2.5 x adjusted fat thickness in inches) + (0.2 x KPH %) + (0.0038 x HCW) – (0.32 x REA in square inches). Quality grade was calculated according to the standard USDA quality grid (USDA 1997).

Strip loins (IMPS 180) (n = 76) were identified using edible grader ink to put numbers on the external fat surface linked to the specific carcass. Upon fabrication, loins were collected and transported to the North Dakota State University Meat Lab, placed in a 4^{o}C cooler, and aged until 14 days postmortem. After aging, two-2.54-cm thick steaks were cut from the cranial end of the strip loins. The first steak was designated for Warner-Bratzler shear force (WBSF), vacuum packaged and placed in a -20^{o}C freezer until shear force evaluations could be made. The second steak was immediately overwrapped with clear cellophane and placed in simulated retail conditions.

Warner-Bratzler shear force

Steaks for WBSF were thawed at room temperature overnight for approximately 18 hours. Steaks were then weighed and a thermocouple (Omega Engineering Inc., Stamford, CT) inserted in the geometric center of the steak. Steaks were then cooked on clamshell style grills

(George Foreman Model No. GRP99; Columbia, MO) to an internal temperature of 71^{o}C and reweighed to determine cooking loss. Steaks were then allowed to cool overnight in a 4^{o}C cooler, and in the morning allowed to equilibrate to room temperature. Six-1.27 cm cores were removed from the center of the steaks parallel to the muscle fibers. These cores were then sheared perpendicular to the muscle fibers, using a Warner-Bratzler shear force apparatus (United-Smart 1 test system SSTM500; United calibration corporation, Huntington Beach, CA).

Simulated retail display

After packaging, steaks for simulated retail display were randomly place on smokehouse racks in a 4^{o}C cooler under continuous fluorescent lighting (American Fluorescent, model no. PPS232RC, Waukegan, IL). L*, a*, and b* measurements were taken every 24 hours for seven days on a portion of each steak where subcutaneous fat could be excluded. Measurements were taken using a Minolta colorimeter (CR-310 Chromameter, Konica Minolta, Tokyo, Japan) using illuminant D65, a 5-cm aperture, and a 2^{o} standard observer. Due to space limitations, two separate racks were used, with one placed over the other. To prevent differences between racks, an equal number of steaks were put on each rack and racks switched every day after readings were taken.

Statistical analysis

The data were analyzed as a 2 x 2 factorial using the PROC GLM procedure of SAS (SAS Institute Cary, NC) with forage level and corn processing as the main effects. Pen was the experimental unit for carcass measurements. Since strip loins were not collected from every carcass, animal was the experimental unit for meat tenderness and meat color measurements. Means were separated using the pdiff option of SAS and were considered significant when $P \leq 0.05$.

Results and Discussion

Feedlot performance

Although feedlot performance is not part of this thesis, the least square means and standard errors for final body weight, average daily gain, dry-matter intake, and feed to gain ratio over the entire 141 day feeding period are presented in table 2.2. There were no interactions between the corn and forage treatment, therefore the data is presented as main effects of corn and forage treatment. There was no difference in final weight or average daily gain between the whole and rolled corn treatments ($P \geq 0.20$). There was no difference in dry-matter intake for either treatment ($P \geq 0.60$). The low forage steers had a higher final weight ($P = 0.03$), resulting in a higher average daily gain ($P = 0.02$), and a lower feed to gain ratio ($P = 0.001$). A heavier final weight, with similar beginning weights and daily feed intake, would cause a difference in average daily gain.

Table 2.2. Performance of steers fed diets with whole or rolled corn and twenty or forty percent forage[1].

Variable	Rolled corn	Whole Corn	20% forage	40% forage	SEM	Corn *P* - value	Forage *P* - value	Corn* Forage *P* - value
N	6	6	6	6				
Starting Weight, Kg	418	416	417	418	1.13	0.31	0.50	0.96
Final Weight, Kg	696	680	704	671	8.40	0.20	0.03	0.77
Average Daily Gain, Kg/day	1.90	1.79	1.96	1.73	0.06	0.26	0.02	0.76
Dry-matter Intake Kg	13.1	13.1	12.9	13.3	0.42	0.97	0.60	0.56
Feed:Gain	3.15	3.34	3.00	3.49	0.07	0.09	0.001	0.48

[1]Average Daily Gain, Dry-matter intake, and Feed:Gain are over the entire 141 day finishing period.

Carcass characteristics

Least square means and standard errors for carcass characteristics are presented in table 2.3. There were no differences in fat thickness, longissimus area, KPH percentage, marbling, or USDA quality grade ($P \geq 0.11$). These results are in agreement with Harrison et al. (1978), who found no differences in cattle fed either a 56 or 75 percent concentrate corn silage based diet for a similar number of days on feed. Both the present study and those carried out by Harrison et al. (1978) had forage levels that would have been considered somewhat higher when compared to a typical finishing diet. Additionally, the smaller differences between treatments cause these characteristics to be similar. However, Arnett et al. (2012) found jersey steers fed a higher forage diet had less back fat, less marbling, and lower USDA quality grades. Both the low and high forage diet used in the study done by Arnett et al. (2012) was closer to a typical finishing diet and could possibly account for differences between the two studies. Previous studies using

Table 2.3. Influence of corn processing and forage level on carcass characteristics.

Corn Treatment	Rolled		Whole					
Forage Treatment	20	40	20	40	SEM	Corn *P*-value	Forage *P* – Value	Corn*Forage *P* - Value
N	3	3	3	3				
Hot Carcass Weight, Kgs.	410	414	416	391	6.7	0.23	0.16	0.067
Longissimus area, sq. cm	78.7	80.0	78.7	78.0	1.63	0.57	0.78	0.59
Fat thickness, cm	1.3	1.3	1.3	1.2	0.06	0.62	0.33	0.23
KPH, %	1.7	1.8	1.8	1.8	0.03	0.26	0.39	0.14
USDA yield grade	3.8	3.8	3.9	3.5	0.1	0.39	0.058	0.17
Marbling score	449	466	433	447	9.8	0.11	0.15	0.85
USDA quality grade[c]	2.4	2.2	2.3	2.5	0.1	0.32	0.96	0.15

[a]Yield grade was determined using the yield grade equation of 2.50 + (2.5 × adjusted fat thickness in inches) + (0.2 × percent KPH fat) + (0.0038 × hot carcass weight) - (0.32 × longissimus muscle area in square inches).

[b] 400 = small 0, 500 = modest 0.

[c]2.0 = Choice, 1.0 = Select.

steam-flaked corn and dry-rolled corn have shown differences in fat thickness (LaBrune et al., 2008; Leibovich et al., 2009). These differences may be due to the alteration of starch granules that occurs when steam-flaking, but does not during dry-rolling. In a review by Theurer (1986), the author considered dry-rolled corn to be non-processed or minimally processed.

There was a tendency for the forty percent forage whole corn treatment group to have lighter hot carcass weights compared to all other treatments ($P = 0.07$). This difference in carcass weights might be caused in part by the differences in energy level of the diet. Carcass weights typically increase with increasing energy level in the diet. These differences are supported by Burson et al. (1980) who found increasing the energy density of the diet resulted in heavier carcasses. Kerth et al. (2007) also found cattle finished in a typical feedlot setting had heavier carcasses compared to grazing. Results from this study indicate that the combination of whole corn and high forage may have a more detrimental effect on hot carcass weight than either treatment fed separately.

There was a tendency for the higher forage, which had lighter carcasses, group to have lower USDA yield grades ($P \leq 0.06$). USDA yield grade is dependent upon hot carcass weight, longissimus area, fat thickness, and KPH percentage (USDA, 1997). Lighter carcasses with similar longissimus areas, fat thickness, and KPH percentage, which we found in this study will

Table 2.4. Influence of corn processing and forage level on shear force and cook loss from beef strip loin steaks.[1]

Corn Treatment	Rolled		Whole				
Forage Treatment	20	40	20	40	Corn *P*-value	Forage *P* – value	Corn* Forage *P - value*
N	15	21	18	21			
Shear force, kg	2.37±.04	2.35±.04	2.46±.05	2.52±.04	0.17	0.82	0.70
Cook loss, %	21.1±.02	20.2±.02	20.5±.02	21.4±.02	0.86	0.99	0.60

[1]Values reported as least square means ± standard error of the mean.

have a lower USDA yield grade than heavier carcasses. Kerth et al. (2007) and Bidner et al. (1986) found carcasses from grazing cattle to have lower yield grades than carcasses from cattle finished in a feedlot setting. The larger differences found in the previous studies could be due to the inherently larger differences in forage level with grazing versus feedlot studies.

Tenderness and cook loss

Least square means and standard errors for Warner-Bratzler shear force and cook loss are presented in Table 2.4. There were no differences in Warner-Bratzler shear force or cook loss between any of the treatments ($P \geq 0.174$). These results are in agreement with Bidner et al. (1986) and Arnett et al. (2012) as determined by both Warner-Bratzler shear force and sensory panel. The present study suggests that when age at time of slaughter is held constant, tenderness between high and low forage groups would be similar. Growth rate has been shown to be related to meat tenderness (Aberle et al., 1981). Aberle et al. (1981) reported as growth rate of animals increase, the tenderness of those steaks increases. These results are in contrast to the current study, as we found no difference in tenderness while reporting differences in growth rate between the high and low forage treatments. This may be a result of the complex nature of meat tenderness. Aberle et al. (1981) found the lower gaining cattle to have greater muscle collagen content.

Meat color

There were no treatment by day interactions ($P \geq 0.50$) indicating there was no differences in color stability among treatments. There were no interactions between forage and corn treatment ($P \geq 0.22$). The higher forage level treatment resulted in steaks with lower L* values ($P < 0.001$), indicating a darker colored steak throughout the display period (Figure 2.1). These results are in agreement with the past literature (Bidner et al., 1981; Bidner et al., 1986;

Schroeder et al., 1980; Duckett et al., 2007). There have been various explanations as to the difference in color between high and low forage treatments, including a higher pH for the high forage and more myoglobin, among others. While none of these were measured in the current study, it is likely a combination of those factors creating the differences in lightness. The rolled corn treatment group had higher a* values (*P* < 0.001), indicating the steaks were redder throughout the display period (Figure 2.2). The rolled corn treatment could result in a greater amount of glycogen in the muscle at time of slaughter. This increase in glycogen could decrease the pH of the meat, and thereby decrease the water holding capacity. This decrease in pH, and subsequent decrease in water holding capacity, could increase the redness of steaks postmortem. The rolled corn treatment also had higher b* values throughout the display period (*P* < 0.001) indicating that the steaks were more yellow (Figure 2.3). Though marbling was not different (*P* = 0.106) between the corn treatments, an increase in yellowness of steaks may be attributed to an increase in intramuscular fat.

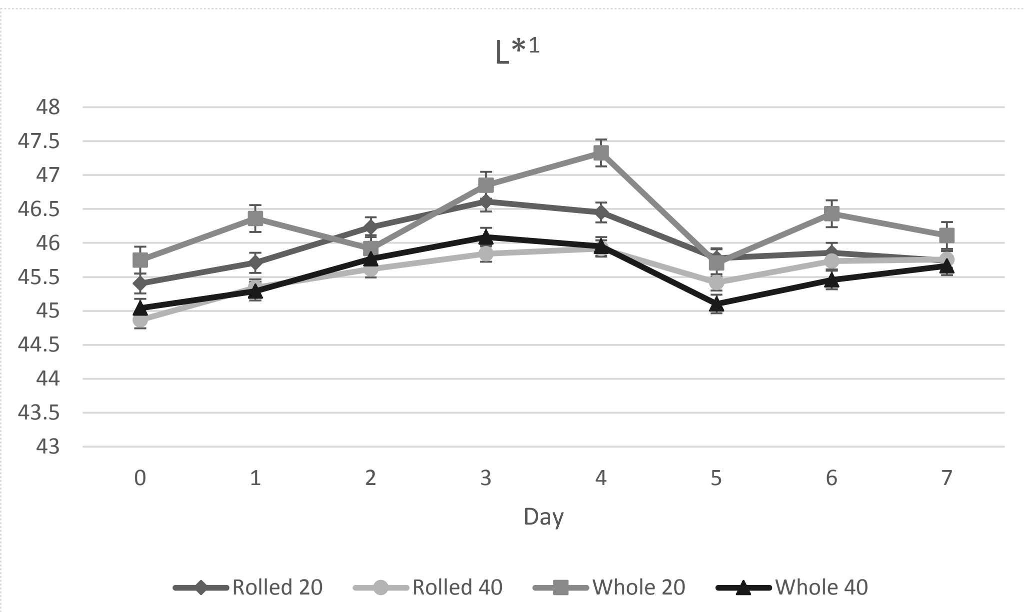

Figure 2.1. Instrumental L* color score of beef loin steaks from cattle fed high or low forage with whole or rolled corn.

[1]Forage treatment: *P* < 0.001, Corn treatment: *P* = 0.27, Forage*Corn interaction: *P* = 0.22

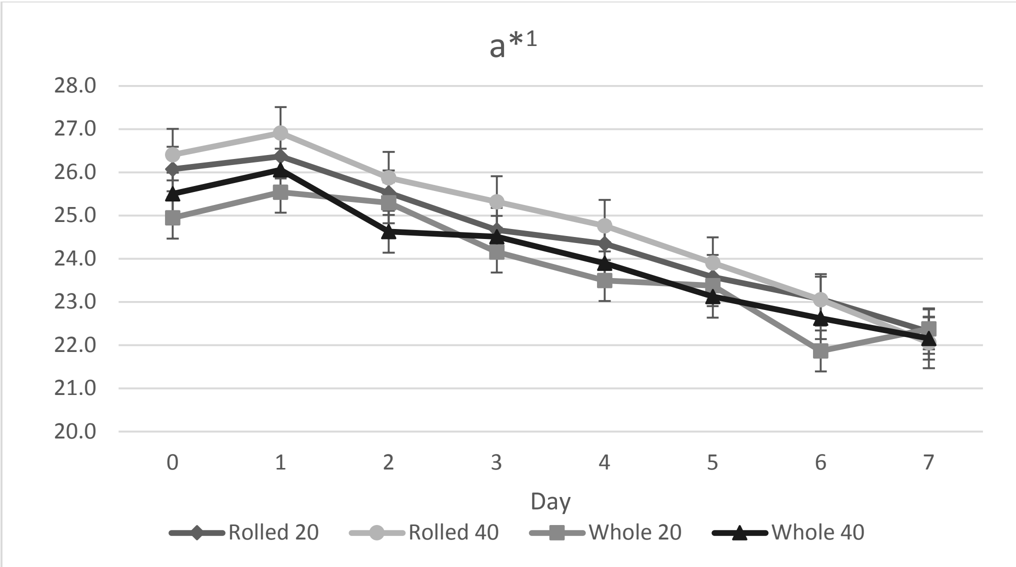

Figure 2.2. Instrumental a* color score of beef loins steaks from cattle fed high or low forage with whole or rolled corn.

[1]Forage treatment: $P = 0.17$, Corn treatment: $P < 0.001$, Forage*Corn interaction: $P = 0.75$

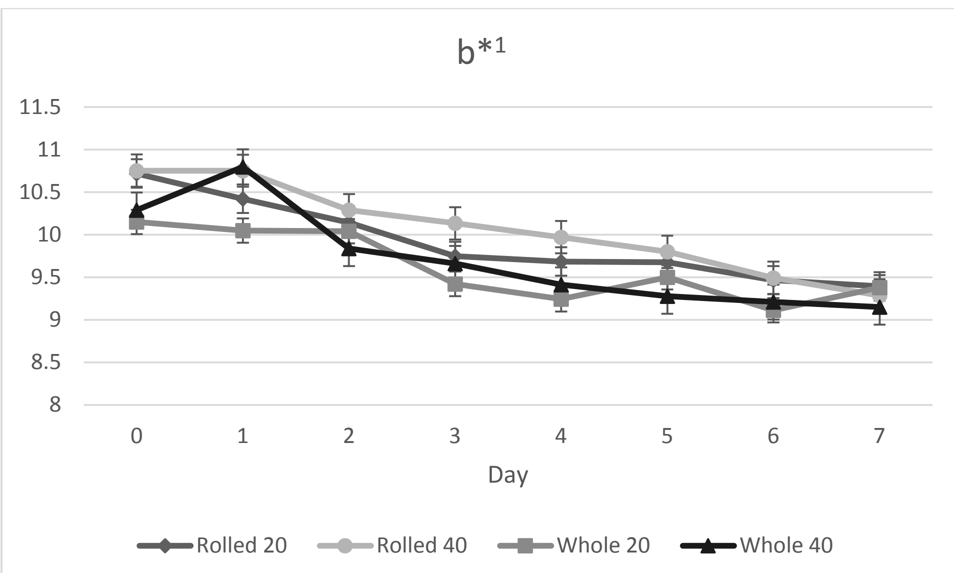

Figure 2.3. Instrumental b* color score of beef loin steaks from cattle fed high or low forage with whole or rolled corn.

[1]Forage treatment: $P = 0.17$, Corn treatment: $P < 0.001$, Forage*Corn interaction; $P = 0.73$

Conclusions

Increasing forage level and the extent of grain processing may be a feasible option to a typical finishing diet in times of high corn prices. The use of similar diets could be used for a low input feeding strategy as there were no negative impacts on meat tenderness and cook loss. However, use of forage levels similar to this study could have negative impacts on meat color, as the steaks in this study were darker.

Feeding whole corn as opposed to dry-rolled corn may be beneficial as there were no negative impacts on carcass characteristics or meat tenderness. Alternatively, feeding whole corn with the high forage diet used in this study could result in lower hot carcass weights. Finally, feeding dry-rolled corn may be beneficial to meat color as the steaks from those treatments were redder throughout the display period. Results from this study indicate that non-typical feedlots could use whole as opposed to dry-rolled corn without negatively impacting carcass characteristics or meat tenderness.

Literature Cited

Aberle E. D., E. S. Reeves, M. D. Judge, R. E. Hunsley, and T. W. Perry. 1981. Palatability and muscle characteristics of cattle with controlled weight gain: time on a high energy diet. J. Anim. Sci. 52:757-763.

Arnett E. J., F. L. Fluharty, S. C. Loerch, H. N. Zerby, R. A. Zinn, and P. S. Kuber. 2012. Effects of forage level in feedlot finishing diets on carcass characteristics and palatability of jersey beef. J. Anim. Sci. 90:960-972.

Bidner T. D., A. R. Schupp, R. E. Montgomery, and J. C. Carpenter, Jr. 1981. Acceptability of Beef Finished on All-Forage, Forage-Plus-Grain, or High Energy Diets. J. Anim. Sci. 53:1181-1187.

Bidner T. D., A. R. Schupp, A. B. Mohamad, N. C. Rumore, R. E. Montgomery, C. P. Bagley, and K. W. McMillin. 1986. Acceptability of Beef from Angus-Hereford or Angus-Hereford-Brahman Steers Finished on All-Forage or a High-Energy Diet. J. Anim. Sci. 62:381-387.

Burson D. E., M. C. Hunt, D. M. Allen, C. L. Kastner and D. H. Kropf. 1980. Diet energy density and time on feed effects on beef longissimus muscle palatability. J. Anim. Sci. 51:875-881.

Duckett S. K., J. P. S. Neel, R. N. Sonon Jr., J. P. Fontenot, W. M. Clapham, and G. Scaglia. 2007. Effects of winter stocker growth rate and finishing system on: II. Ninth-tenth-eleventh-rib composition, muscle color and palatability. J. Anim. Sci. 85:2691-2698.

Engel C. L., A. Taylor, C. S. Schauer, R. Maddock, and K. C. Olson. 2015. Effects of whole or rolled corn and 20 or 40 percent forage levels on finishing performance of yearling steers. 2015 North Dakota Beef Report. North Dakota State University

Harrison A. R., M. E. Smith, D. M. Allen, M. C. Hunt, C. L. Kastner, and D. H. Kropf. 1978. Nutritional Regime Effects on Quality and Yield Characteristics of Beef. J. Anim. Sci. 47:383-388.

Kerth C. R., K. W. Braden, R. Cox, L. K. Kerth, and D. L. Rankins Jr. 2007. Carcass, Sensory, fat color, and consumer acceptance characteristics of Angus-cross steers finished on ryegrass (Lolium multiflorum) forage or on a high-concentrate diet. Meat Science. 75:324-331.

LaBrune H.J., Reinhardt C. D., Dikeman M. E., Drouillard J. S. 2007. Effects of grain processing and dietary lipid source on performance, carcass characteristics, plasma fatty acids, and sensory properties of steaks from finishing cattle. J. Anim. Sci. 86:167-172.

Leibovich J., Vasconcelos J. T., and Galyean M. L. (2009). Effects of corn processing method in diets containing sorghum wet distillers grain plus solubles on performance and carcass characteristics of finishing beef cattle and on in vitro fermentation of diets. J. Anim. Sci. 87:2124-2132

Mandell I. B., E. A. Gullett, J. G. Buchanan-Smith, and C. P. Campbell. 1997. Effects of diet and slaughter endpoint on carcass composition and beef quality in Charolais cross steers. Can. J. Anim. Sci. 77:403-414.

Schroeder J. W., D. A. Cramer, R. A. Bowling, and C. W. Cook. 1980. Palatability, shelflife and chemical differences between forage-and grain-finished beef. J. Anim. Sci. 50:852-859.

Theurer C. B. 1986. Grain processing effects on starch utilization by ruminants. J. Anim. Sci. 63:1649-1662.

USDA, 1997. United States standards for grades of carcass beef. USDA agricultural marketing service.