ALTERNATIVE BEEF FINISHING STRATEGIES: EFFECTS ON ANIMAL

PERFORMANCE, RETAIL SHELF LIFE, SENSORY, FATTY

ACID PROFILE AND LIPID STABILITY

Except where reference is made to work of others, the work described in this dissertation is my own or was done in collaboration with my advisory committee. This dissertation does not include proprietary or classified information.

_____

Kirk Wayne Braden

Certificate of Approval:

_____

Kyle R. Willian
Assistant Professor
Chemistry
Tuskegee University

_____

Chris R. Kerth, Chair
Associate Professor
Animal Science

_____

David I. Bransby
Professor
Agronomy and Soils

_____

Jessica Gentry
Assistant Professor
Animal Science
Middle Tennessee State University

_____

Stephen L. McFarland
Acting Dean
Graduate School

ALTERNATIVE BEEF FINISHING STRATEGIES: EFFECTS ON ANIMAL PERFORMANCE, RETAIL SHELF LIFE, SENSORY, FATTY ACID PROFILE AND LIPID STABILITY

Kirk Wayne Braden

A Dissertation

submitted to

the Graduate Faculty of

Auburn University

in Partial Fulfillment

for the Degree of

Doctor of Philosophy

Auburn University
December 15, 2006

ALTERNATIVE BEEF FINISHING STRATEGIES: EFFECTS ON ANIMAL PERFORMANCE, RETAIL SHELF LIFE, SENSORY, FATTY ACID PROFILE AND LIPID STABILITY

Kirk Wayne Braden

_____
Signature of Author

_____
Date of Graduation

VITA

Kirk W. Braden, the son of Donald and Sharon Braden, was born on January 22, 1979 in Big Springs, TX. Kirk grew up on the family cotton, cattle and sheep farm in St. Lawrence, TX. In August, 1998 he enrolled at Texas Tech University and graduated in May, 2001, with a B.S. degree in Animal Science. Following graduation he returned to Texas Tech University to pursue a Masters of Science degree in Animal Science with an emphasis in Meat Science and Muscle Biology and graduated in August, 2003. In August 2003 Kirk married Crystal Sultemeier. Upon graduation from Texas Tech University, Kirk enrolled at Auburn University to fulfill the requirements for the degree, Doctor of Philosophy. Kirk plans to graduate in December, 2006.

DISSERTATION ABSTRACT

ALTERNATIVE BEEF FINISHING STRATEGIES: EFFECTS ON ANIMAL PERFORMANCE, RETAIL SHELF LIFE, SENSORY, FATTY ACID PROFILE AND LIPID STABILITY

Kirk Wayne Braden

Doctor of Philosophy, December 15, 2006
(M.S., Texas Tech University, 2003)
(B.S., Texas Tech University, 2001)

177 Typed Pages

Directed by Christopher R. Kerth

The effect of supplemental concentrate levels to steers finished on winter annual ryegrass (*Lolium multiflorum* Lam.) or full concentrate (GRAIN) was studied. Initial color, fatty acid profile, retail shelf-life, lipid stability and Vitamin E levels were determined. Treatment did not effect initial lean L*, a*, or b* values ($P > 0.05$). However, treatment did effect subcutaneous fat L* ($P = 0.01$) and b* ($P = 0.002$) values. All ryegrass treatments had higher b* values when compared to GRAIN. Total conjugated linoleic acid (CLA) was lower ($P = 0.04$) in GRAIN than 0.0% supplementation. Total, saturated, monounsaturated, poly-unsaturated, n-6, and PUFA:SFA FA levels were not affected by treatment ($P = 0.13$, 0.15, 0.15, 0.23, 0.06, and 0.56, respectively). Proportion of n-3 FA ($P = 0.02$) was highest in the 0.0%

treatment. The ratio of n-6:n-3 FA ($P < 0.001$) generally increased with elevated supplementation. Visual measures of lean uniformity generally increased with elevated forage in the diet ($P = 0.001$). Steaks from GRAIN cattle had lower a* ($P = 0.001$) and higher metmyoglobin ($P = 0.001$), than all other treatments. Measures of lean discoloration generally decreased in proportion to increased forage in the diet. LS stability increased with amount of forage in the diet ($P = 0.04$) and vitamin E levels in longissimus muscle samples were not affected by treatment diet ($P = 0.54$).

The effect of supplemental Tasco meal (*Ascophyllum nodosum*) and soy hull pellets in a winter annual ryegrass based finishing diet was also examined. Forage and animal performance, carcass and initial color, sensory and shear attributes, fatty acid profile and retail shelf-life and lipid stability analyzes were performed. There were no affects ($P > 0.05$) of Tasco treatment on any of the evaluated forage, animal performance, carcass, initial color, sensory, shear, fatty acid profile, retail shelf-life and lipid stability factors. However, supplementing steers did increase ($P = 0.02$) overall dressing percentage regardless of Tasco treatment. Initial subcutaneous fat b* values tended to increase (indicating a more yellow color) for cattle supplemented with Tasco and soy hull pellets ($P = 0.08$) over all other forage-finishing diet treatments. Additionally, n-3 polyunsaturated fatty acids tended ($P = 0.10$) to increase for cattle supplemented solely with Tasco on winter annual ryegrass. The ratio of n-6:n-3 tended to decrease in cattle not supplemented with soy hull pellets ($P = 0.06$). Fatty acid and cook-loss levels did increase ($P < 0.05$) with extended days of postmortem ageing, regardless of Tasco or soy hull pellet treatment. Off-flavor scores increased ($P < 0.05$) with extended steak exposure to simulate retail display conditions and postmortem ageing treatment.

ACKNOWLEDGEMENTS

In the pursuit of one's dreams there are always those individuals that contribute time, expertise, advice, guidance and friendship along the way. While pursing my doctorate there are great many that have been and will continue to be instrumental in the achievements of my life. To begin, my advisory committee, Dr. Chris Kerth, Dr. Jessica Gentry, Dr. Kyle Willian and Dr. David Bransby, have truly been integral in my doctoral pursuit. I have acquired a wealth of knowledge and skills from these four inspirational individuals. Thank you for being such a positive impact on my professional and personal life. All of you have helped to mold me into the individual I am today.

I would also like to thank all of the individuals that contributed in some manner to the overall completion of my research especially the graduate students in meat science and muscle biology at Auburn University. To Sean Roberts, Ryan Cox, Jeremiah Alexander and Carla Hopkins-Shoemaker, you are great group of individuals that embody true work ethic. Another group I would like to thank would be those that have contributed their time and/or friendship. Dr. Edzard van Santen, thank you for your expertise, time and guidance in statistical analysis. Dr. Viven Allen, thank you for helping me initially plan my research goals and setting me on the correct path. You have always been there for professional guidance.

Additionally, I would like to thank my parents Donald and Sharon Braden for supporting my dreams. They have given so much, and I only hope some day to repay such a debt. My younger brother and sister, Whit and Shawna Braden, thank you for your support and constant affirmation. To my entire extended family thank you for the motivational guidance, support and agricultural stewardship; you are all truly great individuals.

Most importantly, my wife Crystal is the one person that has kept me on track, with love, devotion and un-flinching motivation. In no way can I thank her enough for the hours of assistance and years of patience; except to look to our lives together in the future.

Style manual or journal used: Journal of Animal Science

Computer software used: Microsoft Word

TABLE OF CONTENTS

LIST OF TABLES xiii

LIST OF FIGURES xv

I. INTRODUCTION 1

II. REVIEW OF LITERATURE 6

Alternative Finishing Strategies 6

Market Options and Consumer Demand 7
Forage-Finishing Systems 9
Production 9
Animal Performance 13
Supplementation 16
Palatability Factors 17
Forage-Finished Beef Palatability 18

Fatty Acid Profile 21

Dietary Influences 25
Human Health and Diet 27

Retail Shelf-Life 29

Influences 30
Lipid and Pigment Oxidation 30
Antioxidants 31
Retail Shelf-Life and Lipid Stability of Forage-Finished Beef 33

Ascophyllum nodosum 35
Research Objectives 38

III. FINISHING STEERS ON WINTER ANNUAL RYEGRASS (LOLIUM MULTIFLORUM LAM.) WITH VARIED LEVELS OF CORN SUPPLEMENTATION II. EFFECTS ON FATTY ACID PROFILE, RETAIL DISPLAY SHELF-LIFE AND LIPID OXIDATION 40

Introduction 41
Materials and Methods 42

Animals and Diet 42
Sample Collection and Preparation 43
Initial Lean and Fat Color Measurements 44
Determination of Fatty Acid Profile 44
Retail Presentation 45
Visual Color Analysis 45
Instrumental Color Analysis 45
Determination of Lipid Oxidative Stability 46
Vitamin E Determination 46
Statistical Analysis 47

Results 48

Initial Color Measurements 48
Fatty Acid Profile 48
Simulated Retail Display 50
Lipid Oxidative Stability and Vitamin E 52

Discussion 52

Initial Color Measurements 52
Fatty Acid Profile 54
Retail Display Shelf Life and Lipid Stability 58

Implications 62
Tables 64
Figures 69

IV. TASCO SUPPLEMENTATION IN A FORAGE-FINISHING DIET: EFFECTS ON CARCASS CHARACTERISTICS, PALATABILITY, FATTY ACID PROFILE, LIPID STABILITY AND RETAIL SHELF-LIFE 74

Introduction 75
Materials and Methods 76

Animals and Treatment Regimen 76

Carcass Evaluation 78
Carcass Fabrication and Sample Collection 79
Initial Lean and Fat Color Measurements 80
Retail Presentation 81
Visual Color Analysis 81
Instrumental Color Analysis 81
Shear and Sensory 82
Proximate Analysis of LM 83
Determination of Fatty Acid Profile 84
Determination of Lipid Oxidation 84
Statistical Analysis 85

Results 86

Animal Performance and Carcass Traits 86
Initial Color 86
Sensory and Shear 86
Fatty Acid Profile 87
Retail Shelf-Life and Lipid Oxidation 88

Discussion 88

Animal Performance 88
Initial Color, Sensory and Shear 90
Fatty Acid Profile, Retail Display and Lipid Oxidation 92

Implications 94
Tables 94
Figures 103

V. CONCLUSION AND IMPLICATIONS 116

LITERATURE CITED 119

APPENDICES 143

Appendix A. Retail Display Shelf-Life Visual Evaluation 144
Appendix B. Instrumental Color Evaluation 149
Appendix C. Sensory Evaluation 151
Appendix D. Warner-Bratzler Shear Force Determination 153
Appendix E. Lipid Extraction for FA Analysis 155
Appendix F. Methylation for FA Profile 157
Appendix G. Thiobarbituric Reactive Substance (TBA) Assay 159

LIST OF TABLES

CHAPTER III.

Table 1. Least square means ± SEM for initial lean and fat Hunter color measurements from steers finished on ryegrass with various levels of supplementation or ad-libitum mixed ration grain diet 64

Table 2. Least square means ± SEM for longissimus muscle fatty acid composition (C13-C18) reported as mg /100 g of tissue for steers finished on ryegrass with various levels of supplementation or ad-libitum mixed ration grain diet..... 65

Table 3. Least square means ± SEM for longissimus muscle fatty acid composition (C20-C24) reported as mg /100 g of tissue for steers finished on ryegrass with various levels of supplementation or ad-libitum mixed ration grain diet..... 66

Table 4. Least square means ± SEM for longissimus muscle fatty acid composition summary reported as mg /100 g of tissue for steers finished on ryegrass with various levels of supplementation or ad-libitum mixed ration grain diet..... 67

Table 5. Least square means ± SEM for µg/g alpha-tocopherol in LM for steers finished on ryegrass with various levels of supplementation or ad-libitum mixed ration grain diet..... 68

CHAPTER IV

Table. 1. Approximate composition[1] of Tasco-14, an Ascophyllum nodosum seaweed meal; from – Allen et al., 2001a, p. E23..... 94

Table 2. BW, ADG, and finishing interval mineral consumption of steers finished on winter annual ryegrass supplemented with or without Tasco and/or concentrate..... 95

Table 3. Availability (kg DM ha^{-1}) and quality attributes of winter annual ryegrass pastures grazed by steers being supplemented with or without Tasco and/or concentrate..... 96

Table 4. Least square means ± SEM for evaluated average daily animal gain and carcass traits of steers finished on winter annual ryegrass supplemented with or without Tasco and/or concentrate 97

Table 5. Least square means ± SEM for initial 48 hr postmortem color and subcutaneous fat instrumental color values from steers finished on winter annual ryegrass supplemented with or without Tasco and/or concentrate. 98

Table 6. Least square means ± SEM for sensory and cook-loss attributes for striploin steaks after postmortem ageing and simulated retail display exposure from steers finished on winter annual ryegrass supplemented with or without Tasco and/or concentrate 99

Table 7. Least square means ± SEM for 48 h postmortem pH, Warner-Bratzler shear force and proximate attributes of striploin steaks from steers finished on winter annual ryegrass supplemented with or without Tasco and/or concentrate 100

Table 8. Least square means ± SEM for longissimus muscle fatty acid composition (C14-C22) reported as mg /100 g of tissue from steers finished on winter annual ryegrass supplemented with or without Tasco and/or concentrate..... 101

Table 9. Least square means ± SEM for longissimus muscle fatty acid composition (diet/health/summary factors) reported as mg /100 g of tissue from steers finished on winter annual ryegrass supplemented with or without Tasco and/or concentrate 102

LIST OF FIGURES

CHAPTER III.

Figure 1: Least squares means ± SEM for visual uniformity scores of strip loin steaks from steers finished on ryegrass with various levels of supplementation at 0% (0.0), 0.5% (0.5), 1.0% (1.0), 1.5% (1.5), 2.0% (2.0) of BW or ad-libitum mixed ration corn grain diet 69

Figure 2. Least squares means ± SEM for instrumental CIE a* and b* values of strip loin steaks from steers finished on ryegrass with various levels of supplementation at 0% (0.0), 0.5% (0.5), 1.0% (1.0), 1.5% (1.5), 2.0% (2.0) of BW or ad-libitum mixed ration corn grain diet 70

Figure 3: Least squares means ± SEM for instrumental chroma and hue values of strip loin steaks from steers finished on ryegrass with various levels of supplementation at 0% (0.0), 0.5% (0.5), 1.0% (1.0), 1.5% (1.5), 2.0% (2.0) of BW or ad-libitum mixed ration corn grain diet..... 71

Figure 4: Least squares means ± SEM for instrumental metmyoglobin and oxymyoglobin pigment values of strip loin steaks from steers finished on ryegrass with various levels of supplementation at 0% (0.0), 0.5% (0.5), 1.0% (1.0), 1.5% (1.5), 2.0% (2.0) of BW or ad-libitum mixed ration corn grain diet 72

Figure 5: Least squares means ± SEM for thiobarbituric reactive substance values of strip loin steaks from steers finished on ryegrass with various levels of supplementation at 0% (0.0), 0.5% (0.5), 1.0% (1.0), 1.5% (1.5), 2.0% (2.0) of BW or ad-libitum mixed ration corn grain diet 73

CHAPTER IV

Figure 1. Least square means ± SEM for visual lean color of striploin steaks by retail display day within postmortem ageing days from steers finished on winter annual ryegrass supplemented with or without Tasco and/or concentrate 103

Figure 2. Least square means ± SEM for visual lean uniformity of striploin steaks by retail display day within postmortem ageing days from steers finished on winter annual ryegrass supplemented with or without Tasco and/or concentrate 104

Figure 3. Least square means ± SEM for visual lean discoloration of striploin steaks by retail display day within postmortem ageing days from steers finished on winter annual ryegrass supplemented with or without Tasco and/or concentrate 105

Figure 4. Least square means ± SEM for visual lean browning of striploin steaks by retail display day within postmortem ageing days from steers finished on winter annual ryegrass supplemented with or without Tasco and/or concentrate 106

Figure 5. Least square means ± SEM for CIE L* instrumental values of striploin steaks by retail display day within postmortem ageing days from steers finished on winter annual ryegrass supplemented with or without Tasco and/or concentrate 107

Figure 6. Least square means ± SEM for CIE a* instrumental values of striploin steaks by retail display day within postmortem ageing days from steers finished on winter annual ryegrass supplemented with or without Tasco and/or concentrate 108

Figure 7. Least square means ± SEM for CIE b* instrumental values of striploin steaks by retail display day within postmortem ageing days from steers finished on winter annual ryegrass supplemented with or without Tasco and/or concentrate 109

Figure 8. Least square means ± SEM for lean Chroma instrumental values of striploin steaks by retail display day within postmortem ageing days from steers finished on winter annual ryegrass supplemented with or without Tasco and/or concentrate 110

Figure 9. Least square means ± SEM for lean Hue instrumental values of striploin steaks by retail display day within postmortem ageing days from steers finished on winter annual ryegrass supplemented with or without Tasco and/or concentrate 111

Figure 10. Least square means ± SEM percent myoglobin instrumental values of striploin steaks by retail display day within postmortem ageing days from steers finished on winter annual ryegrass supplemented with or without Tasco and/or concentrate 112

Figure 11. Least square means ± SEM for lean oxymyoglobin instrumental values of striploin steaks by retail display day within postmortem ageing days from steers finished on winter annual ryegrass supplemented with or without Tasco and/or concentrate 113

Figure 12. Least square means ± SEM for lean metmyoglobin instrumental values of striploin steaks by retail display day within postmortem ageing days from steers finished on winter annual ryegrass supplemented with or without Tasco and/or concentrate 114

Figure 13. Least square means ± SEM for thiobarbituric reactive substance values of striploin steaks by retail display day within postmortem ageing days from steers finished on winter annual ryegrass supplemented with or without Tasco and/or concentrate 115

I. INTRODUCTION

The concept of finishing cattle on forages, as an alternative to traditional primarily concentrate finishing strategies, has been evaluated by many throughout the last several decades. Various world, market, human diet and production factors served as key motivational elements in the initial investigations of alternative beef forage-finishing systems (Schupp et al., 1980). Forage-finished beef has fallen in and out of market availability and demand throughout the past 60 years and currently is associated with specific niche market consumers. A number of factors have been associated with and are generally responsible for forage-finished beef production and demand. Initial research generally implicated forage-finishing systems as the main cause of several negative animal performance and product related attributes. Finishing cattle on forages generally increased the finishing phase and resulted in carcasses with below average carcass weights (Bennett et al., 1995). Additionally, carcasses from cattle finished on primarily forage diets have been found to exhibit a range of undesirable characteristics, such as suppressed quality grades, yellow external fat covering and dark lean color (Brown, 1954; Yang et al., 2002a). Moreover, beef from forage-finished cattle was found to have less than desirable flavor, tenderness and juiciness (Bowling et al., 1977; Harrison et al., 1978; Brown et al., 1979; Schroeder et al., 1980; Melton et al., 1982). Correspondingly, researchers found that several factors affecting palatability attributes, such as fatty acid

profile, tended to increase overall product oxidation and, therefore, decrease certain retail shelf-life characteristics (Wheeling et al., 1975; Reagan et al., 1977; Melton et al., 1982; Gatellier et al., 2005). Nonetheless, the development and modification of forage-finishing strategies designed to produce beef with desirable production and product characteristics remains a possibility (Griebenow et al., 1997; Allen et al., 1996).

The benefits of finishing beef cattle on forage have long been recognized as an alternative to finishing in confinement feeding facilities. Interest in establishing systems where animals are fed solely or partially on forage throughout the growing and finishing phases (McMillin et al., 1990; Bennett et al., 1995; Allen et al., 1996) has recently increased. Much of the agricultural land utilized in the Southeast is highly suitable for production of quality forages (McMillin et al., 1990; Allen et al., 1996). Furthermore, much of this agricultural land is in tillage or row crops and is under-utilized in the winter months. A method of utilizing row crop lands during idle months as forage-finishing systems may exist. These forage or grass systems may be utilized in finishing strategies as possible alternatives to traditional finishing on all concentrate diets. The availability of feed grains for animal consumption in the Southeast is virtually non-existent; however, the opportunity to finish cattle on forage is a possibility. Forage-finishing strategies could serve to open phases of the beef life cycle to producers in the Southeast that are not currently available. A majority of the cattle from the Southeast are finished, harvested, and marketed in the Midwest which limits the marketing options of producers in the Southeast.

Beef consumption has steadily risen since its decline in the 1980's and 1990's and consumers have become more informed and demanding. The appearance of niche

markets has become frequent and various consumer demands such as leaner beef are common (Mandell et al., 1997; Montgomery et al., 1982). Currently consumers are looking for a "natural", healthier, and locally raised beef product. Grass- or forage-fed beef may have the opportunity to target those consumers within these identified markets.

Data have shown that at least 23% of consumers would choose Argentina grass- or forage-fed beef over that of domestic grain-fed beef, and these consumers were willing to pay a premium for grass/forage fed beef (Umberger et al., 2002). A current survey of consumers in three southeastern states found 34% of consumers surveyed, preferred forage-finished beef to traditional concentrate-finished beef (Cox et al., 2006). According to Cox et al. (2006) these consumers were willing to pay up to a $3.02/kg premium for forage-finished beef steaks.

Furthermore, research has shown that forage-fed beef has a more desirable fatty acid profile when compared to grain-fed beef. Beef from forage-fed animals tends to be leaner and posses a more desirable omega-6/omega-3 ratio as well as higher amounts of polyunsaturated fatty acids and conjugated linoleic fatty acids (Mitchell et al., 1991; Melton et al., 1992; Yang et al., 2002b). These fatty acids have been determined, by the World Health Organization and the U.S. Institute of Medicine, to be of great importance in the diet. Many desirable health characteristics can be attributed to cattle fed an all-forage or high-forage diet. Thus, the opportunity exists for cattle producers in the Southeast to market grass- or forage-fed beef within identified niche markets.

The role forage finishing systems may play in the production of beef in the Southeast is of great importance to the sustainability and profitability of producers in the southeastern U.S. However, the effects of forage-finishing on USDA quality grade and

the time an animal must be on feed to achieve at least USDA Choice (Small marbling) could prove detrimental to forage finishing strategies. Data have shown that beef cattle fed all- or high-forage diets are less likely to grade USDA Choice, and those that do grade USDA Choice, require a longer finishing period when compared to cattle on all grain diets (McMillan et al., 1984). The economic importance of quality grade is well established. Research conducted by Savell et al. (1987) stated that packers, through signals they receive from purveyors and retailers, have demanded beef that grades at least USDA Choice; when it grades less, a substantial price discount usually has been paid. Most often carcasses from forage-fed cattle grade USDA Select (Slight Marbling) to USDA Standard (Traces marbling). Cattle finished on all- or high-forage diets have been found to achieve USDA Choice when finished for additional days when compared to cattle on all grain diets (Abdullah et al., 1979). Increased finishing times could increase inherent input cost as well as increase the grazing demand on available forage. Forage-fed carcasses discounted for undesirable quality grades coupled with increased days on feed could thwart some of the opportunities forage-feeding systems would contribute to beef producers in the Southeast.

Additionally, the significance of quality grade and/or marbling as well as tenderness on overall beef palatability has been well documented by various researchers (Tatum et al., 1982; Kim & Lee, 2002; Platter et al., 2003). Platter et al. (2003) noted that consumer acceptance of steaks increases approximately 10% for each full marbling score increase between Slight to Slightly Abundant. In research conducted by Wheeler et al. (1999), USDA Choice steaks were found to be more tender than USDA Select steaks. Furthermore, Park et al. (2000) found that beef with high intramuscular fat has high

juiciness, tenderness, and flavor scores when rated by consumers. A method to improve quality grade and decrease finishing times necessary to obtain at least USDA Choice would increase profitability and overall palatability of beef from forage-finishing systems; thus, increasing the overall success, efficacy and sustainability of forage finishing systems in the Southeast. Therefore, supplementation strategies designed to increase, or reduce negatively associated production and product effects, could increase efficiency of forage-finishing systems. The purpose of the current work is to evaluate the effect of varied supplementation practices on animal and forage performance, carcass and palatability attributes, retail shelf-life and fatty acid profile and lipid stability. Supplementing cattle with modest amounts of concentrates may reduce finishing time while on forage and increase carcass quality while reducing deleterious effects on product attributes.

II. REVIEW OF LITERATURE

Alternative Finishing Strategies

The beef industry is ever changing in regards to finishing, producing and marketing beef products (Bastian, 2002; Schroeder et al., 2003). Changes in the beef industry, and the meat industry as a whole, commonly reflect national and world events. Prior to World War II most beef produced and sold in the United States was from grass-fed or limited grain-fed cattle (Schupp et al., 1980). In the 1950s and 1960s, with the development of the initial modern large-scale cattle finishing operations, demand for primarily grain-finished beef increased (Schupp et al., 1980). By the 1970s, most American consumers demanded beef from carcasses graded at least USDA Choice and consumers quickly became accustomed to the palatability parameters and satiety associated with highly grain-finished beef (Schupp et al., 1980). However, a shift in the American diet paradigm in the late 1970s increased consumer health consciousness and demand for foods termed "healthy" in the diet (Griebenow et al., 1997; Schupp et al., 1980). Federal governing bodies began campaigns to convince Americans to reduce animal fat intake and this placed producing and marketing entities in a "defensive" position (Schupp et al., 1980). In response to growing health concerns, increasing grain prices and continual increase in environmental factors, beef from forage-finished animals gained a large share of the slaughter cattle market (Schupp et al., 1980; Melton et al.,

1982; Griebenow et al., 1997). Nonetheless, by the early 1980s consumer demand and acceptability of beef from forage-finishing systems declined and traditionally grain-finished beef regained slaughter cattle market share (Schupp et al., 1980). Several investigators in the late 1970s and early 1980s examined the palatability and shelf-life characteristics of beef from forage-finishing systems compared to grain-finishing. Trial results generally indicated forage-finished beef to have a less desirable and commonly inferior palatability profile when compared to grain-finished beef (Bowling et al., 1977; Harrison et al., 1978; Brown et al., 1979; Schroeder et al., 1980; Melton et al., 1982). Regardless of initial research findings, the production of forages in the southeastern region of the United States is highly conducive to a strategy of finishing beef on high quality forages (Sapp et al., 1998). A combination of production and marketing factors available in the southeastern United States and current market environment may serve as motivation to for re-evaluation of forage-fed beef production (Bagley et al., 1990; McMillin et al., 1990; Sapp et al., 1998).

Market Options and Consumer Demand. Consumer demands and market motivation factors are continually evolving and changing shape for all types of meat (Resurreccion, 2003). However, the most impacting market changes have occurred in the beef chain. The beef market has continually lost market share compared to other protein sources such as chicken, and chicken consumption continues to increase (Resurreccion, 2003). According to industry indications, beef must directly compete for every consumer dollar spent on protein in general. Routine consumer survey studies have shown the inability of beef to compete with protein sources such as chicken in terms of fat level and cholesterol content (Resurreccion, 2003). Several real and perceived factors are leading

concerns for consumer beef purchase decisions (Menkhaus et al., 1993). Perceived quality perception factors were cholesterol, calorie content, artificial ingredients, convenience characteristics, display presentation and high price. Clearly, there is an ever increasing awareness and concern related to the dietetic quality of beef coupled, with intrinsic palatability characteristics. Growing bases of consumers in the United States now demand a wide range of product-specific attributes (Resurreccion, 2003) and forage-finished beef has emerged as a leading market niche. According to Cox et al. (2006), in a survey of consumers in three southeastern states, approximately 34% of those surveyed preferred forage-finished beef when compared to concentrate-finished beef. Researchers found consumers preferring forage-finished beef willing to pay a premium to purchase the product. The consumer preference of forage-finished beef was slightly higher when compared to results of Umberger et al. (2002). Umberger et al. (2002) found 23% of the consumers surveyed preferred Argentine, forage-fed beef when compared to domestic concentrate-finished beef, and these consumers were also willing to pay a premium.

Forage-finishing cattle generally results in leaner beef with certain intrinsic factors that can be specifically marketed (Griebenow et al., 1997; Sapp et al., 1998; Raes et al., 2003). The promotion of forage-finished beef, under targeted consumer demands as a functional food, continues to rise (Milner, 1999). Functional foods are defined as any food or food ingredient that may provide a health benefit beyond the traditional nutrients it contains (Institute of Medicine, National Academy of Science, 1994). Comparative forage-based finishing systems generally produce beef with a higher amount of polyunsaturated fatty acids (PUFA), specifically *n*-3 PUFA and conjugated linoleic acid, compared with concentrate finished beef (Enser et al., 2000; French et al., 2000; Gatellier

et al., 2005). Conjugated linoleic acid has some anticarcinogenic and antiatherogenic activities and thus could be of some benefit to human health (Enser et al., 2000). Undoubtedly, beef from cattle finished on primarily forages possesses traits that appeal to a variety of consumer demands. Increased consumer demands coupled with a growing certified branded beef market (USDA, 2001; McKenna et al., 2002) clearly show market possibilities for beef produced outside of traditional parameters that accommodates identified niche markets.

Forage-Finishing Systems

For many years investigators have developed and examined forage-finishing systems for the production of beef on all- or primarily-forage. Many factors contribute to the overall success and adequacy of forage finishing systems and numerous researches have examined the related system factors (Coombs et al., 1990; Allen et al., 1996; Griebenow et al., 1997). Development of forage-finishing systems that addresses animal and forage constraints is perhaps the most challenging aspect. Animal performance, forage performance, environmental factors and the interactions all play a central role in the forage-finishing systems and these factors have far-reaching impacts on final beef quality (Allen et al., 1996; Griebenow et al., 1997).

Production. The southeastern region of the United States contains near 50% of the nations mature beef cow population; nonetheless, limited amounts of cattle are finished and harvested within this region (USDA, 1989; Bagley et al., 1990). The southeastern region of the United States are well suited for production of forages with the possibility for semi year-round systems (Bagley et al., 1987; Allen et al., 1996). A majority of research has been conducted in peak forage growth periods with little

attention to season- or year-long production (Matches et al., 1974; Bagley et al., 1990). However, a seasonal approach to systems research, where animals graze for extended grazing intervals, is generally more representative of actual production situations (Bagley et al., 1990). In a study conducted by Coombs et al. (1990) a variety of forages were utilized to construct a forage-finishing system for year round production; however, this system was uniquely suited for the extreme southern portions of the southeastern United States. Researchers found variable results depending upon a finishing diet composition of corn silage or grazed forage. Coombs et al. (1990) found corn-silage-fed animals heavier at slaughter than cattle finished on grass forage, and cattle from grass forage treatments were more variable dependent upon forage growth season. Clearly, the seasonality of forage growth increased carcass and animal performance variation and hence increased product variation (Coombs et al., 1990; McMillin et al., 1990). The control of beef production parameters to reduce animal performance and final product variation is particularly significant and thus is a key factor for the production of beef in controlled concentrate based beef production systems. However, when Coombs et al. (1990) conducted economical analyses a clear profit potential advantage for forage-finishing livestock existed at selected times using efficient management techniques. These results (Coombs et al., 1990) are consistent with those found by Allen et al. (1996) in relation to forage vs. corn silage finishing diets.

A leading constraint of forage-finishing systems is the inability to provide a proper array of protein and energy for maximal animal performance. High quality forage generally contains much higher levels of nitrogen in relation to energy, to the extent nitrogen in the diet is not used efficiently (Lake et al., 1974). Concentrates high in

energy, such as corn, can be supplemented to reduce the protein-to-energy gap by decreasing the forage protein intake and increasing the digestible energy content of the diet (Lake et al., 1974; Griebenow et al., 1997). A balanced protein-to-energy ratio may positively affect a variety of animal performance and production parameters (Lake et al., 1974; Bodine et al., 2003). Clearly, the most important factor of forage-finishing systems is the type, quality, availability and management of grazed forage.

Selection of forage for finishing beef cattle is most critical for efficient and maximal animal performance potential. An assortment of forages can be chosen for specific production scenarios resulting in a unique set of growth, grazing tolerance and quality parameters are inherent of the forage species chosen. Furthermore, according to research by Bagley et al. (1988) a number of summer and winter annual and perennial forage species can be utilized in year-round or seasonal forage-finishing systems. Bagley et al. (1990) utilized cool-season annual forages 36%, warm-season annuals 10%, warm-season perennials 17% and grass-legume mixtures 10% of the grazing periods when evaluating a year-round beef production system. A number of forage-livestock management systems utilize high quality cool-season annuals such as ryegrass, wheat and rye (Utley et al., 1975; Burris et al., 1979; Bagley et al., 1990) for cattle requiring feedstuffs necessary for highest rates of performance. When comparing forages for maximal animal performance and gain, researchers have found cool-season annual forages to be generally superior to other forages (Bagley et al., 1988; Bagley et al., 1990; Bransby et al., 1997). Bransby et al. (1997) found increased weight gains for latter portions of the beef cycle (stocker and finisher) when animals grazed annual ryegrass in the spring months. Annual ryegrass, regardless of cultivar, is a high quality and adequate

protein feedstuff for animal production. However, nutrional quality of winter annual ryegrass is commonly seasonal, as the highest quality is present in spring months and generally declines quickly with increased maturity (Bransby et al., 1997; Redfearn et al., 2002). Redfearn et al. (2002) found crude protein to decline drastically as the growing season progressed. There are a variety of winter annual ryegrass cultivars such as; Gulf, Jackson, Marshal, Rio, Rustmaster and Surrey (Redfearn et al., 2002). Little variation has been found in overall forage quality, related to crude protein, between the various cultivars. However, forage quality within a season may vary according to maturity, as maturity increases quality decreases, and some cultivars mature more rapidly. Specific cultivars will have differences in production of animal gains by growing cattle (Bransby et al., 1997; Wyatt et al., 2001). Bransby et al. (1997) found increased weight gain of cattle grazing Marshall ryegrass compared to Gulf. However, animal performance advantages were most likely due to forage quality and forage mass as suggested by plant height differences (Bransby et al., 1997; Redfearn et al., 2002). Clearly, the total amount of forage available for grazing, or herbage mass, combined with forage quality are the leading factors accounting for forage effect on animal performance variation.

Adequate and efficient management of forage-livestock systems and research require an accurate, rapid and economically feasible method to measure forage/herbage mass. Herbage mass determination is crucial to management decisions, livestock performance and determination of grazing strategy (Guerreo et al., 1984; Bransby et al., 1997). A number of methods may be employed to ascertain herbage mass; such as, manual clipping of forage within a specified area (quadrants; Gonzalez et al., 1991), capacitance meters (Greathead et al., 1987), meter stick (Whitney, 1974) and settled disk

meter height (Bransby et al., 1977). Manual clipping of quadrants, while moderately accurate, is not conducive nor an efficient method of data collection in reasonably large scale research systems. Gonzalez et al. (1990), in a study comparing all nondestructive techniques, found all methods sufficiently accurate for determination of forage mass.

Animal Performance. Animal performance is perhaps one of the most important evaluation factors of live animal production. Most often, live animal weight gain is utilized as the performance measure criteria. However, live animal production performance may be also be measured by selected carcass traits upon final disposition and harvest. Cattle finishing diet has profound effects on performance, measured by gain and carcass characteristics (Coombs et al., 1990; McMillin et al., 1990; Mandell et al., 1998). Cattle finished on primarily forage diets have commonly had decreased weight gains when directly compared to cattle finished on concentrate-based diets. Forage diets, typically low in energy in comparison to concentrate diets, generally produce carcasses with smaller hot carcass weights, decreased subcutaneous fat levels, lower USDA quality grades and smaller longissimus muscle area (ribeye area). Decreased forage-finished animal weight gains, regardless of specific forage and concentrate type, have been well documented by numerous researchers throughout a cross-section of the recent past (Bowling et al., 1978; Bidner et al., 1981; Bagle et al., 1990; French et al., 2000; O'Sullivan et al., 2003). Camfield et al. (1999) and McMillin et al. (1990) also found biological type, in terms of maturity and frame size, to be of significant importance in forage-finishing systems. Research has found intermediate- to small- framed breed types maturing early to intermediately to be most successful in forage-finishing systems.

As early as 1978, Bowling et al. (1978) found steers finished on grain to reach targeted harvest weights for desirable USDA carcass grade characteristics much more rapidly (~180 d) when compared to those finished on forages. Similarly, Bidner et al. (1981) and Bagley et al. (1990) found lower weight gains for cattle finished on forages in contrast to cattle finished on concentrates or high-quality corn silage finishing diets. In both instances cattle days on feed were reduced if animals were on concentrate-based diets. Additionally, upon harvest, carcasses of forage-finished cattle have been found to have less desirable carcass traits when compared to carcasses of concentrate-fed animals (Dinius et al., 1978; Bidner et al., 1981, 1986; Miller et al., 1981; Crouse et al., 1984; McMillin et al., 1990; Mandell et al., 1997; O'Sullivan et al., 2003). McMillin et al. (1990) found animals finished on silage to have higher dressing percentages, hot carcass weights, back-fat measurements and USDA yield grades when compared to animals finished on all forages. Carcasses from silage-finished cattle had higher marbling scores and a more white external fat when compared to forage-finished counterparts (McMillin et al., 1990). Additionally, McMillin et al. (1990) found carcasses of silage-finished cattle to be of more value on the rail, based on carcass weight and quality, when directly compared to carcasses from forage-finished cattle.

Many factors such USDA carcass cutability and quality factors affect overall carcass value; however, when external carcass fat appears yellow in color a price de-valuation is realized (Walker et al., 1990; Strachan et al., 1993). Several researchers have found carcasses of forage-finished cattle to have a characteristic yellow fat and have contributed this occurrence mainly to carotenoids, of which β-carotene, in forages, is predominate (Knight et al., 1996). Correspondingly, Yang et al. (2002a) and Kerth et al.

(2005) found subcutaneous fat b* (measure of yellowness) values to increase as levels of forage increased in the finishing-diet. However, Bidner et al. (1986) found no differences due to finishing diets, of forage and/or concentrates on fat color. Various researchers have found subcutaneous fat yellowness to decrease with extended final finishing periods on concentrates and theorized different rates of fat deposition may contribute to differences in fat color due to varying rates of dilution in the total carotenoid pool (Strachan et al., 1993; French et al., 2000).

Adipose tissue is a component of live-weight gain, and fat deposition shows relatively little change until the growing animal attains approximately half its physiological maturity (Fiems et al., 2000). In the early growth stages, 50–60% of the deposited energy intake is protein when fed high quality rations ad libitum; the remainder is fat (Fiems et al., 2000). In later stages of growth 85–90% of the energy deposited is fat. Economic reasons have driven the desire to reduce the quantity of carcasses with excess fat (Fiems et al., 2000). Fat deposition requires more energy than protein deposition and a majority of the excess fat is often removed from the carcass at the slaughterhouse (Fiems et al., 2000). Therefore, a strategy may exist to trim undesirable fat covering, hence removing economically damaging yellow fat characteristics of carcasses from forage-finished cattle (Kerth et al., 2005).

Decreased weight gains and less favorable carcass characteristics for forage-finished cattle are a product of diet, environmental and animal related production influences. However, as previously discussed, forage diet composition is perhaps the most contributing factor. Clearly, diet balance and nutritional element availability are of extreme importance and energy is most often the limiting factor of forage-finishing diets

(Schupp et al., 1980; Allen et al., 1996). Several investigators have examined the role of supplemental feed elements in forage-finishing strategies as a method of increasing animal performance, efficiency and energy availability (Bagley et al., 1990; Allen et al., 1996; O'Sullivan et al., 2003). Griebenow et al. (1997) and Reagan et al. (1981) found concentrate supplementation of animals on primarily forage-finishing diets to produce carcasses of acceptable quality. Clearly, supplementation strategies designed for forage-finishing systems offer a viable alternative for production of carcasses with similar quality and cutability characteristics when compared to traditional, concentrate-finished cattle.

Supplementation. Protein-to-energy ratios of forage-finishing diets are commonly imbalanced and this disproportion allows for inefficient nitrogen utilization and poor gain in comparison to balanced rations. Therefore, supplementing cattle on forage-finishing diets with high-energy feed-stuffs to increase performance and weight gain is routinely utilized and has been well investigated. Bryant et al. (1965) found that supplementing energy, in the form of grain, to cattle on forage diets increased daily gain compared to forage alone. Many investigators since have found similar outcomes (Fontenot et al., 1985; Goetsch et al., 1990; Allen et al., 1996; Griebenow et al., 1997). Grain or high-energy supplements have also been fed to cattle on forages in an effort to decrease the necessary days on finishing regimen required for finishing cattle (Huber et al., 1967; Hendrix et al., 1975; Hoveland et al., 1977; Allen et al., 1996). Supplementation of high-energy concentrates for increased weight gain is generally more efficient when forage quality begins to decline (McMillin et al., 1990).

Palatability Factors

Marbling, tenderness, maturity and feeding regime among other factors, all contribute to beef palatability (Zinn et al., 1970; Bowling et al., 1977; Tatum et al., 1982). However, consumer purchasing decisions are usually based on tenderness, juiciness and flavor (Savell et al., 1987; Kim and Lee, 2002).

Marbling is used as the most important factor in evaluating beef quality and often has been implicated as a contributing factor to beef palatability (Tatum et al., 1982; Kim & Lee, 2002). Beef loins with high intramuscular fat have high scores in juiciness, tenderness and flavor according to Park et al. (2000). Findings of Savell et al. (1987) suggest that juiciness, tenderness, and flavor intensity ratings decreased when marbling level decreased from slightly abundant to traces. It has also been reported that Warner-Bratzler shear values decreased with increased marbling (Kim and Lee, 2002). Miller et al. (1997) reported that steaks from USDA Select grade carcasses had lower juiciness, tenderness, and flavor intensity than steaks from carcasses that graded USDA Choice. Campion et al. (1975) reported that taste panel tenderness and overall acceptability were related to the quality grades of carcasses. Similar research has found that steaks with a slight degree of marbling were observed to be juicier than steaks with a lower degree of marbling, but that marbling had no effect on tenderness, flavor intensity or acceptability (Kim and Lee 2002; Jones et al., 1991; Crouse and Smith, 1978). Further research has concurred that palatability tends to improve as marbling increases (Hoke and Hedrick, 1969; Tatum et al., 1980; Kim and Lee, 2002). Conversely, low positive correlations between marbling score of longissimus muscle with taste panel acceptability scores have been reported (Crouse et al., 1978). Nonetheless, according to Tatum et al. (1982),

marbling had a low, but positive, relationship to all of the palatability traits of beef. In a study of longissimus steaks of varying USDA quality grade, it was found that low Select steaks were less tender than top Choice steaks when cooked well done (Wheeler et al., 1999). Furthermore, Jones et al. (1991) concluded that the percentage of unacceptable ratings for steaks based on overall palatability declined from 38.5% for traces marbling to 23.7% for modest marbling levels. The relationship between marbling and tenderness in a study conducted by Seideman et al. (1987) was considerably greater than observations that have been previously reported (Campion et al., 1975; Crouse et al., 1978). The actual mechanism in which marbling effects beef palatability is not fully understood. Nonetheless, research proposing the amount of variation and the extent to which marbling and USDA quality grade effect beef palatability have been made. Campion et al. (1975) found that marbling trends tend to be correlated with tenderness when evaluated over a wide range of tenderness values. The insurance factor of marbling may apply as increased intramuscular fat deposits may allow beef to be more highly temperature abused in regards to a wide range of cooking methods. It is for this reason that marbling may play the most important role in beef palatability in regards to juiciness.

Forage-Finished Beef Palatability. Beef cattle have a natural advantage of being able to convert low-quality sources of nutrition into high quality food products and protein sources when consumed as beef (Fortin et al., 1985; Bidner et al., 1986). However, feed source has generally been implicated as the largest source of variation in sensory attributes due to environmental factors (Melton et al., 1990). Mottram (1998) found approximately 1000 volatile compounds to be responsible for meat flavor and several were capable of undergoing dietary-influenced changes. In similar research,

Larick et al. (1987) identified 53 volatiles using chromatography in cooked beef of which 31 were markedly different between samples from cattle finished on forage or concentrated diets.

Contrasting research findings exist for sensory characteristics of beef from a broad mix of forage, forage and concentrate or solely concentrate finishing diets. Simmone et al. (1996) and Hedrick et al. (1983) found similar sensory characteristics between forage- and concentrate-finished beef. Sapp et al. (1999) and Mandell et al. (1998) found few differences in overall palatability; however, some evidence suggested forage-finished beef to have slightly less flavor and more off-flavor (Mandell et al., 1998). Some evidence suggests forage type to be a key variable in sensory differences in forage-finished beef (Larick and Turner. 1990) and high quality pastures may produce beef similar to traditional finishing systems (Melton et al., 1990). However, Reagan et al. (1977) found that most data will suggest that grain-fed beef is much more desirable to the consumers than forage-fed beef, simply because of a more desirable flavor.

Bidner et al. (1986) reported that steers finished on an all-forage or a 70-d, grain-fed diet produced similarly acceptable consumer products, providing no significant differences in consumer panel ratings for loin, rib, or round steaks. Smith et al. (1977) found forage –fed beef palatability characteristics to dissipate after roughly 49 days of concentrate feeding; however, Sapp et al. (1999), in a much shorter 20 d concentrate feeding period, found sensory characteristics to remain unchanged. Melton et al. (1990) theorized most differences found between finishing systems may be confounded with fat level. Generally, diets higher in energy, or concentrates, produce a more acceptable product (Melton et al., 1990).

In relation to forage-finished beef palatability, tenderness has largely been found unaltered by exclusively modulating finishing regimen when all other animal and production parameters are held constant. French et al. (2001) found no differences due to finishing regimen in Warner-Bratzler shear force measurements and Simmone et al. (1996) and Schaake et al. (1993) found similar taste panel tenderness values for forage- and concentrate-finishing regimens. However, Sapp et al. (1999), in finishing trials of forage, forage + concentrate or concentrate, found mixed diet tenderness to be decreased in comparison, but stated all tenderness measurements where within average acceptable limits for consumers to rate products as tender.

A rather intricate succession of thermally-induced reactions occurs between non-volatile components of lean and fatty tissues resulting in a large array of reaction products. A range of volatile compounds formed during cooking or thermal induction are significant contributing factors to overall flavor attributes (Mottram, 1998). Hence, two major contributors to overall meat flavor and volatile formation are water soluble and lipid components (Mottram, 1998). Lipid levels and corresponding fatty acid profile of the triglyceride are highly correlated to meat flavor (Melton et al., 1982; Elmore et al., 1999). Additionally, selected phenols have been indicated as causative elements in meat pastoral or grassy flavor (Priolo et al., 2001).

Forage-fed or finished beef is commonly associated with an off-flavor and decreased palatability (Sapp et al., 1999). Schaake et al. (1993) found concentrate-finished beef to be higher in the consumer preferred beef flavor palatability elements and Melton et al. (1982) further stated forage-finished beef to be less desirable in flavor and have a less intense beef flavor. Clearly, various elements in the lipid fraction of forage-

finished beef are of significant importance to overall palatability and flavor. Priolo et al. (2001) found, in a review, eicosapentanoic (EPA) and docosapentanoic (DHA) acids in the phospholipids fraction to play a leading role in meat flavor as polyunsaturated fatty acids such as EPA and DHA are particularly prone to undergo auto oxidation. Furthermore, oxidative products of linolenic acid have been associated with species flavor as a result of volatile compound formation during cooking (Priolo et al., 2001). Four-heptenol, a product of linolenic acid oxidation could be partially responsible for a grassy, unpleasant odor and flavor (Yang and Baumeister, 1999). Melton and co-workers (1982) found C18:3 to be positively correlated with a milky-oily aroma and flavor and with sour flavor; where as, oleic (C18:1) was negatively correlated with the same flavor and odor attributes. Oleic acid is commonly increased in beef from concentrate-finished beef, and linolenic acid (C18:3) is elevated in forage-finished beef. Melton et al. (1982) found high levels of linolenic acid highly related to less desirable beef flavor to untrained American consumers. Without a doubt, fatty acid profile and its modulation are of extreme importance when evaluating flavor elements of beef from diverse finishing systems.

Fatty Acid Profile

There is a rather diverse range of fatty acids produced, as well as absorbed, in the ruminant animal. This diversity can be linked to a number of factors such as diet diversity, ruminal microbe composition, presence/lack of feedstuffs protection, rumen pH, fatty acid chain length, fatty acid intake type, and level of fat in the diet. Possibly the most important factor affecting fatty acid diversity is the structure, type and level of fat (lipid) consumed. The rumen environment, containing various microbes and protozoa,

rapidly and extensively modifies dietary lipids on their trip through the rumen. Under normal circumstances virtually no lipid escapes the rumen unchanged. Rumen microbes and protozoa modify lipids through a variety of means. When a fatty acid enters the rumen unprotected and unchanged they are usually in the esterified form. The ruminal microbes and protozoa then quickly and thoroughly hydrolyze them into free fatty acids along with glycerol and other compounds. Lipolysis is catalyzed by various microbial lipases, resulting in the liberation of the free fatty acid portions from the carbon "backbone".

Anaerovibrio lipolytica produces a microbial lipase that is best known for its lipase activity (Jenkins. 1993). *A. lipolytica* produces a cell-bound esterase and a lipase which is an extracelluar enzyme packaged in membranous particles (Jenkins, 1993). This lipase hydrolyzes acylglycerols completely to free fatty acids and glycerol with virtually no production of mono/diglycerides (Jenkins, 1993). Upon esterification, free fatty acids are non-ionically bound to particulate matter in the rumen (Church, 1988). Free fatty acids generally must be bound to particulate matter for biohydrogentation to occur at normal rates. Diets high in grain products generally yield lower total biohydrogenation of free fatty acids when compared to diets lower in similar grain feedstuffs (Church, 1988). This effect may be due to the lack of particulate matter and the change in microbial makeup exerted by the effects of increased grain consumption.

Following lipolysis and adhesion to particulate matter, biohydrogenation occurs. Biohydrogenation in the rumen is a near complete process in which a large proportion of fatty acids leaving the rumen have been completely or partially hydrogenated. The biohydrogenation of fatty acids in the rumen is crucial to the microbial environment as

microbes can dispose of H from the reducing environment of the rumen (Church, 1988). As mentioned most fatty acid are saturated through biohydrogenation; however, the process of saturation of the mono and poly-unsaturated fatty acid is incomplete leading to a variety of fatty acid products (Church, 1988). Biohydrogenation of unsaturated fatty acid in the rumen is principally achieved by rumen bacteria. The role of protozoa in biohydrogenation of fatty acid appears to be minimal (Harfoot et al., 1988). *Butyrivibrio fibrisolvens* as well as a diverse range of rumen bacteria have been isolated that have the capacity to biohydrogenate unsaturated fatty acid (Harfoot et al., 1988).

The process of unsaturated fatty acid biohydrogenation occurs through several complex biochemical processes. The biochemical processes responsible for biohydrogenation do not occur by one ruminal bacteria, but rather a range of bacteria are responsible for biohydrogenation processes. Rumen bacteria are only partially responsible for production of fatty acid in ruminant animals. Fatty acids have been found to be synthesized within animal tissues. A fraction of several fatty acids produced in the ruminant animal are of endogenous origin (Griinari et al., 1997). Several investigators theorize endogenous cis-9, trans-11 CLA would originate from the desaturation of trans-11 $C_{18:1}$ by Δ9-desaturase (Baumann et al., 1999). Endogenous synthesis via Δ9-desaturase represents the predominant source of a variety of fatty acid and being a primary source of CLA in milk fat as well as tissue (Baumann et al., 1999).

Lipid presented to the small intestine of ruminant animals resembles little of the initial feedstuff once traveled through the rumen. In ruminant animals a majority of the fat enters the small intestine as esterified fatty acids which are highly saturated and non-ionically bound in an insoluble complex to particulate matter (Church. 1988). Ingesta

from the quadrolocular stomach is characterized by having an extremely low pH and therefore fatty acids are protonated upon entrance. Immediately following protonation, fatty acid soups, insoluble in the rumen, are solubilized which increases absorption of fatty acids (Church. 1988). Virtually no long chain fatty acid leaves the tract prior to the small intestine in ruminant animals, and a vast majority of saturated fatty acids are rapidly absorbed prior to and at the entrance to the small intestine. The influx of dietary lipids to the small intestine is accompanied by the entry of perhaps half as much additional lipid in the form of intestinal secretions, of which are primarily of biliary origin (Church, 1988). Nearly 20% of the fatty acids absorbed in the small intestine are absorbed through the upper jejunum, while the other 60% of the fatty acids are absorbed in the remainder of the small intestine jejunum (Church, 1988). Total fatty acid absorption is accomplished prior to the ileum (Church, 1988).

Numerous steps are involved in the absorption of fatty acid into tissues. Fatty acids are absorbed into intestinal cells, re-esterified, and packaged with tri-, mono-, and diglycerides, phospholipids, cholesterol, and apoprotein. Approximately 10% of the fatty acids entering the enterocyte are converted from stearic to oleic acid via a tissue bound fatty acid desaturase. The content of CLA in fat from rumaint-derived food products will be dependent on the ruminal production of both CLA and trans-11 $C_{18:1}$ and the tissue activity of Δ9-desaturase (Baumann et al., 1999). Following completion of packaging, fatty acids exit the cell to the lymph system (Church, 1988). The fatty acids of C:14 and smaller chain length are transported via the blood to the liver and readily oxidized. Generally, the rate of absorption decreases with increased chain length and/or saturation (Church, 1988).

Dietary Influences. The science of diet modulation is wide-ranging and many aspects of the diet have been found to ultimately influence events from digestion to final absorption and excretion. Much of the current emphasis placed on ruminal lipid metabolism is on the manipulation of physiochemical events in the rumen with the goal of manipulating two predominant outcomes: 1) control of antimicrobial effects of fatty acids so that added supplemental fat can be fed to ruminants without disruption or negative effects on the normal rumen environment, and 2) regulation of microbial biohydrogenation to alter the absorption of a select set of fatty acids that can enhance performance as well as possibly improve nutritional qualities of animal food products (Jenkins, 1993).

Numerous effects of diet; (forage-based diets leading to higher concentrations of n-3 polyunsaturated fatty acids in body tissues and grain based diets leading to higher concentrations of n-6 polyunsaturated fatty acids) have been established and verified (Marmer et al., 1984; Mitchell et al., 1991). Dietary oils, grass being higher in the n-3 series precursor fatty acid 18:3 (α-linolenic) and grains higher in the n-6 series precursor fatty acid 18:2 (linoleic) are partially responsible for the divergent effects diet imparts on the overall final composition of beef in concentrate- or forage-finishing systems (Marmar et al., 1984). Diets commonly rich in concentrates normally results in increased levels of unsaturation of fatty acids in ruminant fat depots. Diets predominately composed of concentrates allow for a shift in microorganisms that decreased the rate of biohydrogenation of dietary unsaturated fatty acid when compared to primarily forage-(roughage/cellulose) based diets in which the microbial environment completely hydrogenates unsaturated fatty acids (Priolo et al., 2001). Decreased rumen pH often

results in bacterial population shifts and consequent changes in the pattern of fermentation end products (Van Soest, 1994). Leat et al. (1977) provided evidence showing that changes in rumen bacteria populations are associated with modifications in the biohydrogenation pathways consistent with the altered trans-octadecenoic acid profile found in ruminal digesta and tissue lipids. In addition, Griinari et al. (1998) demonstrated that an altered rumen environment induced by feeding high, concentrate and low-fiber diets is associated with a change in the trans-octadecenoic acid profile of milk fat and tissue.

Further evidence in support of a specific bacteria (*cis*-9, *trans*-10 isomerase) is provided by observations that low-fiber diets increase the proportion of *trans*-10, *cis*-12 CLA isomer in milk fat (Griinari et al., 1999). The addition of plant oils has been shown to substantially increase CLA. Added plant oils have consisted of sunflower, soybean, corn, canola, linseed, and peanut. Generally, oils having high levels of linoleic acid give the greatest response in upregulation of CLA production. Research performed by Kelly et al. (1998) found that there is a clear dose-dependent increase in CLA in milkfat when animals were supplemented with plant oils high in linolenic acid. A possible mechanism of CLA upregulation was hypothesized by Harfoort et al. (1973) in which high levels of linolenic acid irreversibly inhibited the biohydrogenation of trans-11 octadecenoic acid. The lack of hydrogentation would allow a greater amount of substrate available for endogenous synthesis of *cis*-9, *trans*-11 CLA.

The inclusion of plant oils in the diet generally has an inhibitory effect on rumen microbial growth (Jenkins, 1993). Therefore, plant oils are not commonly added to the diet. However, to minimize the negative effects of added plant oils, calcium salts of the

fatty acid can be fed so that a majority of the fatty acids bypass the rumen and only a small portion are biohydrogenated (Baumann et al., 1999). Further increases in CLA synthesis and deposition may be accomplished by the addition of fish oils or fish meals. It appears that fish oils are near twice as effective at producing increased CLA when compared to plant oils (Chouinard et al., 1998). Fish oil supplementation may serve an inhibitory role in ruminal biohydrogenation of *trans*-octadecenoic acid in which a greater amount of substrate is available as previously mentioned. The inhibitory effect could involve inhibition of microbial growth or a specific inhibition of the reductase producing bacteria that reduce octadecenoic acid (Baumann et al., 1999). Supplementation of marine algae, a source of long chain (n-3) fatty acid, has been found by numerous researchers to increase the level of n-3 fatty acid and their derivatives in ruminant animals. A large majority of research has found decreased saturated fatty acid levels as well as greater polyunsaturated and more specifically DHA and CLA (Franklin et al., 1999). Levels of DHA have been found to increase in cows fed marine algae when compared to control animals (Franklin et al., 1999). The protection of marine algae allowed for decreased rumen biohydrogenation of DHA to the extent that allowed for more efficient incorporation of DHA (Franklin et al., 1999).

Human Health and Diet. Selected fatty acids have been found to have an array of positive health attributes. Some of the fatty acids, that are related to human health benefits are CLA, omega-3 LC PUFA and the ratio of omega-6:omega-3 ingested. The principal source of CLA are of ruminant animal origin as a product of ruminal biohydrogenation and endogenous ruminant gut synthesis (Dhiman et al., 2005). Recommended intake levels are generally near 0.8g/d (Ritzenthaler et al., 2001);

however, some disparity in recommended intake may be due to the lack of human trial data (Whigham et al., 2000). A majority of data, suggesting physiological effects of CLA, have been collected in laboratory animals in which dosage rates are much higher than found in humans. Pariza (2004), in a review of animal model research, proposed a number of physiological effects of CLA. Physiological affects consisted of anticarcinogenic effects in development of cancer states, enhanced immune function, reduction in inflammatory response, reduction in atherosclerosis development, reduced body fat gain and reduced hypertension in moderately hypertensive individuals.

Long chain polyunsaturated omega-3 fatty acids can be found in considerable quantity in oily fish such as mackerel, herring and salmon. Small amounts of omega-3 fatty acids can be found in meat products of domesticated livestock and it is of considerable interest to increase quantities in meat products available for consumer purchase. A number of omega-3 fatty acids exist; however, α-linolenic acid, EPA and DHA are the only known biologically active forms in terms of human health benefits. Eicosapentanoic and docosapentanoic acids are primarily responsible for most associated physiologic effects (Kris-Etherton et al., 2002; Yamashita et al., 2005). Perhaps the single most important fatty acids are EPA and DHA, as they have been implicated in several disease prevention capacities. Increased intake of omega-3 fatty acids has been found to decrease cardiovascular disease mortality, prevent cardiovascular disease causative factors, reduce hypertension in hypertensive individuals, decrease high plasma triglyceride levels and possibly increase adenosine triphosphate (ATP) production efficiency in the myocardium via reduced oxygen costs (Kris-Etherton et al., 2002; Yamashita et al., 2005). Cardiovascular disease risk factors are decreased mainly via

modulation of platelet aggregation in atherosclerosis conditions by down regulation of eicosanoid synthesis. Additionally, plasma triglyceride levels are decreased via a down regulation in transcription factors modulating triglyceride production and clearing via the liver (Yamashita et al., 2005). The eicosanoid synthesis precursor, arachidonic acid, is found in less quantity in diets high in omega-3 fatty acids as the omega-6 fatty acid linoleic acid is the precursor for arachidonic acid synthesis. Linoleic acid is in high quantity in vegetable oils and is found in significant quantity in meat and egg yolk. Therefore, increasing omega-3 levels in meat and egg products would be of importance. A diet predominating in omega-3 fatty acids would favor numerous health benefits. A survey of literature found a ratio of n-6:n-3 of 4:1 to 10:1 (Yamashita et al., 2005); however, a ratio of 4:1 is the most commonly recommended.

Retail Shelf Life

Consumers have learned through experience that meat that is bright-pink to bright-red is the most desirable (Kropf, 1980). Color is perhaps the most critical component of fresh red meat appearance. Faustman et al. (1989) found that the consumer's perception of beef quality is strongly influenced by product appearance. Additionally, research indicates that consumers use the bright, cherry-red color of fresh beef as an indicator of meat quality and wholesomeness (Cassens et al., 1988). Consumers are not willing to pay market price for discolored beef and this, in return, most often results in a loss of profit in the beef chain. If muscles are discolored at the 'sell-by date' or earlier, retail cuts must be marked down in price, faced, repackaged or ground (Smith et al., 1993). It has been estimated that average value deterioration is 3.7% for the entire meat department and 5.4% for fresh meat (Williams et al., 1992). Williams

et al. (1992) also concluded that the US industry stands to gain $175 million to $1 billion (US) annually by increasing case-life by 1-2 days.

Influences. The retail display and shelf life of beef is affected by many factors including the development of off-odors and off-flavors, muscle pigment oxidation and the presence of food-spoilage bacteria. The deterioration in meat quality occurs mainly because of the oxidation of lipids and muscle pigments (Smith et al., 1996). Research conducted by Smith et al. (1996) found that delaying the breakdown of lipid can maintain or extend case-life of retail cuts by assuring that they have bright-pink to bright-red color. Enhancing lipid stability can stabilize the color of beef, prolong its shelf-life and favorably impact its economic value and image in the marketplace (Williams et al., 1992).

Lipid and Pigment Oxidation. Discoloration of muscle is a combined function of (a) lipid oxidation in intramuscular fat and (b) oxidation of oxymyoglobin to metmyoglobin (Smith et al., 1996). The bright-red appearance of normal beef is due to oxymyoglobin, a ferrous heme pigment that oxidizes to the brown, unfavorable appearance of metmyoglobin. Lipid oxidation and muscle pigment oxidation are caused by similar processes (Faustman et al., 1989). The undesirable brown pigment metmyoglobin results from oxidation of the red oxymyoglobin and purple deoxymyoglobin (Mitsumoto et al., 1997). Therefore, muscle-pigment oxidation and meat discoloration should be delayed by delaying the breakdown of lipid (Faustman et al., 1989). Similarly, the conversion of oxymyoglobin to metmyoglobin is positively correlated to lipid oxidation and appears to be dependent on antioxidant status (Faustman et al., 1998). Mikkelsen et al. (1992) found that the free radicals produced during lipid

oxidation can alter the heme chemistry and initiate pigment oxidation causing loss of desirable color.

According to Arnold et al. (1993) and Faustman et al. (1989), lipid and oxymyoglobin stability are greater in meat which contains higher concentrations of the antioxidant vitamin E, and dietary vitamin E supplementation of cattle delayed lipid oxidation and color deterioration to beef. Interest in dietary strategies for improving overall quality of beef and other meat products has been renewed by the color stabilizing effect of vitamin E within meat (Faustman et al., 1998).

Antioxidants. Faustman et al. (1998) concluded that dietary supplementation of livestock with vitamin E results in improved meat quality. Previous studies have found that dietary supplementation of vitamin E suppressed lipid oxidation and retarded metmyoglobin formation (Mitsumoto et al., 1991, 1993, 1995). Schaefer et al. (1995) concurs with theories described by Arnold et al. (1993), regarding α-tocopherol activity, that Vitamin E acts as an antioxidant by reacting with free radicals arising from oxidative reactions initiated in the phospholipid-rich membranes of meat (Buckley et al., 1989). Research by Mitsumoto et al. (1997) supports the theory that membranal vitamin E (D- α -tocopherol) from vitamin E supplementation scavenges free radicals produced from oxidized lipid and decreases the formation of lipid peroxy free radicals and thus lipid oxidation, and that membranal vitamin E protects oxymyoglobin from oxidation to metmyoglobin (Schaefer et al., 1995). Therefore, Mitsumoto et al. (1997) concluded that dietary vitamin E supplementation directly prevents lipid oxidation in the membrane and indirectly on pigment oxidation in muscle.

Many have concluded that dietary vitamin E supplementation to cattle can improve meat color, pigment, and lipid stability in beef steaks when compared to contemporary animals not receiving vitamin E supplementation (Mitsumoto et al., 1997). In a research note, Faustman and others (1989) stated that steaks from vitamin E supplemented animals were more resistant to color change in prolonged display many days postmortem. Most research concludes that vitamin E supplementation effects do not occur early in the display periods. As the steaks are displayed over time with prolonged exposure to the air, steaks that are from vitamin E supplemented animals do not discolor or degrade in overall quality as much as steaks not of vitamin E supplemented animals. Faustman et al. (1998) found that the extent to which vitamin E may effect oxidation and color may depend, in part, on the α-tocopherol status of cattle upon initiation of supplementation. Plasma α-tocopherol concentration may be used as an indicator of dietary vitamin E intake (Faustman et al., 1998). The origins of free radicals that initiate lipid oxidation are believed to be unsaturated fatty acids in mitochondrial and microsomal membranes (Arnold et al., 1993; Rice and Kennedy, 1988; Monahan et al., 1990). The higher concentrations of α-tocopherol in mitochondria and microsomes may provide greater protection against the initiation of oxidation that can affect the entire muscle cell (Arnold et al., 1993). ά-tocopherol may exert color stabilizing effects by indirectly delaying oxymyoglobin oxidation via direct inhibition of lipid oxidation (Faustman et al., 1998). Accordingly, a study conducted by Arnold et al. (1993) found that lipid oxidation was markedly inhibited in longissimus lumborum of steers that received supplemental α tocopherol acetate before slaughter. Faustman et al. (1998) found that improved stability

of oxymyoglobin with elevated concentrations of α-tocopherol demonstrated a link between lipid oxidation and oxymyoglobin oxidation.

Retail Shelf-Life and Lipid Stability of Forage-Finished Beef. A number of factors can affect the retail display and shelf-life of beef products from forage-finishing systems; however, diet fed to the animal is perhaps one of the most important aspects (Kerry et al., 2000). According to O'Sullivan et al. (2003), diet has a tremendous effect on meat quality as it effects meat composition and therefore, shelf-life. However, several researchers have found mixed effects of forage diets on product retail attributes and an array of tissue level antioxidants and specific forage type factors were indicated as possible causative elements (Arnold et al., 1993; Gatellier et al., 2005). Contrasting results have come from several forage-finishing studies. Reagan et al. (1977) found beef from forage-finishing systems to have similar retail shelf-life characteristics to beef from cattle finished on concentrates and was further evident when primal cuts were stored in vacuum-packaging less than 21 days. Gatellier et al. (2005) and Sapp et al. (1999) found retail color to deteriorate more rapidly if beef was from animals finished on grains. Inversely, Wheeling et al. (1975) found forage-finished beef to have greater surface discoloration, paler lean and lower consumer ratings when compared to concentrate-finished beef and Schroeder et al. (1980) exhibited forage-finished beef retail color to decrease in acceptability more rapidly. Furthermore, Bidner et al. (1986) published evidence suggesting forage-finished beef to have darker lean color in comparison. Quite evidently, a mixed array of findings have been found for the retail display and shelf-life of forage-finished beef compared to common concentrate-finished beef and a number of

production system and animal factors play crucial roles in development of retail characteristics.

French et al. (2000, 2001) exhibited results suggesting little evidence for differences in longissimus color when different finishing regimens were compared. However, Priolo et al. (2001), in a review of several forage-finishing studies, suggested beef from forage-finishing systems to have darker lean, and after 200d on pasture, beef was 10% less bright. Priolo et al. (2001) stated diet components affect retail display characteristics mainly via modulation of fatty acid profile. Changes in fatty acid profiles favoring higher degrees of unsaturated fatty acids plainly affect several retail attributes such as development of oxidized pigment formation. However, elevated levels of muscle metmyoglobin levels are routinely found in concentrate-finished beef (O'Sullivan et al., 2003). Research has also found similar oxymyoglobin, oxygenated muscle myoglobin pigment responsible for the bright-cherry red color of fresh beef, across differing finishing systems through 10 days of display storage and forage-finished steaks to retain redness via measurement of muscle a* measures (Sapp et al., 1999). Sapp et al. (1999) further showed steaks from pasture-finished animals to be similar, to superior to, grain-finished beef through 10 days of display, and suggested possible antioxidant effects. Clearly, links between fatty acid profile modulation and muscle pigment transition exist as crucial elements in the development of retail color characteristics. O'Sullivan et al. (2003) and Gatellier et al. (2005) found lipid oxidation measures to increase with concentrate-finished beef over that of forage-finished; whereas, high levels of polyunsaturated fatty acids, commonly found in forage-finished beef, are prone to undergo auto-oxidation more rapidly. A complex system of elements contributes to

pigment oxidation and vitamin E and other tissue level antioxidants are not solely responsible.

Ascophyllum nodosum

Seaweeds contain a variety of hormones and compounds that show the ability to alter antioxidant status. Seaweed meals have been found to increase antioxidant activity in both plants (Allen et al., 2001a; Allen et al., 2001b; Fike et al., 2001; Schmidt and Zhang, 1997; Zhang and Schmidt, 1999; Chapman, 1950) and animals (Saker et al., 2001; Allen et al., 2001; Fike et al., 2001; Montgomery et al., 2002). A further advantage is that the trace elements found in seaweeds are present in organic form which makes them more readily assimilated (Chapman, 1950). With the exception of manganese, *Ascophyllum nodosum* has a wide range of trace elements which are of value to animals in amounts greater than those to be found in grass (Chapman, 1980).

Tasco-forage is a proprietary product which is an extract from *Ascophyllum nodosum* obtained off the coast of Nova Scoatia, Canada (Allen et al., 2001a). Tasco-forage has been found to reverse the negative effects of grazing infected fescue when applied to endophyte (*Neotyphodium coenophialum*) -infected tall fescue (*Festuca arundinacea* Schreb.). Animals grazing infected fescue exhibit reduced serum cholesterol levels. However, this effect has been reversed by the supplementation of Tasco (Allen et al., 2001a). The effect of Tasco on serum cholesterol implicates its activity in lipid metabolism. A study conducted by Allen et al. (2001b) on beef steers grazing Tasco-forage found that a greater amount of marbling was observed at harvest in retail cuts of meat if steers had grazed Tasco-treated fescue. Further research conducted by Allen et al. (2001b) confirmed that application of Tasco increased marbling score and had a tendency

to increase USDA quality grade (Allen et al., 2001b). Steers that grazed Tasco-treated pastures prior to feedlot finishing had a quality grade of at least USDA Choice, whereas steers that grazed the untreated pastures had a quality grade of USDA Select (Allen et al). Increases in marbling score occurred at the USDA Choice vs. USDA Select line which would significantly affect the links of the beef chain by increased marketability and profit. The increase in USDA Choice carcasses has implications for improving the palatability of beef as discussed previously.

Researchers hypothesized that Tasco had an affect on serum cholesterol and may well influence fat metabolism (Allen et al., 2001b). Allen et al. (2001b) further states that improved marbling and USDA quality grades of steers that grazed Tasco-treated pastures would improve the profitability of beef from feedlot to packer.

Ascophyllum nodosum is a known source of plant growth regulators, and has increased activity of the antioxidant superoxide dismutase and specific vitamin precursors (Fike et al., 2001; Allen et al., 2001a). *Ascophyllum nodosum* (in a proprietary seaweed-based water soluble product) applied to tall fescue has increased antioxidant activity in the livestock grazing it. It is known that seaweeds contain a class of compounds that include effective antioxidants known as substituted phenols and poly-phenols (Le Tutour, 1991). Research conducted on sheep and steers grazing *Ascophyllum nodosum* treated forages has found increased serum vitamin A in response to the treatment, and may be a useful indicator of a generalized enhancement of antioxidant status (Fike et al., 2001). ά-tocopherol, β-carotene, ascorbic acid, and superoxide dismutase have been shown to increase in several species of grasses in response to treatment of *Ascophyllum nodosum* application (Zhang, 1997; Ayad, 1998; Zhang & Schmidt, 1999).

A majority of research focuses on the use of *Ascophyllum nodosum* treatment of forages. It has been concluded that *Ascophyllum nodosum* treatment may prolong the shelf-life and color of beef steaks (Montgomery et al., 2001; Allen et al., 2001a). Application of *Ascophyllum nodosum* to pastures resulted in beef steaks that were redder than steaks from animals that were from untreated pastures (Montgomery et al., 2001). Treating forage with *Ascophyllum nodosum* prolonged shelf-life. Differences generally became greater with increasing postmortem aging and length of time on retail display (Montgomery et al., 2001). Furthermore, Montgomery et al. (2001) found that steaks were more uniform, less discolored and less browned from steers that had grazed *Ascophyllum nodosum* treated forages. They also concluded that *Ascophyllum nodosum* applied to forage during the grazing season can improve color stability and extend beef shelf-life. Researchers found that steers from *Ascophyllum nodosum* treated pastures had improved lean uniformity and decreased lean discoloration and browning throughout simulated retail display, and that *Ascophyllum nodosum* supplementation exhibited improved color stability in beef steaks which may be related to elevated antioxidants in the animal (Montgomery et al., 2001). Further research using direct supplementation of *Ascophyllum nodosum* (in a proprietary seaweed extract) has been conducted and results appear to concur with those of Montgomery et al. (2001) and Fike et al. (2001). Similar characteristics of shelf-life extension in strip-loin steaks have been shown with direct supplementation of an *Ascophyllum nodosum* extract to steers during the final 14 days on feed in finishing facilities (Allen et al., 2001a). Brown seaweed (*Ascophyllum nodosum)* has demonstrated antioxidant properties in animals fed seaweed directly in the diet as evidenced by improved lean color and uniformity in extended days of simulated retail

display (Allen et al., 2001a). Additionally, there were numerous parallels between effects obtained by the supplementation of beef animals with vitamin E and the supplementation with *Ascophyllum nodosum.*

Research Objectives

As in numerous prior studies, the purpose of the present research was to compare the various forage, animal and product elements of finishing diet of steers finished on winter annual ryegrass (*Lolium multiflorum*. Lam). Primarily forage-finishing systems with varied levels of supplementation holds promise to correct several animal performance and product inadequacies and little research has focused on supplementation strategy effects on these production and product traits. Various levels of corn (*Zea mays*) supplementation, while steers grazed winter annual ryegrass, was evaluated against a control group of steers finished solely on concentrates in a traditional dry-lot scenario. Factors evaluated included: initial color attributes, 48 hour post-mortem fatty acid profile, retail display and shelf-life characteristics, lipid oxidative stability and muscle tissue levels of vitamin E. In subsequent research Tasco-14®, a proprietary product derived from the brown seaweed *Ascophyllum nodosum* with several animal and product impacting characteristics, was evaluated for its effect of steers finished on winter annual ryegrass. Finishing diet modulation effects were determined on animal performance, initial 48 hour longissimus lean and subcutaneous fat color, product proximate analysis, sensory attributes, fatty acid profile, retail display shelf life and lipid stability. Sensory, fatty acid profile and lipid stability measurements was acquired across 21 and 34 days of vacuum-packaged postmortem aging with 5 days of simulated retail display per postmortem aging period. The central objective of the research presented is to determine

production parameters effecting animal and product attributes of steers finished on winter annual ryegrass forage and the feasibility of producing beef on forage-based finishing systems.

III. FINISHING STEERS ON WINTER ANNUAL RYEGRASS (*Lolium multiflorum* Lam.) WITH VARIED LEVELS OF CORN SUPPLEMENTATION. II. EFFECTS ON FATTY ACID PROFILE, RETAIL DISPLAY SHELF-LIFE AND LIPID OXIDATION

ABSTRACT: Fall-born crossbred steers (n = 72) were randomly assigned to one of six treatment diets; continual access to 1 ha winter annual ryegrass (*Lolium multifloram* Lam.) with 0.0, 0.5, 1.0, 1.5, or 2.0% of BW in supplemental corn (*Zea mays*) or concentrate-based diet (GRAIN). Steers were assigned to pens of four and pen (n = 18) served as experimental unit. Steers were harvested when average pen backfat reached 0.64 cm. At harvest, fatty acid (FA) LM samples were removed, vacuum-packaged and stored at -80°C. After 48h chilling, striploins (IMPS #180) were collected from the left side of each carcass and lean and fat initial CIE L*, a*, and b* color values were recorded. Shelf life and lipid stability (LS) samples were removed at postmortem (PM) d 21 and 42 and subjected to simulated retail display at 4°C for 4 d. Visual (PM 21) and instrumental (PM 21, 42) color measurements were obtained. Treatment did not effect initial lean L*, a*, or b* values ($P > 0.05$). However, treatment did affect subcutaneous fat L* ($P = 0.01$) and b* ($P = 0.002$) values. All ryegrass treatments had higher b* values when compared to GRAIN. Total conjugated linoleic acid (CLA) was lower ($P = 0.04$) in GRAIN than 0.0%. Total, saturated, monounsaturated, poly-unsaturated, n-6, and PUFA:SFA FA levels were not affected by diet ($P = 0.13$, 0.15, 0.15, 0.23, 0.06, and

0.56, respectively). Proportion of n-3 FA was highest ($P = 0.02$) in the 0.0% treatment. The ratio of n-6:n-3 FA generally increased ($P < 0.001$) with elevated supplementation. Visual measures of lean uniformity increased with elevated forage in the diet ($P = 0.001$). Steaks from GRAIN cattle had lower a* ($P = 0.001$) and higher metmyoglobin ($P = 0.001$), than all other treatments. Measures of lean discoloration decreased ($P < 0.05$) in proportion to increased forage in the diet. Lipid stability increased ($P = 0.04$) with amount of forage in the diet and vitamin E levels in LM samples were not affected by treatment diet ($P = 0.54$).

INTRODUCTION

Forage-finished beef has emerged as a leading market niche for present day consumers, and the process appeals to a number of specific consumer demands. According to Cox et al. (2006) approximately 34% of consumers surveyed in the southeastern U.S. are willing to pay a premium for forage-finished beef. Numerous live and postmortem factors can affect the quality, color, and dietetic quality of beef, and finishing diet composition is one of the most important live production factors (O'Sullivan et al., 2003; Gatellier et al., 2005). Beef from forage-based finishing systems has a higher amount of polyunsaturated fatty acids (PUFA), more specifically *n*-3 PUFA, compared with concentrate-finished beef and the targeted ratio (4:1) of *n*-6/*n*-3 PUFA is commonly attainted in forage-finished beef (Enser et al., 1998). Appropriate *n*-6/*n*-3 PUFA ratios (below 4) and increased CLA intake have been shown to prevent human disease (Simopoulous, 1991; Gatellier et al., 2005).

Lipids from forage-finished beef contain high levels of PUFA which are more prone to being attacked by free radicals. The oxidation of lipids in meat is one of the most significant aspects of loss in flavor quality and the formation of rancid and lean discoloration characteristics. Smith et al. (1996) concluded that quality and color deterioration is mainly due to oxidation of lipid and muscle pigments. The bright, cherry-red color of fresh beef is used by consumers as an indicator of meat quality and wholesomeness (Cassens et al., 1988), and any deviation from this may create a degree of unacceptability (Kropf, 1980). Therefore, our objectives were to evaluate the effects of a winter annual ryegrass finishing diet, with various levels of grain supplementation, compared to a concentrate-finished diet on fatty acid methyl ester (FAME) profile, retail display color, and lipid oxidative stability of loin muscles from beef steers.

MATERIALS AND METHODS

Animals and Diet

Fall born steers from the E.V. Smith Alabama Agricultural Experiment Station Beef Unit were assigned to one of three (primarily British breeding, primarily Continental breeding, or *Bos indicus* × *Bos taurus*) biological types. Steers within biological type were randomly assigned to 18 pens. Three pens where randomly assigned to each of six treatment diets. A complete description of the animals and the diet treatments is provided by Roberts et al. (2006). Treatment diets consisted of grazing winter annual ryegrass (*Lolium multifloram*) with various levels of corn supplementation or a full typical concentrate diet of whole corn (GRAIN; *Zea mays*). Corn supplementation levels were 0.0, 0.5, 1.0, 1.5, and 2.0% of average pen BW (adjusted

every 28 d) as further discussed by Roberts et al. (2006). Pens assigned to ryegrass supplementation treatments were placed in a 1 hectare paddock (0.25 hectare/animal) of winter annual ryegrass. Animals were housed at the E.V. Smith Alabama Agricultural Experiment Station Beef Unit and all procedures were approved by the by the Auburn University Animal Care and Use Committee (PRN #2003-0579). Animals were humanely harvested at the Auburn University Lambert Meat Laboratory when average pen back fat reached 0.64 cm. Individual animal back fat was measured every 28 d by an Aloka 500 real-time ultrasound with a 17.2 cm 3.5 MHz linear transductor (Corometrics Medical Systems, Wallingford, CT). Corresponding average days on finishing diet for each treatment were 172 ± 8.5, 169 ± 8.5, 158 ± 8.9, 143 ± 8.5, 155 ± 8.9, and 151 ± 8.5 for 0.0, 0.5, 1.0, 1.5, 2.0%, and GRAIN finishing treatment diets, respectively.

Sample Collection and Preparation

Within 1 h post exsanguination, a 2.54-cm-thick muscle sample was taken from the LM between the 12th and 13th ribs of the right carcass side. Muscle samples were immediately vacuum-packaged and stored at -80°C until subsequent fatty acid profile and Vitamin E analyses. Muscle pH was obtained between the 12 and 13th rib of the left carcass side at 1 and 24 h postmortem utilizing a Thermo Orion meter (Orion Research, Boston, MA). Strip loins (IMPS #180) were collected from the left carcass side of all 72 animals at 48 h postmortem and vacuum-packaged. Vacuum-packaged strip loins were stored at 2ºC until 21 d postmortem. On d 21 and 42 postmortem strip loins were removed from packaging and fabricated into two 2.54-cm-thick steaks for retail display and oxidative stability analysis. Steak samples for oxidative stability analysis were cut into 3 equal portions and randomly assigned to 1, 3, or 5 d of simulated retail display.

Strip-loins were then vacuum-packaged and stored at 2°C for subsequent retail display analysis. Oxidative stability samples were removed from simulated retail display according to designated day treatment, vacuum packaged and stored in darkness at -20°C until subsequent analysis.

Initial Lean and Fat Color Measurements

Following fabrication within each harvest interval Commission Internationale de l'Eclairage (CIE) lean and external fat L* (muscle lightness), a* (muscle redness), and b* (muscle yellowness) were recorded utilizing a Hunter Miniscan XE Plus (Hunter laboratories Model MSXP-4500C, Reston, VA) using illuminant D65 at 10° and a 3.5-cm aperture was utilized. Lean color measurements were taken from two readings on the anterior face of the strip loin and averaged to obtain a representative measure of initial lean color. External fat color measurements were acquired by taking the average of two readings on anterior and posterior portions of the strip loin.

Determination of Fatty Acid Profile

Following frozen storage at -80°C LM samples were thawed at 4°C for 2 h and trimmed to remove external adipose tissue. Total lipid was determined following the chloroform-methanol procedure of Folch et al. (1957). Nonadecanoate acid (C19:0; Avanti Polar Lipids, Inc.) was added as an internal standard. Fatty acid methyl esters (FAME) were prepared following the procedures of Park and Goins (1994). The FAME were analyzed using an Agilent Technologies 6890N gas chromatograph, and separated using a 60-m DB-23 capillary column (0.25 mm i.d. and 0.25 um film thickness, Agilent Technologies). Column oven temperature was programmed at 150-190°C at 10°C/min, 190-230°C at 4°C/min and held at 230°C for 20 min with a 20:1 split ratio. The injector

and detector were maintained at 250°C. Helium was the carrier gas at a flow rate of 1 mL/min. Individual fatty acids were identified by comparison of retention times with standards (Nu-Chek Prep, Inc.) and quantified using the internal standard.

Retail Presentation

At each postmortem period, steaks were placed under simulated retail display conditions. All steaks for color analysis were placed on Styrofoam trays, covered with polyvinyl chloride film (PVC), and placed in a Tyler (Model M1, Hussmann Corporation, Bridgeton, MO) retail display case at 2ºC for 4 d for visual and instrumental analysis and 5d for lipid stability analysis. All steaks were subjected to 24-h exposure retail display lighting. At the surface of the steak, the illumination intensity was 800 lx utilizing Phillips Alto® Collection bulbs (F34T12/CW/RS/EW).

Visual and Instrumental Color Analysis

During each 4-d postmortem period steaks were evaluated daily by a trained panel, consisting of at least six members, for beef color, color uniformity, surface discoloration, and lean browning according to AMSA (1991) retail color panel evaluation guidelines. Commission Internationale de l'Eclairage (CIE) L* (muscle lightness), a* (muscle redness), b* (muscle yellowness), and reflectance spectra values were determined daily, through the over-wrap for each postmortem display day combination from two random readings on each steak with a Hunter Miniscan XE Plus (Hunter laboratories Model MSXP-4500C, Reston, VA) using illuminant D65 at 10° and a 3.5-cm aperture. Spectral reflectance values were determined and recorded every 10 nm over a range of 400- to 700-nm. The two random readings for each steak were averaged to obtain a representative measure of color. Muscle Chroma (color intensity/saturation), hue

angle (wavelength of light radiation red, yellow, green, blue and purple), myoglobin (fresh muscle pigment), oxymyoglobin (oxygenated muscle pigment), and metmyoglobin (brown oxidized muscle pigment) values were obtained utilizing equations as described by Hunt (1980) and Clydesdale (1991).

Determination of Lipid Oxidative Stability

Lipid oxidative stability was evaluated by utilizing a thiobarbituric acid (TBA) reactive substance assay modified from Buege and Aust (1978). Lipid oxidative stability samples were removed from frozen storage and a 10-g sample was homogenized with 30 mL of distilled water. Approximately 4 mL of homogenate was combined with 8 mL of trichloracetic/thiobarbituric acid reagent and 100 μL of 10% butylatedhydroxyanisole. Samples were incubated in a 99°C water bath for 15 min, allowed to cool in cold water for 10 min and spun at 2000 × g for 10 min. The absorbance of the supernatant was read against a blank containing like reagents at 531 nm. Malonaldehyde standards were constructed utilizing 1,1,3,3-tetraethoxypropane and thiobarbituric acid reactive substances were reported as mg/10g of meat.

Vitamin E Determination

Following frozen storage at -80°C, vacuum-packaged muscle tissue samples were shipped frozen on dry ice, to the University of Connecticut (University of Connecticut, Department of Animal Science, Storrs, CT) for Vitamin E determination. Longissimus samples were prepared for Vitamin E determination according to procedures of Sheehy et al. (1994) and analyzed by HPLC methods for vitamin E in tissues according to Buttriss and Diplock (1984).

Statistical Analysis

Initial color, pH, FAME, TBA, and Vitamin E data were analyzed as a completely randomized design using the general linear models procedures of SAS (SAS Inst. Inc., Cary, NC). Initial lean and fat color measurements, 1, 24 and 48 hr pH, individual FAME, TBA reactive substances and Vitamin E were included in the model with treatment as a fixed variable. Individual FAME data were analyzed as 0.001 if particular FAME values were 0 for analysis of variance for whole treatment effect on individual FAME response. Retail data were analyzed for a completely randomized design, with a split plot repeated measures arrangement using the mixed models procedures as implemented in PROC MIXED (Littell et al., 1996; SAS Inst. Inc., Cary, NC). Visual color, lean uniformity, lean discoloration, lean browning, L*, a*, b*, Chroma, hue, myoglobin, oxymyoglobin, and metmyoglobin were included in the model with treatment, postmortem period, display day and all two and three way interactions as fixed effects. Display day was analyzed as a repeated measure within postmortem period. Steak was the subject of the repeated statement and based on the AICC criteria first order autoregressive was chosen as the optimum covariance structure (Littell et al., 1996). Pen was used as experimental unit and significant ($P \leq 0.05$) treatment effect means were separated using Fisher's protected LSD.

RESULTS

Initial Color Measurements

Finishing diet treatment had no effect on initial lean L*, a*, and b* values (P = 0.12, 0.09 and 0.08, respectively; Table 1). Initial subcutaneous strip loin fat a* values were not affected by treatment (P = 0.93). L* (lightness) value was lowest ($P < 0.05$) for 1.5% animals, but there were no differences between the remaining finishing diet. All animals finished on ryegrass had higher b* values ($P < 0.05$) when compared to GRAIN animals. Yellowness (b*) values were higher ($P < 0.05$) in 0.5% animals compared to 0.0, 1.0 and 2.0% animals. There were no affects of finishing diet on 1-, 24- or 48-h postmortem pH (P = 0.14, 0.25 and 0.54, respectively; Data not shown).

Fatty Acid Profile

Fatty acid methyl ester weights (mg) per 100 g of LM tissue are reported in Tables 2, 3, and 4. Feeding the 0.0% diet increased (P = 0.01) levels of methyl tridecenoate (13:1) when compared to all other finishing regimens (Table 2). Longissimus muscle samples from GRAIN steers had a higher proportion of methyl pentadecenoate (15:0; P = 0.05) compared to 0.0, 0.5 and 1.0% steers. However, there were no differences ($P > 0.05$) in 15:0 levels between GRAIN, 1.5 and 2.0% finishing regimen. There were no differences attributed to finishing diet in levels of 14:0, 14:1 *cis*-9, 15:1 *cis*-9, 16:0, 16:1 *trans*-9, or 16:1 *cis*-9 fatty acids (P = 0.13; 0.33; 0.30; 0.09; 0.08 and 0.55, respectively). GRAIN steers had a higher ($P < 0.05$) quantity of 17:0 when compared to 0.5%, 1.0% and 1.5% animals, but did not differ ($P > 0.05$) in 17:0 levels when compared to 0.0% and 2.0% animals. Steers receiving 1.0% supplementation had similar ($P > 0.05$) 17:0 levels to steers in 0.5% and 1.5% supplementation groups.

Animals receiving the increased grain diets (2.0% and GRAIN) had much higher proportions ($P < 0.05$) of 18:2 cis-9,12 when compared to all other treatment regimens. The amount of 18:2 cis-9,12 for remaining treatment diets (0.0%, 0.5%, 1.0% and 1.5%) did not differ ($P > 0.05$). Amounts of 17:1 *cis*-9, 18:0 18:1 *trans*-9, 18:1 *cis*-11 18:1 *trans*-7, 18:1 *cis*-9, 18:1 *cis*-7, 18:2 *cis*-10,12, and 18:3 *cis*-9,12,15 were not affected by finishing regimen ($P > 0.05$).

LM samples from 0.0% steers had 90-676% higher levels ($P < 0.05$) of 18:3n3 when compared to all other finishing diets. Proportions of 18:3n3 did not differ for 1.0%, 1.5%, 2.0%, and GRAIN, and 0.5% steers had a higher ($P < 0.05$) amount of 18:3n3 when compared to 1.5%, 2.0% and GRAIN.

Long chain fatty acids (C20-C24) were not affected ($P > 0.05$) by finishing regimen treatment with the exception of methyl-5-eicosenoate (20:1 *cis*-12; $P = 0.03$) and methyl docosatetraenoate (22:4 *cis*-7,10,12,16; $P = 0.006$; Table 3). Samples from steers fed 1.5% finishing regimen had higher ($P < 0.05$) 20:1 *cis*-12 when compared to all other treatments. GRAIN animals had much higher ($P < 0.05$) levels of 22:4 *cis*- 7,10,12,16 when compared to all other treatment regimens. There were no differences ($P > 0.05$) in 22:4 *cis*-7,10,12,16 levels when comparing ryegrass-based treatments 0.5%, 1.0%, 1.5% and 2.0%: however, 2.0% animals had higher ($P < 0.05$) levels of 22:4 *cis*-7,10,12,16 when compared to 0.0%.

Total conjugated linoleic acid (CLA) was lower ($P = 0.04$; Table 4) in GRAIN steers compared to 0.0%. Samples from 0.0% steers were similar ($P > 0.05$)for CLA content to 1.0% and 2.0%, but was higher ($P < 0.05$) than 0.5% and 1.5%. There were no effects of finishing regimen on SFA, MUFA, PUFA, n-6, PUFA:SFA ratio and Total FA

($P = 0.15$, 0.14, 0.23, 0.06, 0.56, and 0.13, respectively). Total quantity of n-3 fatty acids was highest ($P < 0.05$) for 0.0% steers when compared to all other finishing treatments. Animals receiving 2.0% supplementation had a higher, with the exception of GRAIN, ($P < 0.05$) n-6:n-3 ratio when compared to all other ryegrass treatment diets. Samples from GRAIN steers had the overall highest ratio (12.54) of n-6:n-3 fatty acids. Each additional 1.0% of supplemental grain resulted in an increase ($P < 0.05$) in the n-6:n-3 ratio.

Simulated Retail Display

All visual and instrumental measures of lean color and discoloration declined with increased days of simulated retail display ($P = 0.001$; data not shown). However, no effect of supplementation treatment or supplementation treatment × d of retail display interaction was found for visual color ($P = 0.63$; 0.28), lean browning ($P = 0.16$; 0.47) and lean discoloration ($P = 0.12$; 0.28), respectively (data not shown). Measures of lean uniformity were affected by diet treatment dependent upon d of retail display ($P = 0.001$; Figure 1). Forage or forage mixed diets maintained ($P < 0.05$) lean uniformity scores throughout four d of simulated retail display with the exception of 1.5% which decreased ($P < 0.05$) in lean uniformity. Additionally, GRAIN steaks had much higher ($P < 0.05$) lean uniformity scores (less uniform), being less uniform when compared to all supplementation treatments with the exception of 1.5%.

Steak L* values were not affected by supplement diet ($P = 0.32$), postmortem ageing × diet ($P = 0.86$), retail display day × diet ($P = 0.10$) and postmortem ageing × display day × diet interaction ($P = 0.42$; data not shown). Measures of steak redness decreased ($P < 0.05$) over time; however decline was dependent upon a diet treatment by retail display day interaction ($P = 0.001$; Figure 2), regardless of postmortem ageing

period ($P = 0.28$). Steaks from animals on 0.0, 0.5 1.0 and 2.0% diets were redder ($P < 0.05$), on display d 3, 4 and 5 when compared to 1.5% and GRAIN animals. Steak CIE b* values were affected by supplement diet dependent upon retail display d ($P = 0.001$; Figure 2), but not postmortem ageing period interactions ($P = 0.11$). By the final d of retail display 1.0% and 2.0% steaks had much higher ($P < 0.05$) b* values when compared to all other diet treatments.

Measures of color saturation (chroma) decreased ($P < 0.05$) and true redness (hue angle) increased with increased postmortem ageing ($P = 0.001$; Figure 3). Steak chroma value decline was dependent upon a diet by retail display day interaction ($P = 0.001$), as 1.5% and GRAIN steaks had the lowest ($P < 0.05$) chroma values in the last two display days when compared to all other treatments. GRAIN and 1.5% steaks had a higher ($P < 0.05$) hue value on display d 3 and 4 when compared to all other treatments.

Fresh muscle pigment values (myoglobin) were not affected by main affects of diet treatment ($P = 0.42$) and postmortem ageing ($P = 0.13$) nor were they affected by any two or three way interactions of supplement treatment, d of retail display and postmortem ageing ($P > 0.05$; data not shown). Muscle oxymyoglobin (oxygenated muscle pigment) values declined ($P < 0.05$) over d of retail display period for all treatments; however, steaks from 1.5% and GRAIN steers had lower ($P < 0.05$) values at display d 3 and 4 when compared to all other treatments ($P = 0.001$; Figure 4). Oxymyoglobin value decline was independent of postmortem ageing period and postmortem ageing period by display d by supplement treatment ($P = 0.21$; 0.42), respectively. Muscle discoloration, as measured by metmyoglobin values (oxidized muscle pigment) was elevated ($P < 0.05$) in the 1.5% and GRAIN steaks at display d 3

and 4 when compared to all other treatment regimen (retail display d by diet interaction; $P = 0.001$) regardless of postmortem ageing period. Additionally, GRAIN steaks had the highest values of metmyoglobin formation in the final display day,

Lipid Oxidative Stability and Vitamin E

Lipid oxidation, as measured by thiobarbituric reactive substance assay increased with postmortem ageing ($P = 0.001$), retail display d ($P = 0.001$) and postmortem ageing by display d interaction ($P = 0.001$; Figure 5). A clear affect of diet was evident ($P = 0.003$); however this affect was dependent upon retail display d ($P = 0.04$). Lipid oxidation vales were highest for GRAIN steaks followed by 1.5% ion d 5 of both postmortem ageing periods when compared to all other treatment regimens. Levels of vitamin E within LM tissue were independent of diet ($P = 0.54$; Table 5).

DISCUSSION

Initial Color Measurements

Feeding regimen did not affect 48-h postmortem striploin lean color characteristics, as measured by L*, a*, and b* values in the present study. In two similar studies, French et al. (2000, 2001) found that supplementing continental, crossbred steers with various levels of concentrate on forage-based diets had no effect on LM color values. However, Bidner et al. (1981) and Bennet et al. (1995) indicated that beef from primarily forage-fed animals was darker in lean color compared to grain-fed animals. The presence of darker lean in forage-fed animals was attributed, by Bidner et al. (1981), to a higher content of myoglobin. Strachan et al. (1993), reported lean from steers finished for extended periods on concentrate to be darker in color than that from steers finished for 0

to short intervals on concentrate. The overall color of fresh red meat plays a crucial role in consumer acceptance and purchasing decision (Morrissey et al., 1994). According to O'Sullivan et al. (2003) diet has a significant effect on meat quality parameters as they pertain to composition, palatability, and shelf-life.

Numerous researchers have reported differences in fat color associated with ratios of forage:concentrate feeding. Yang et al. (2002a) and Kerth et al. (2005) found that subcutaneous fat b* (yellowness) values were higher with increased forage composition in the diet. However, Bidner et al. (1986) presented evidence that there were no differences in fat color between various levels of all forage, all grain and mixed diets. In the present research, finishing diets composed of primarily ryegrass with supplementation had higher b*, more yellow fat when compared to animals of concentrate/grain feeding. A general increase in subcutaneous fat b* values as diet forage composition increased was not seen. Previous research by Strachan et al. (1993) and French et al. (2000) reported that animals fed concentrate for extended lengths of time after an all forage diet had a less yellow, more white fat subcutaneous fat color. Knight et al. (1996) stated that animals fed concentrates for increased time periods had decreased yellow pigment (*B*-carotene) in subcutaneous fat. Correspondingly, Yang and Kaufmann. (2002) found that animals fed forage for longer spans of time had elevated plasma, muscle and adipose tissue *B*-carotene levels when compared to those on concentrate/grain diets. French et al. (2000) theorized different rates of fat deposition may also contribute to differences in fat color due to varying rates of dilution of total carotenoid pools. Steers in the present study were all fed to a common subcutaneous fat thickness and harvested within a relatively narrow time window, therefore, the lack of increase in b* values with increased forage

diet composition may be due to comparatively similar fat deposition rates across treatments with a concentrate component.

Fatty Acid Profile

Increased emphasis on the dietetic qualities of muscle foods has led to increased analysis of the factors controlling and contributing to these qualities (Mills et al., 1992). Finishing diet composition greatly influences dietetic quality of meat and these effects are most often found in the lipid fatty acid profile (Marmer et al., 1984; Mitchell et al., 1991). Fatty acid profile effects overall palatability (Westerling and Hedrick, 1979; Melton et al., 1982) and retail color (Gatellier et al., 2005) of fresh lean. The effects of a finishing diet of forage vs. grain composition on fatty acid composition have been well documented (Marmer et al., 1984: Enser et al., 1998; Gatellier et al., 2005). Feeding strategy and diet can impart a significant effect on muscle fatty acids, particularly C18:3 in beef despite the hydrogenating effects of the rumen microbes (Enser et al., 1998). Longissimus muscle samples from steers in all treatment diets, in the present study did not differ for many of the fatty acids of C14 - 18:2 cis-10,12. Mandell et al. (1998) reported that proportions of 14:0 and 16:1 were higher if animals had been finished on concentrate diets versus alfalfa silage. It was reported by Duckett et al. (1993) that a minimum of 112 d of grain diet consumption are required to significantly change 14:0 and 16:1 concentrations. Steers in the present study receiving grain in the diet, either solely or as a supplement were on the finishing diet for a minimum of 143 d; however, no changes in 14:0 or 16:1 levels were observed for treatment diets. Shroeder et al. (1980) and Mitchell et al. (1991) in similar studies found that proportions of 16:0 and 18:0 did not differ between most mixed forage:concentrate diets.

Treatment did affect levels of C13, C15, and C17. Steers consuming an all ryegrass diet had much higher levels of C13 when compared to all other treatment regimens and C13 levels generally decreased with amount of grain in the diet. Treatment effects on 15:0 and 17:0 fatty acids appear to be variable; however, animals consuming an all concentrate diet had the highest numerical values. These results appear to agree with Miller et al. (1981) who found that animals finished on pasture had lower levels of 16:0 and 17:0 fatty acids. Our results show quantities of 18:2 to be higher in animals fed all concentrates to all other treatment diets which is contrary to findings by Larick and Turner (1989). Larick and Turner (1989) reported that animals fed concentrate while on forage had higher quantities of PUFA 18:2 and 18:3 than animals finished on all concentrate. Inversely, Mitchell et al. (1991) found that 18:2 levels in steers finished on concentrates were higher to their forage finished counterparts. This may be explained by Miller et al. (1967) who proposed that if corn is the concentrate in the diet, 18:2 levels will be increased correspondingly as corn oil is rich in 18:2. Steers consuming all-forage diets had the highest amount of 18:3n3 and levels of 18:3 tended to decrease with added concentrate diet composition. Numerous researchers have found that 18:3n3 is increased in beef if steers had previously been finished on pasture or forage diets (Duckett et al., 1993; Srinivason et al., 1998; Yang et al., 2002b). Miller et al. (1981) found that 18:3n3 was twice as high in pasture finished animals when compared to animals finished for 100 d on concentrate. Steers finished on mixed diets including forage and concentrates still had higher proportions of 18:3n3 when compared to animals finished on all concentrates according to Melton et al. (1982). The increase in 18:3n3 levels in forage-finished beef is most likely due to predominance of 18:3 in forage lipids (Woods et al., 2003). The

disparity of composition of dietary lipids, forage being higher in the n-3 series precursor fatty acid 18:3, and concentrates, higher in the n-6 series precursor fatty acid 18:2, are partially responsible for the effect diet imparts on the overall fatty acid composition (Marmar et al., 1984).

Diet had little effect on proportions of long chain (C:20-24) fatty acids in the present study with the exception of 20:1 and 22:4. Levels of 20:1 were negligible and had little discernable treatment effect. Steers fed an all-concentrate diet had a clearly higher level of 22:4 when compared to all other diets and the proportions of 22:4 appeared to decline in conjunction with increased forage in the diet. Contrary to our results, Brown et al. (1979) and Miller et al. (1981) found that animals finished on pasture had much higher levels of branched chain 20:3 and 20:4 than animals on concentrate diets. However, Yang et al. (2002b) reported quantities of 20:4, 20:5 and 22:5 to be more abundant in forage finished animals. Furthermore, Mitchell et al. (1991) found no differences in 20:4 for forage vs. concentrate treatments. It seems clear that results are highly variable and the actual effect of diet may be unclear. It may be plausible that a number of contributing factors in the diet and rumen environment dictate the abundance of long chain fatty acid production and absorption after ruminal biohydrogentation. We found little evidence of treatment diet interaction with proportions of 20:5 (eicosapentanoic acid/EPA) and 22:6 (docosahexanoic acid/DHA); whereas Gatellier et al. (2005) found higher proportions of EPA and DHA in forage-finished animals.

Longissimus samples from steers, in the current study generally had higher levels of CLA if they were from forage-based finishing diets. Samples from the all-ryegrass treatment had the highest numerical value of CLA. The inclusion of CLA in the diet has

been linked to a number of human health improvements (Pariza, 2004) and CLA levels have generally been found to increase in proportion to added forage diet content. The proportions of SFA, MUFA, PUFA, and PUFA:SFA ratio were not affected by diet treatment in our study and these results are similar to those of Gatellier et al. (2005) for SFA and MUFA levels. However, Mitchell et al. (1991) found that MUFA proportions were increased and SFA were decreased if animals had been finished on concentrates. MUFA proportions were higher in concentrate-finished steers and PUFA were higher in forage-finished steers when compared to the opposing diet (Srinivason et al., 1998). The degree of saturation as well as the ratio of MUFA:PUFA appear to be highly variable and may be due to a number of animal, study, and fatty acid isolation factors. Forage-fed animals (0.0%) had a significantly higher level of n-3 fatty acids and this effect was also seen in the ratio of n-6:n-3 fatty acids, in the present study. Marmer et al. (1984), in a similar study found that there were diet effects on n-3 PUFA. Forage-based diets are higher in the n-3 series fatty acid precursor, 18:3 and concentrate-based diets are higher for the n-6 series precursor 18:2 (Marmer et al., 1984). Our results are similar, as animals grazing all ryegrass had generally higher levels of 18:3, and animals on a majority of concentrate exhibited elevated 18:2. All steers in 0.0, 0.5, 1.0, and 1.5% treatments had n-6:n-3 ratios below 4, and 2.0% steers had a ratio of 4.93. A recommended ratio of below 4 has been proposed by numerous researchers (Enser et al., 1998). Omega-3 fatty acids have been shown to reduce the incidence of cardiovascular disease and decrease overall atherosclerosis (Kris-Etherton et al., 2002). It appears, according to our research that minimum levels (at or below 1.5%) of grain (corn) may be added to an all forage diet

while still attaining the appropriate n-6:n-3 ratios, but adding any corn significantly reduces the levels of omega-3 polyunsaturated fatty acids.

Retail Display Shelf Life and Lipid Stability

Many factors affect the consumer purchasing decision of fresh beef, and among them, color is of great importance as an indicator of meat quality and wholesomeness (Cassens et al., 1988). Consumers often associate overall quality and eating experience with general product appearance and color is a critical component of fresh beef appearance (Faustman et al., 1989). Consumers, through experience, have learned that the desirable color of fresh beef is bright-pink to bright-red and any deviation from this may create a degree of unacceptability (Kropf, 1980). According to Smith et al. (1993) discoloration of muscle creates a degree of consumer unacceptability and products usually will not be purchased at full original market prices by US consumers. Value deteriorations for fresh meat in commercial supermarkets have been estimated at 5.4% of the original market price (Williams et al., 1992). A number of factors affect the retail display and shelf life of beef, including development of off odors, development of off flavors, muscle pigment oxidation and the presence of food spoilage bacteria. Smith et al. (1996) concluded quality deterioration of meat occurs mainly via lipid and pigment oxidation.

While a number of factors affect fresh beef quality and color, diet fed to the animal in finishing has one of the most significant impacts (Kerry et al., 2000). In studies examining the effects of forage or mixed forage finishing diets on fresh beef color and lipid stability a range of variable results have been found. O'Sullivan et al. (2003) found no affect of mixed forage-finishing diets on retail color of beef steaks not packaged in

modified atmosphere environments. Yet others have found significant increases (Sapp et al., 1999) in retail shelf life extension parameters if beef was from animals on forage or mixed forage-finishing diets. Conversely, Schroeder et al. (1980) found retail color attributes to decrease more rapidly if steaks were from forage-fed animals. It is apparent that there are mixed effects of forage-based finishing diets on fresh beef color, and this may be due to a virtual array of factors relating to tissue level antioxidants and specific forage in the diet (Arnold et al., 1993; Gatellier et al., 2005).

In the present study, we found most significant instrumental measures of retail color to deteriorate more rapidly if beef was from animals finished primarily on concentrates. These results concur with those of Gatellier et al. (2005) and Sapp et al. (1999) that found similar measures of retail color to deteriorate more rapidly if animals were from a primarily concentrate finishing strategy. Visual color assessment of fresh beef steaks in the present study found no significant effect of diet on lean color, browning or discoloration. However, Reagan et al. (1977) and Wheeling et al. (1975) found fresh beef from principally forage-finished beef to have greater surface discoloration, paler lean and lower consumer ratings when compared to cattle on concentrate diets.

When assessing the differences in fresh beef L*, a* and b* values in the present study, we found that the effects of diet depended upon extended d of retail display. However, French et al. (2001) found no differences in a similar study with respect to L*, a* and b* values. We found no related diet affect of L* values and these results concur with those of Gatellier et al. (2005) that found L* values to be generally stable through storage. With respect to a* values, Sapp et al. (1999), similar to our results, found higher steak a* values in forage beef and values generally declined at a slower rate when

compared to concentrate-finished animals. Elevated positive a* values indicate a more red lean appearance, where as, negative a* values indicate a more green lean color. Steaks from steers consuming forage in the diet, regardless of supplementation treatment, had elevated lean a* values (were darker and more red) when compared to GRAIN steers, with the exception of 1.5%. Bidner et al. (1986) theorized darker lean in forage beef compared to concentrate to be possible due to higher levels of myoglobin – the haem pigment largely responsible for fresh meat color. We found variable, but significant effects of diet on steak b* values; however, Gatellier et al. (2005) found lower b* values in mixed diet steaks after 6 d of storage when compared to pasture.

Total color saturation or lean chroma values decreased with GRAIN and 1.5% steers in comparison to all other treatment diets. Generally, striploin lean color increased in intensity, brightness and true redness if animals where from primarily forage-based finishing treatments. Measures of true redness generally increased (shown by decreased hue angle values) and these results were similar to lean a* trends. Hue angle measurements are highly correlated with sensory assessment of beef discoloration and may be a more accurate measure of consumer evaluation of beef discoloration when compared to a* value (Chan et al., 1996).

Steak metmyoglobin and oxymyoglobin pigment instrumental values were significantly affected by treatment dependent upon display day in the present study. However, diet did not affect instrumentally determined lean myoglobin values regardless of postmortem ageing period and d of retail display. Similar to our findings, Lanari et al. (2002) found little to no change in myoglobin content with varied combinations of grass and grain in the diet. In the present study, increased lean a* values of steaks from

primarily forage-finished steers can not be completely explained by amount of myoglobin. However, oxymyoglobin values of striploin steaks increased dramatically in forage-finished steers when compared to GRAIN with the exception of 1.5%. Sapp et al. (1999), in a similar study to the present, found increased oxymyoglobin content in steaks from pasture-finished animals and these results were supported by elevated a* value trends. Our results suggest similar affects of forage as steaks from primarily forage-finished steers retained redness (higher a* and oxymyoglobin values) over extended periods of simulated retail display exposure when compared to GRAIN steaks. Correspondingly, we found increased metmyoglobin values in latter display days if steaks were from primarily concentrate finished animals which differs form those of O'Sullivan et al. (2003). Increased pigment oxidation (metmyoglobin levels) in GRAIN animals may be due to suppressed levels of tissue antioxidant levels when compared to animals consuming forage in the finishing diet. Tissue antioxidants or vitamin E have been shown to decrease overall pigment oxidation and influence color development (Arnold et al., 1993). Furthermore, Wood et al., (2004) stated that the oxidation of oxymyoglobin to metmyoglobin generally paralleled the production of rancidity and Renerre et al. (2000) clearly affirmed pigment oxidation products to promote lipid oxidation and vice versa; however, this relationship is sometimes low.

Lipid oxidation is the combined effort of several intrinsic and extrinsic factors such as temperature, antioxidants, and muscle pigments. Gatellier et al. (2005) found significant positive correlations in haeminic iron content of muscle and measures of lipid oxidation via thiobarbituric acid reactive substance assay (TBARS) at the end of prescribed storage conditions. Haeminic iron can be described as a pro-oxidant

compound, as its reaction with hydrogen peroxide gives free radicals which can initiate lipid oxidation. We found measures of lipid oxidation (TBARS) to increase dependent upon a diet by day of retail display interaction in the present study despite the lack of change in myoglobin values. TBARS increased in GRAIN samples, when compared to forage diets, in the latter days simulated retail display exposure. O'Sullivan et al. (2003) and Gatellier et al. (2005), in similar studies, both found TBARS to increase if samples were from animals finished on increased concentrate in the diet. Lipid oxidation is generally increased in meat with high PUFA, as PUFA are more prone to undergo auto-oxidation than meat with higher amounts of SFA. There were no differences in PUFA , SFA or PUFA:SFA ratio due to supplementation treatment. Therefore, differences in TBARS cannot solely be explained by fatty acid composition. However, many (O'Sullivan et al., 2004; Wood et al., 2004) have theorized decreased TBARS levels in primarily forage-finished animals to be a possible product of elevated tissue vitamin E; despite a generally recognized assumption that meat form animals finished on forages is more susceptible to oxidation than animal on concentrate (Reverte et al., 2003). In the current study, differences in retail shelf-life and lipid oxidation could not be explained by elevated Vitamin E in steaks from animals finished primarily on forage and perhaps a range of antioxidants other than Vitamin E may have been a factor.

IMPLICATIONS

The results of this study indicate that finishing steers on winter annual ryegrass with added corn increases fat b* values (yellowness) and increases health aspects of fatty acids such as omega 3, omega 6:omega 3 ratio and conjugated linoleic acid. Finishing cattle on winter annual ryegrass increased shelf-life and decreased measures of lipid

oxidation regardless of supplementation. Therefore, finishing steers on forages with added concentration may be employed as an alternative finishing system without negatively impacting measures of fatty acid profile, retail shelf-life or lipid stability.

Table 1. Least square means ± SEM for initial lean and fat Hunter color measurements from steers finished on ryegrass with various levels of supplementation or ad-libitum mixed ration grain diet

		0.0%[a]	0.5%[a]	1.0%[a]	1.5%[a]	2.0%[a]	Grain[a]	P > F
Lean[b]								
	L*	34.34 ± 0.99	32.01 ± 0.99	34.96 ± 1.05	34.42 ± 0.99	36.25 ± 1.05	35.78 ± 1.05	0.12
	a*	18.90 ± 1.31	24.77 ± 1.31	20.08 ± 1.38	22.00 ± 1.31	23.08 ± 1.38	21.99 ± 1.38	0.09
	b*	17.09 ± 1.35	23.43 ± 1.35	18.97 ± 1.43	21.04 ± 1.35	21.55 ± 1.43	19.83 ± 1.43	0.08
Fat[c]								
	L*	70.05[d] ± 0.91	70.26[d] ± 0.91	68.85[d] ± 0.96	65.05[e] ± 0.91	67.50[de] ± 0.96	68.63[d] ± 0.96	0.01
	a*	11.93 ± 1.40	11.63 ± 1.40	11.57 ± 1.48	12.90 ± 1.40	11.98 ± 1.48	10.71 ± 1.48	0.93
	b*	27.84[e] ± 1.19	31.72[d] ± 1.19	26.97[e] ± 1.26	30.24[de] ± 1.19	27.23[e] ± 1.26	22.00[f] ± 1.26	0.002

[a]Diets consist of ryegrass pasture plus corn supplemented at 0% (0.0), 0.5% (0.5), 1.0% (1.0), 1.5% (1.5), 2.0% (2.0) of bodyweight, or grain concentrate diet in dry-lot (grain).
[b]Strip loin lean color L*, a*, and b* values at 48 h postmortem.
[c]External fat color L*, a*, and b* values over strip loin at 48 h postmortem.
[d.e, f] Means within the same row with different letters differ $P < 0.05$, n = 3 for each mean.

Table 2. Least square means ± SEM for LM fatty acid composition (C13-C18) reported as mg /100 g of tissue for steers finished on ryegrass with various levels of supplementation or ad-libitum mixed ration grain diet.

	0%[a]	0.5%[a]	1.0%[a]	1.5%[a]	2.0%[a]	Grain[a]	P > F
Days on Feed[b]	172 ± 8.5	169 ± 8.5	158 ± 8.9	143 ± 8.5	155 ± 8.9	151 ± 8.5	
Fatty acid							
13:1	2.06^{c} ± 0.33	0.65^{d} ± 0.33	0.29^{d} ± 0.33	0.33^{d} ± 0.35	0.29^{d} ± 0.35	0.00^{d} ± 0.33	0.01
14:0	114.13 ± 20.59	93.53 ± 20.59	59.87 ± 20.59	116.16 ± 21.71	113.22 ± 21.71	150.16 ± 20.59	0.13
14:1 cis-9	20.97 ± 5.56	17.59 ± 5.56	11.81 ± 5.56	19.38 ± 5.86	26.67 ± 5.86	29.39 ± 5.56	0.33
15:0	19.82^{cd} ± 2.52	13.83^{de} ± 2.52	10.57^{e} ± 2.52	17.46^{cde} ± 2.66	17.68^{cde} ± 2.66	22.76^{c} ± 2.52	0.05
15:1 cis-9	14.00 ± 2.57	7.04 ± 2.57	11.11 ± 2.57	9.77 ± 2.71	13.46 ± 2.71	15.06 ± 2.57	0.30
16:0	1124.57 ± 152.39	954.81 ± 152.39	625.56 ± 152.39	1048.01 ± 160.64	1063.06 ± 160.64	1359.74 ± 152.39	0.09
16:1 trans-9	9.75 ± 9.83	21.13 ± 9.83	4.58 ± 9.83	29.85 ± 10.36	7.31 ± 10.36	45.40 ± 9.83	0.08
16:1 cis-9	122.48 ± 27.90	78.10 ± 27.90	68.54 ± 27.90	67.27 ± 29.41	120.70 ± 29.41	109.09 ± 27.90	0.55
17:0	43.57^{cd} ± 6.13	33.48^{de} ± 6.13	22.93^{e} ± 6.13	33.96^{de} ± 6.47	41.84^{cd} ± 6.47	56.13^{c} ± 6.13	0.03
17:1 cis-9	26.89 ± 5.60	15.94 ± 5.60	15.50 ± 5.60	18.18 ± 5.90	31.88 ± 5.90	38.53 ± 5.60	0.06
18:0	719.53 ± 100.24	574.20 ± 100.24	400.18 ± 100.24	545.19 ± 105.67	591.73 ± 105.67	688.35 ± 100.24	0.33
18:1 trans-9	9.31 ± 5.30	2.73 ± 5.30	1.90 ± 5.30	0.00 ± 5.59	2.83 ± 5.59	13.72 ± 5.30	0.46
18:1 cis-11	97.61 ± 18.35	56.88 ± 18.35	44.85 ± 18.35	17.68 ± 19.34	50.95 ± 19.34	57.88 ± 18.35	0.16
18:1 trans-7	13.95 ± 5.79	0.00 ± 5.79	0.00 ± 5.79	0.00 ± 6.11	0.00 ± 6.11	2.65 ± 5.79	0.50
18:1 cis-9	1474.27 ± 228.78	1045.57 ± 228.78	836.61 ± 228.78	871.15 ± 241.16	1503.09 ± 241.16	1574.45 ± 228.78	0.13
18:1 cis-7	55.25 ± 10.48	41.82 ± 10.48	36.30 ± 10.48	35.65 ± 11.05	67.78 ± 11.05	78.20 ± 10.48	0.07
18:2 cis-10,12	11.52 ± 2.83	3.66 ± 2.83	3.44 ± 2.83	5.83 ± 2.98	10.19 ± 2.98	8.59 ± 2.83	0.28
18:2 cis-9,12	122.78^{d} ± 26.51	98.99^{d} ± 26.51	130.49^{d} ± 26.51	79.60^{d} ± 27.94	187.37^{c} ± 27.94	219.06^{c} ± 26.51	0.02
18:3 cis-9,12,15	48.81^{c} ± 2.98	25.71^{d} ± 5.98	23.00^{de} ± 5.98	11.56b^{ef} ± 6.30	20.94b^{ed} ± 6.30	7.22^{f} ± 5.98	0.005

[a]Diets consist of ryegrass pasture plus corn supplemented at 0% (0.0), 0.5% (0.5), 1.0% (1.0), 1.5% (1.5), 2.0% (2.0) of bodyweight, or grain concentrate diet in dry-lot (grain).
[b] Days on final finishing diet.
[c,d,e,f] Means within the same row with different letters differ $P < 0.05$.

Table 3. Least square means ± SEM for LM fatty acid composition (C20-C24) reported as mg /100 g of tissue for steers finished on ryegrass with various levels of supplementation or ad-libitum mixed ration grain diet.

Fatty acid	0%[a]	0.5%[a]	1.0%[a]	1.5%[a]	2.0%[a]	Grain[a]	P > F
20:0	0.37 ± 0.31	0.00 ± 0.31	0.14 ± 0.31	0.85 ± 0.33	0.37 ± 0.33	0.38 ± 0.31	0.57
20:1 cis-12	0.21[d] ± 0.20	0.00[d] ± 0.20	0.00[d] ± 0.20	1.01[c] ± 0.21	0.00[d] ± 0.21	0.00[d] ± 0.20	0.03
20:1 cis-9	6.17 ± 1.87	4.18 ± 1.87	2.24 ± 1.87	1.61 ± 1.97	7.44 ± 1.97	6.62 ± 1.87	0.24
20:2 cis-11,14	2.04 ± 0.90	1.19 ± 0.90	2.09 ± 0.90	0.78 ± 0.95	1.85 ± 0.95	0.00 ± 0.90	0.55
20:3 cis-8,11,14	10.06 ± 2.56	8.23 ± 2.56	12.75 ± 2.56	6.99 ± 2.70	14.04 ± 2.70	16.69 ± 2.56	0.15
20:4 cis-5,8,11,14	47.96 ± 8.08	42.15 ± 8.08	52.93 ± 8.08	42.46 ± 8.52	51.95 ± 8.52	62.06 ± 8.08	0.55
20:5 cis-5,8,11,14,17	19.78 ± 3.70	12.96 ± 3.70	13.97 ± 2.70	6.22 ± 3.90	13.48 ± 3.90	4.95 ± 3.70	0.13
22:4 cis-7,10,13,16	1.65[e] ± 1.42	4.07[de] ± 1.42	5.03[de] ± 1.42	4.00[de] ± 1.50	6.84[d] ± 1.50	11.56[c] ± 1.42	0.006
22:5 cis-7,10,13,16,19	30.57 ± 4.11	19.82 ± 4.11	21.87 ± 4.11	12.34 ± 4.34	23.31 ± 4.34	14.42 ± 4.11	0.09
24:0	0.61 ± 6.97	15.56 ± 6.97	2.77 ± 6.97	30.31 ± 7.34	2.15 ± 7.34	6.79 ± 6.97	0.09

[a]Diets consist of ryegrass pasture plus corn supplemented at 0% (0.0), 0.5% (0.5), 1.0% (1.0), 1.5% (1.5), 2.0% (2.0) of bodyweight, or grain concentrate diet in dry-lot (grain).
[b] Days on final finishing diet.
[c,d,e] Means within the same row with different letters differ $P < 0.05$.

Table 4. Least square means ± SEM for LM fatty acid composition summary reported as mg /100 g of tissue for steers finished on ryegrass with various levels of supplementation or ad-libitum mixed ration grain diet.

Fatty acid	0%[a]	0.5%[a]	1.0%[a]	1.5%[a]	2.0%[a]	Grain[a]	P > F
18:2 cis-9, trans-11 CLA[c]	31.79[f] ± 5.00	15.42[g] ± 5.00	17.20[fg] ± 5.00	6.67[g] ± 5.27	21.15[fg] ± 5.27	9.00[g] ± 5.00	0.04
SFA[c]	2022.65 ± 275.99	1685.26 ± 275.99	1122.04 ± 275.99	1791.97 ± 290.92	1830.13 ± 290.92	2284.34 ± 275.99	0.15
MUFA[c]	1853.52 ± 291.78	1291.67 ± 291.78	1033.76 ± 291.78	1071.93 ± 307.57	1831.91 ± 307.57	1971.03 ± 291.78	0.14
PUFA[c]	326.93 ± 53.51	231.74 ± 53.51	282.26 ± 53.51	181.89 ± 56.41	351.16 ± 56.41	353.48 ± 53.51	0.23
n-6[d]	196.04 ± 39.08	158.32 ± 39.08	206.21 ± 39.08	145.09 ± 41.20	272.26 ± 41.20	317.97 ± 39.08	0.06
n-3[d]	99.17[f] ± 12.79	58.50[g] ± 12.79	58.84[g] ± 12.79	25.09[g] ± 13.49	57.74[g] ± 13.49	26.60[g] ± 12.79	0.02
n-6:n-3	2.05[j] ± 0.30	2.85[ij] ± 0.30	3.35[hi] ± 0.30	3.81[h] ± 0.31	4.93[g] ± 0.31	12.54[f] ± 0.30	0.0001
PUFA:SFA	0.18 ± 0.04	0.19 ± 0.04	0.27 ± 0.04	0.14 ± 0.04	0.21 ± 0.04	0.17 ± 0.04	0.56
Total FA[e]	4203.11 ± 561.66	3208.68 ± 561.66	2438.07 ± 561.66	3040.40 ± 592.05	4013.17 ± 592.05	4608.86 ± 561.66	0.13

[a]Diets consist of ryegrass pasture plus corn supplemented at 0% (0.0), 0.5% (0.5), 1.0% (1.0), 1.5% (1.5), 2.0% (2.0) of bodyweight, or grain concentrate diet in dry-lot (grain).
[b] Days on final finishing diet.
[c]CLA: conjugated linoleic acid, SFA: saturated fatty acids, MUFA: monounsaturated fatty acids, PUFA: polyunsaturated fatty acids.
[d]n-6 fatty acids include:18:2c10,12, 18:2c9,12, 20:2c11,14, 20:3c8,11,14, 20:4c5,8,11,14, 22:4c7,10,13,16. n-3 fatty acids include 183c0,12,15, 20:5c5,8,11,14,17, 22:5c7,10,13,16,19.
[e]Total FA includes fatty acids from figures 1, 2 and 3.
[f, g, h, i, j] Means within the same row with different letters differ $P < 0.05$.

Table 5. Least square means ± SEM for μg/g alpha-tocopherol in LM for steers finished on ryegrass with various levels of supplementation or ad-libitum mixed ration grain diet.

Diet Regimen	μg/g
0% [a]	1.62 ± 0.45
0.5% [a]	1.55 ± 0.45
1.0% [a]	2.43 ± 0.55
1.5% [a]	2.02 ± 0.47
2.0% [a]	2.09 ± 0.55
Grain [a]	1.80 ± 0.45

[a]Diets consisted of ryegrass pasture plus corn supplemented at 0% (0), 0.5% (0.5), 1.0% (1.0), 1.5% (1.5), 2.0% (2.0) of bodyweight, or grain concentrate diet in dry-lot (grain).

Figure 1: Least squares means ± SEM for visual uniformity scores of strip loin steaks from steers finished on ryegrass with various levels of supplementation at 0% (0.0), 0.5% (0.5), 1.0% (1.0), 1.5% (1.5), 2.0% (2.0) of BW or ad-libitum mixed ration corn grain diet. [a]S = effect of supplement treatment, DD = effect of retail display day, S × DD = effect of supplement × retail display day interaction. [z]Color uniformity (1 = uniform; 5= extreme two toning); n = 12 for each mean

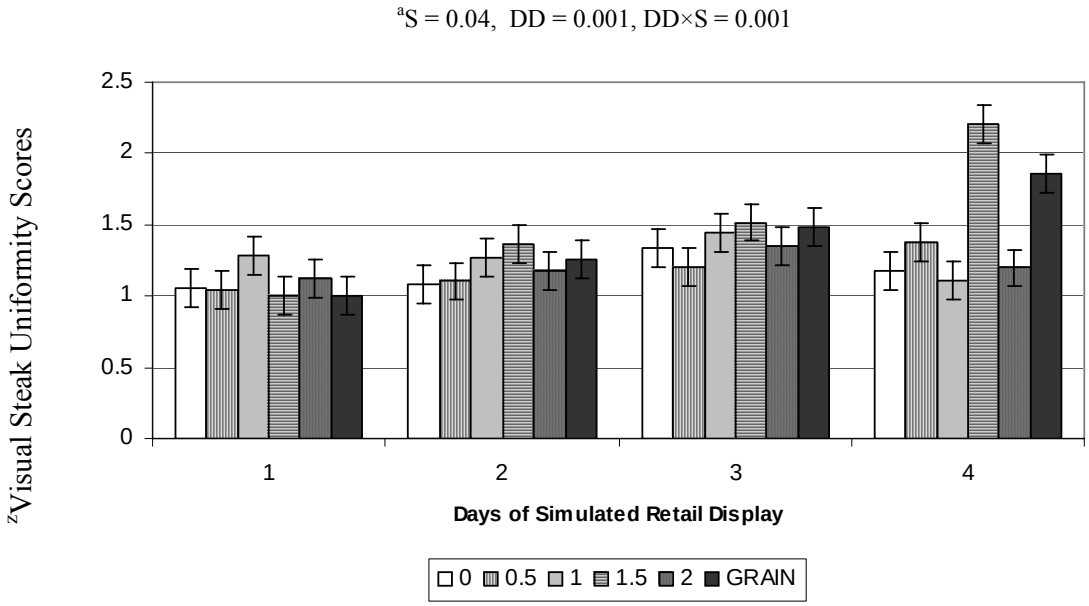
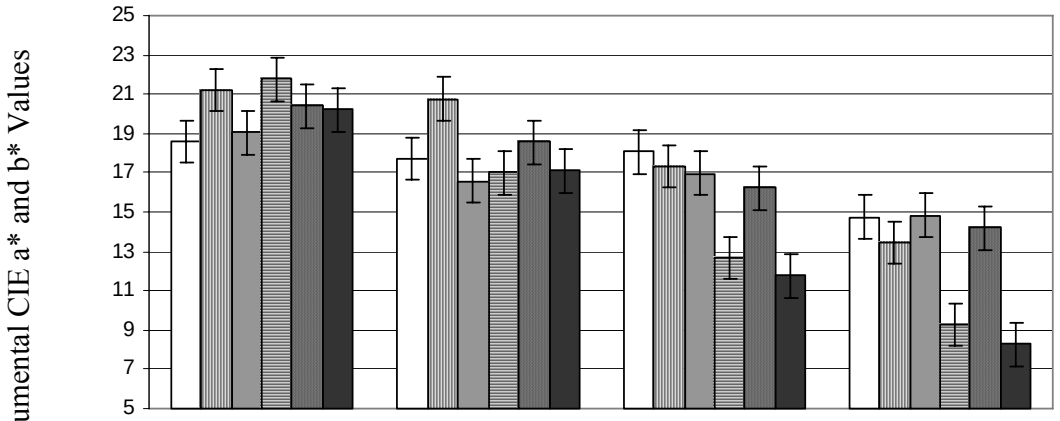


Figure 2. Least squares means ± SEM for instrumental CIE a* and b* values of strip loin steaks from steers finished on ryegrass with various levels of supplementation at 0% (0.0), 0.5% (0.5), 1.0% (1.0), 1.5% (1.5), 2.0% (2.0) of BW or ad-libitum mixed ration corn grain diet. [a]S = effect of supplement treatment, PM = effect of postmortem ageing, DD = effect of retail display day, PM × S = effect of postmortem ageing × supplement interaction, DD × S = effect of retail display day × supplement interaction, PM × DD = effect of postmortem ageing × retail display day interaction, PM × DD × S = effect of postmortem ageing × retail display day × supplement interaction. [y]Lean a* value (positive = red, 0 = neutral, negative = green. [z]Lean b* value (positive = yellow, 0 = neutral, negative = blue); n = 12 for each mean

[y]CIE a*

[a]S = 0.04, PM = 0.001, DD = 0.001, PM×S = 0.09, DD×S = 0.001, PM×DD = 0.01, PM×DD×S = 0.28



[z]CIE b*

[a]S = 0.02, PM = 0.10, DD = 0.001, PM×S = 0.28, DD×S = 0.001, PM×DD = 0.02, PM×DD×S = 0.11

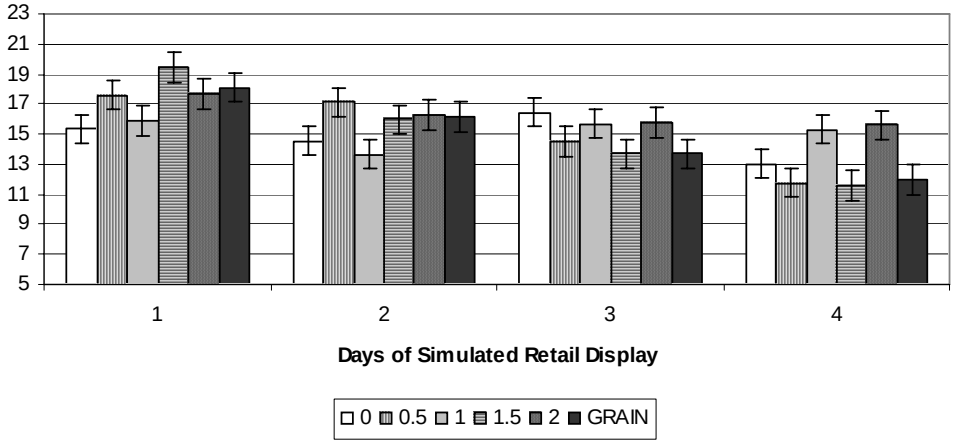
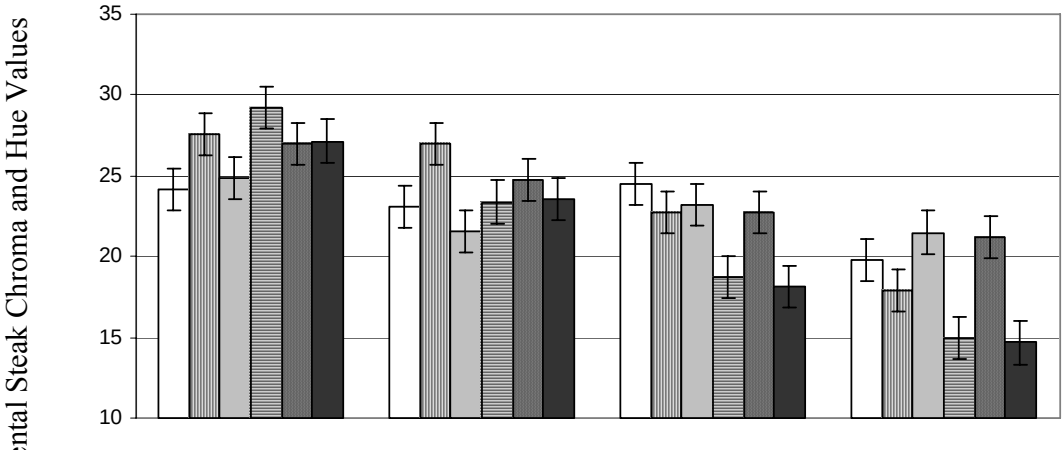


Figure 3: Least squares means ± SEM for instrumental chroma and hue values of strip loin steaks from steers finished on ryegrass with various levels of supplementation at 0% (0.0), 0.5% (0.5), 1.0% (1.0), 1.5% (1.5), 2.0% (2.0) of BW or ad-libitum mixed ration corn grain diet. [a]S = effect of supplement treatment, PM = effect of postmortem ageing, DD = effect of retail display day, PM × S = effect of postmortem ageing × supplement interaction, DD × S = effect of retail display day × supplement interaction, PM × DD = effect of postmortem ageing × retail display day interaction, PM × DD × S = effect of postmortem ageing × retail display day × supplement interaction. [y]Lean chroma value (numerically increasing color saturation). [z]Lean hue value (numerically increasing true red color); n = 12 for each mean

[y]Chroma

[a]S = 0.19, PM = 0.001, DD = 0.001, PM×S = 0.07, DD×S = 0.001, PM×DD = 0.01, PM×DD×S = 0.36



[z]Hue

[a]S = 0.72, PM = 0.001, DD = 0.001, PM×S = 0.07, DD×S = 0.001, PM×DD = 0.02, PM×DD×S = 0.39

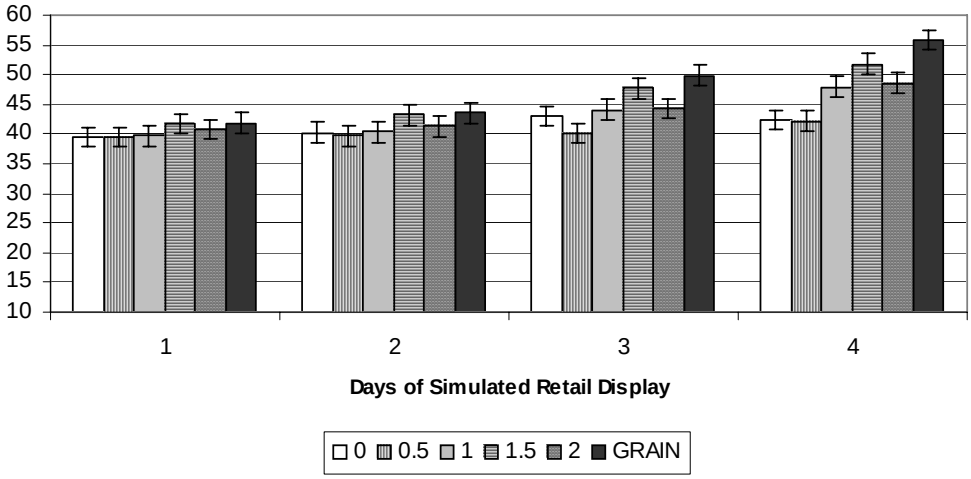
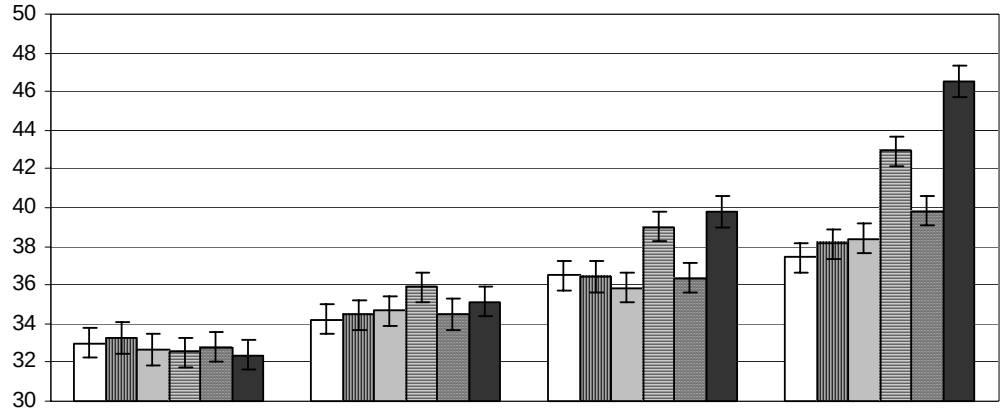


Figure 4: Least squares means ± SEM for instrumental metmyoglobin and oxymyoglobin pigment values of strip loin steaks from steers finished on ryegrass with various levels of supplementation at 0% (0.0), 0.5% (0.5), 1.0% (1.0), 1.5% (1.5), 2.0% (2.0) of BW or ad-libitum mixed ration corn grain diet[a]S = effect of supplement treatment, PM = effect of postmortem ageing, DD = effect of retail display day, PM × S = effect of postmortem ageing × supplement interaction, DD × S = effect of retail display day × supplement interaction, PM × DD = effect of postmortem ageing × retail display day interaction, PM × DD × S = effect of postmortem ageing × retail display day × supplement interaction; n = 12 for each mean

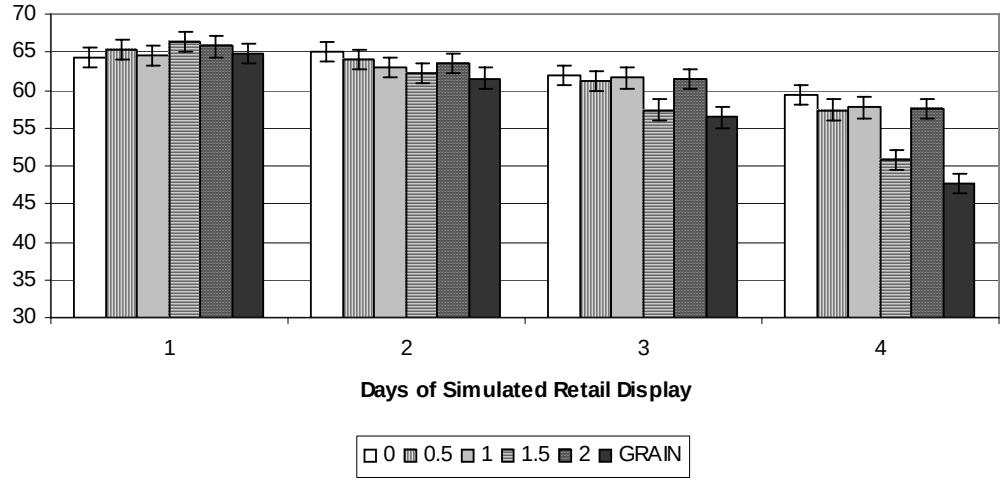
Metmyoglobin

[a]S = 0.002, PM = 0.21, DD = 0.001, PM×S = 0.15, DD×S = 0.001, PM×DD = 0.26, PM×DD×S = 0.42



Oxymyoglobin

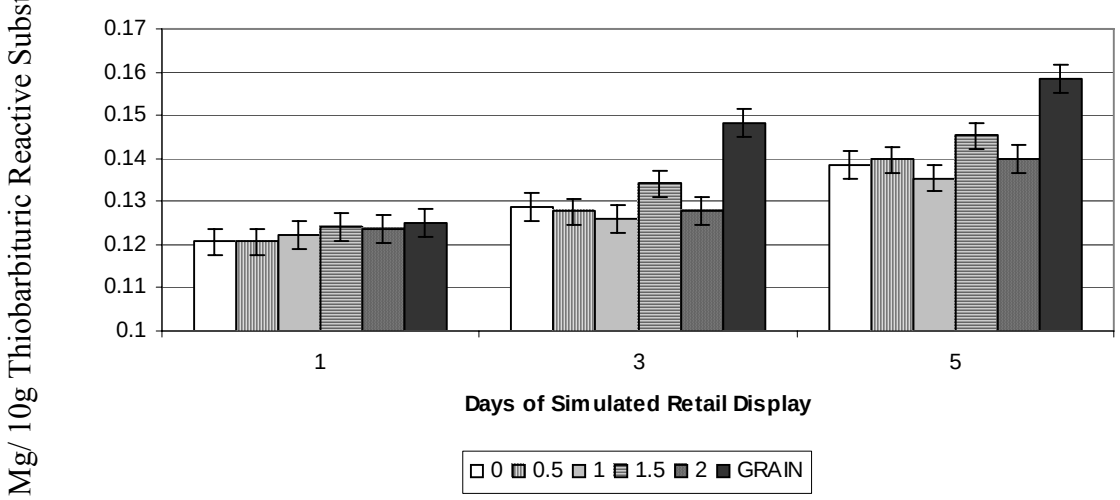
[a]S = 0.01, PM = 0.21, DD = 0.001, PM×S = 0.15, DD×S = 0.001, PM×DD = 0.26, PM×DD×S = 0.42



Instrumental Steak Metmyoglobin and Oxymyoglobin Values as a Precentage

Figure 5: Least squares means ± SEM for thiobarbituric reactive substance values of strip loin steaks from steers finished on ryegrass with various levels of supplementation at 0% (0.0), 0.5% (0.5), 1.0% (1.0), 1.5% (1.5), 2.0% (2.0) of BW or ad-libitum mixed ration corn grain diet[a]S = effect of supplement treatment, PM = effect of postmortem ageing, DD = effect of retail display day, PM × S = effect of postmortem ageing × supplement interaction, DD × S = effect of retail display day × supplement interaction, PM × DD = effect of postmortem ageing × retail display day interaction, PM × DD × S = effect of postmortem ageing × retail display day × supplement interaction; n = 12 for each mean

[a]S = 0.003, PM = 0.001, DD = 0.001, PM×S = 0.68, DD×S = 0.04, PM×DD = 0.001, PM×DD×S = 0.63



IV. TASCO (*Ascophyllum nodosum*) SUPPLEMENTATION IN A FORAGE-FINISHING DIET: EFFECTS ON ANIMAL PERFORMANCE, CARCASS CHARACTERISTICS, PALATABILITY, FATTY ACID PROFILE, RETAIL SHELF-LIFE AND LIPID STABILITY

ABSTRACT: Fall-born, crossbred steers (n=48) were randomly assigned to pens and pens (n = 12) were then randomly assigned to one of four treatment diets consisting of continual access to 1 ha winter annual ryegrass (*Lolium multifloram* Lam.) with 0.0% (RY), 1.0% (RC), 0.0% + Tasco (RT) and 1.0% + Tasco (RTC) of the average pen BW in supplemental soy hull pellets (SHP). Steer weight was recorded approximately every 28 d. Steers were humanely harvested at the conclusion of a 168 d finishing period. USDA carcass characteristics, initial lean and fat instrumental color and LM pH were measured and striploins (IMPS #180) were removed vacuum-packaged and stored at 2°C. Fatty acid (FA) LM samples were removed, vacuum-packaged and stored at -80°C. Shelf life (RET), lipid stability (LS) and FA samples were removed at postmortem (PM) d 20 and 34. Shelf-life and LS samples were subjected to simulated retail display at 4°C for 5 d within each postmortem aging period. Visual and instrumental color measurements were obtained from the LM surface between the 12rh and 13th ribs. There were no affects of Tasco treatment on any of the evaluated animal performance, carcass, initial color, sensory, shear, fatty acid profile, retail shelf-life or lipid stability factors. However,

supplementing steers with SHP did increase ($P = 0.02$) overall dressing percentage regardless of Tasco treatment. Initial subcutaneous fat b* values tended to increase ($P = 0.08$; indicating a more yellow color) for cattle supplemented with Tasco and soy hull pellets over all other forage-finishing diet treatments. Additionally, n-3 polyunsaturated fatty acids tended ($P = 0.10$) to increase for cattle supplemented solely with Tasco on winter annual ryegrass. The ratio of n-6:n-3 tended to decrease in cattle not supplemented with soy hull pellets ($P = 0.06$). Fatty acid and cook-loss levels increased ($P < 0.05$) with extended d of postmortem aging, regardless of Tasco or soy hull pellet treatment. Off-flavor scores increased ($P < 0.05$) with extended steak exposure to simulate retail display conditions and postmortem aging treatment. Supplementing Tasco or SHP had little affect on any of the evaluated production and product attributes.
Key Words: Beef, Forage, Lipid, Oxidation, Tasco

INTRODUCTION

Recent factors in the beef industry, joined with traditional food safety concerns, have prompted the typical beef consumer to examine a wide variety of aspects relating to the production and consumption of beef products, and a range of niche markets have emerged. Cox et al. (2006) estimated approximately 34% of surveyed consumers in the southeastern U.S. (Alabama, Tennessee and Kentucky) were willing to pay a premium for forage-finished beef. The southeastern U.S. has a natural opportunity to utilize high quality forages in unconventional finishing systems as an alternative method of finishing cattle (Bagley et al., 1990). Numerous live and postmortem factors can affect the quality, color and dietetic quality of beef, and finishing diet composition is one of the most

important live production factors (Gatellier et al., 2005). Animals finished on forages traditionally have been found to be inferior to concentrate-finished counterparts when evaluating various live (Bennett et al., 1995) and postmortem measures of animal performance and product palatability (Bowling et al., 1977; Schroeder et al., 1980). Negative animal and carcass attributes associated with forage-finishing could prove detrimental to forage-finishing strategies. A method to improve forage-finished beef carcass and product quality would serve to improve the efficiency and sustainability of forage-finishing systems. Tasco (Acadian Agritech, Dartmouth, Nova Scotia) , a proprietary product derived from the dried brown seaweed *Ascophyllum nodosum* has been shown in various instances to increase marbling score and certain measures of retail display shelf life (Allen et al ., 2001b; Braden et al., 2003). Therefore, we proposed a study in which animals were finished on winter annual ryegrass with or without supplementation and Tasco treatment to evaluate Tasco supplementation effects on animal performance, carcass characteristics, palatability attributes, fatty acid profile and retail display shelf life.

MATERIALS AND METHODS

Animals and Treatment Regimen

Fall-born, crossbred steers (n = 48) from a single calving season of the resident herd of an Alabama Agricultural Experiment Station were assigned to one of three breed type categories; primarily continental breeding, primarily Angus breeding and primarily *Bos indicus* × *Bos taurus* breeding. All research protocols were approved by the Auburn University Animal Care and Use Committee (PRN #2004-0760). Steers, with an average

pre-trial BW of 296.6 kg, were also assigned frame scores based on hip height and age (BIF, 2002). Steers with extreme frame scores > 6 and < 4 were excluded from the study. Steers (n = 4) were then randomly assigned to pens with breed type and frame score equally stratified within pens. Pens (n = 12) were then randomly assigned to one of four treatment diets consisting of; continual access to 1 ha of winter annual ryegrass (*Lolium multiflorum* Lam.) with 0.0% of average pen BW in supplemental soy hull pellets (SHP) and no Tasco (RY), 1.0% of average pen BW in supplemental SHP (RC), 0.0% of average pen BW in supplemental SHP + Tasco (RT) and 1.0% of average pen BW in supplemental SHP +Tasco (RTC). Pen served as experimental unit and therefore each treatment had three replications. All pens received ad. libitum loose mineral (Auburn University, Winter Grazing Mineral for Cattle, W.B. Fleming Company, Tifton, GA).

Pens receiving Tasco (Table 1) treatment received Tasco at 15% of the mineral ration. In December, cattle were allotted to pens and given a 14 d adjustment period. Adjustment regimen for each treatment consisted of; RY and RT = continual access to 1 ha winter annual ryegrass, RC and RTC = continual access to winter annual ryegrass while receiving incremental increases in supplemental SHP, up to 1.0% of average pen BW, within the final 7 d of the 14 d adjustment period. On d, 14 cattle were removed from the adjustment regimen and placed in dry-lot pens without water for 12 hr and an initial trial shrunk weight was recorded on d 14 + 1 of the adjustment period. After initial weight, all steers where placed in finishing treatment regimen paddocks indicating trial initiation.

Following d 1 of the trial period, weights were recorded in approximately 28 d intervals to adjust SHP supplementation levels and track animal performance. In interval

3 a steer was removed from the RT treatment due to injury and a steer of similar weight, breed type and frame score was substituted for forage impact, but not used for statistical analysis. Interval period BW, ADG, daily mineral consumption and daily SHP consumption are summarized in Table 2.

Winter annual ryegrass paddocks (n = 12) at the E.V. Smith Agricultural Research Beef Unit, Shorter AL, measuring 1 ha each were used as the forage component for all treatment regimens similar to conditions described by Roberts et al. (2005). Winter annual ryegrass paddocks were composed of Marshall ryegrass and were planted in September at a seeding rate of 34 kg•ha^{-1}. Nitrogen was applied at a rate of 110 kg ha^{-1} at planting and an additional 65 kg•ha^{-1} was applied in late February. Partial dry matter was determined (Table 3) approximately every 28 d in accordance with animal weigh days utilizing procedures as described by Bransby et al. (1977). Forage quality was determined in January (beginning), March (middle) and June (end) of the finishing period and NDF, ADF and CP values (Table 3) were determined utilizing an Perstrop Analytical NIR and developed prediction equations (USDA-ARS, 1995). On d 168 of the finishing period, animals were removed from treatments, weighed and shipped overnight approximately 720 km to a commercial facility in Center Hill, FL and humanely harvested.

Carcass Evaluation

Following harvest, individual animal HCW were recorded and carcasses were chilled for 48 h at 2°C and 48 h pH was recorded in the LM between the 12/13th rib interface of the left carcass side using a Thermo Orion meter (Orion Research, Boston, MA). At 48 h postmortem (PM) right carcass sides were ribbed between the 12 and 13th

ribs and carcass characteristics were evaluated by trained Auburn University personnel. Preliminary yield grade (PYG), adjusted preliminary yield grade (APYG), LM area, final yield grade, lean maturity, marbling score and final quality grade were recorded (USDA, 1997). Per commercial harvesting facility practices a majority of the (KPH) was removed at harvest. Accordingly, a similar KPH value was utilized to compute final yield grade of all carcasses. All carcasses had similar skeletal maturity scores of A^{20} and a common value was used for final quality grade computation.

Carcass Fabrication and Sample Collection

Striploins (IMPS #180) were collected from the left carcass side of all 48 animals at 48 h PM and vacuum-packaged for cold (4°C ± 2°) storage and transportation to the Auburn University Lambert-Powell Meats Laboratory. At 72 h PM, striploins were removed from storage and a 2.54 cm LM sample was removed from the anterior portion of the striploin. Longissimus muscle samples were minced, immediately vacuum-packaged and placed in storage at -80°C until subsequent fatty acid profile analysis. Remaining portions of striploins were vacuum-packaged and placed in storage for PM aging. On PM d 20, striploins were removed from the package and five 2.54-cm-thick steaks were serially removed from the anterior end for proximate, sensory, Warner-Bratzler Shear (WBS) force, retail display and lipid oxidative stability analysis. Steaks for proximate, sensory and WBS analysis were vacuum-packaged and placed in frozen storage at -20°C. Striploins were vacuum-packaged and replaced in storage for extended PM aging. On PM d 34, striploins were again removed from the package and three 2.54-cm-thick steaks were serially removed from the anterior face for PM 34d retail, sensory and lipid oxidative stability analyse. Steaks for lipid oxidative stability were portioned

into three equal segments and randomly allotted to 1, 3 and 5 d of simulated retail display within PM d 20 and 34. Lipid oxidative stability samples allotted to d 1 simulated retail display treatment was further equally portioned into two samples and one sample was immediately vacuum-packaged and stored at -80°C for initial PM 20 and 34 d fatty acid profile analysis. Steaks for retail display were prepared accordingly and placed in simulated retail display for 5 d within PM d 20 and 34. Upon completion of retail display periods for both PM periods, steaks were removed from simulated retail display conditions, vacuum-packaged and stored at -20°C for subsequent sensory analysis.

Initial Lean and Fat Color Measurements

Following a 48 hr PM chill, Commission Internationale de l'Eclairage (CIE) lean and subcutaneous fat L* (lightness), a* (redness) and b* (yellowness) values were recorded utilizing a Hunter Miniscan XE Plus (Hunter Laboratories, Model MSXP-4500C, Reston, VA) with illuminant D65 at 10° and a 3.5-cm aperture. Reflectance spectra values were also determined for initial lean color. Spectral reflectance values were determined every 10 nm over a range of 400- to 700-nm. The two random readings for each carcass lean and fat measurement were averaged to obtain a representative measure of color. Lean color was determined from two random readings on the exposed surface of the LM between the 12 and 13th ribs and subcutaneous fat attributes were measured from two random readings above and below the 12 and 13th rib interface. Muscle chroma (color intensity/saturation), hue angle (wavelength of light radiation of red, yellow, green, blue and purple), myoglobin (fresh muscle pigment), oxymyoglobin (oxygenated fresh muscle pigment) and metmyoglobin (oxidized fresh muscle pigment)

values were obtained utilizing equations as described by Hunt (1980) and Clydesdale (1991).

Retail Presentation

At each PM period, steaks for retail, d 5 sensory and lipid stability analysis were placed under simulated retail display conditions. All steaks were placed on Styrofoam trays, covered with polyvinyl chloride film (PVC), and placed in a Tyler (Model M1, Hussmann Corporation, Bridgeton, MO) retail display case at 2ºC for 5 d for visual and instrumental color analyse. At d 1, 3 and 5 of display, corresponding lipid stability samples were removed from simulated retail display conditions, vacuum-packaged and stored at -80°C until subsequent analysis. All steaks were subjected to 24-h exposure retail display lighting. At the surface of the steak, the illumination intensity was 800 lx.

Visual Color Analysis

During each 5-d simulated retail display period within each PM period steaks were evaluated daily by a trained panel, consisting of at least six members, for beef color, color uniformity, surface discoloration, and lean browning according to AMSA (1991) retail color panel evaluation guidelines (1 = Extremely dark, uniform, 0% surface discoloration and no lean browning and 8 = Extremely bright cherry-red, 5 = extreme two-toning, 7 = 100% surface discoloration and 6 = dark brown lean color; respectively).

Instrumental Color Analysis

Commission Internationale de l'Eclairage (CIE) L* (muscle lightness), a* (muscle redness), b* (muscle yellowness), and reflectance spectra values were determined daily ,coinciding with visual analysis, through the over-wrap for each DD within PM period combination from two random readings on each steak with a Hunter Miniscan XE Plus

(Hunter laboratories Model MSXP-4500C, Reston, VA) using illuminant D65 at 10° and a 3.5-cm aperture. Spectral reflectance values were determined and recorded every 10 nm over a range of 400- to 700-nm. The two random readings for each steak were averaged to obtain a representative measure of color. Muscle Chroma (color intensity/saturation), hue angle (wavelength of light radiation red, yellow, green, blue and purple), myoglobin (fresh muscle pigment), oxymyoglobin (oxygenated muscle pigment), and metmyoglobin (brown oxidized muscle pigment) values were obtained utilizing equations as described by Hunt (1980) and Clydesdale (1991).

Shear and Sensory

Steaks for WBS force determination were removed from frozen storage and allowed to thaw at 4°C for 12 h. Steaks were removed from the vacuum packaging and cooked to an internal temperature of 71°C on a clam-shell style grill for 7 min (Kerth et al., 2003). Pre and post cooking steak weight was recorded for cook-loss analysis. Cooked steaks were then covered with polyvinyl chloride (PVC) film and chilled at 4°C for 24h. Six cores (1.3 cm in diameter) from each steak were removed parallel to muscle fiber orientation and sheared once according to AMSA (1995) guidelines. Cores were sheared once with a Warner-Bratzler shear fixture on a TA.XT Plus Texture Analyzer (Texture Technologies Corp, Scarsdale, NY) using a cross-head speed of 3.3mm/s. Peak force for all six cores of each steak was averaged and cooking loss percentages were determined for statistical analysis.

Steaks for sensory analysis (PM 20, d 1 and 5; PM 34, d1 and 5) were removed from frozen storage and thawed for 12 hr at 2°C, prepared according to similar procedures as described for WBS analysis and evaluated by a panel of 6 members trained

according to Cross et al. (1978). Steaks were randomly selected and prepared for sensory analysis by d of simulated retail display exposure within PM aging groups. After cooking, steaks were then trimmed of outside edges and cut into 1-cm^2 (cooked steak thickness) samples and stored in warming pans (50°C; approx. 4 min) for service to trained sensory panel. Two samples from each steak were then evaluated for sensory attributes by the trained panel supplied with red light, the evaluation form, an un-salted cracker for cleansing the palate, water and a cup for expectoration. Steaks were evaluated using an eight-point scale (AMSA, 1995) for initial and sustained tenderness, initial and sustained tenderness, flavor intensity and beef flavor, where 1 = extremely dry, tough, bland and uncharacteristic of beef, and 8 = extremely juicy, tender, intense and characteristic of beef, respectively.

Proximate Analysis of LM

Moisture, fat, ash, and protein percentages of the LM from the 12^{th} rib section were measured according to procedures described by AOAC (1998). Samples were removed from the freezer and thawed for 8 h at 2 ± 1ºC. Steaks were removed from the vacuum package and trimmed of all exterior fat and connective tissue. Longissimus muscle samples were cut into 1-cm pieces, vitrified in liquid N, homogenized with a Waring blender (model 1120, Waring Product Division, Dynamics Corporation of America, New Hartford, CT), placed in Whirl-Pak bags (Nasco, Modesto, CA) and stored at -20°C until further analysis. Moisture and fat were determined using the SMART Trac™ Moisture and Fat Analyzer system (CEM Corporation, Matthews, NC) and ash was determined using a Phoenix microwave muffle furnace (CEM Corporation, Matthews, NC). Protein was determined for individual samples by subtracting ash,

moisture and fat percentages from 100 and all data was reported on a percentage basis as an average of duplicate samples.

Determination of Fatty Acid Profile

Following frozen storage at -80°C, LM samples for fatty acid analysis were thawed at 4°C for 2 h and trimmed to remove residual external adipose tissue. Total lipid was determined following the chloroform-methanol procedure of Folch et al. (1957). Nonadecanoate acid (C19:0; Avanti Polar Lipids, Inc.) was added as an internal standard. Fatty acid methyl esters (FAME) were prepared following the procedures of Park and Goins (1994). The FAME were analyzed using an Agilent Technologies 6890N gas chromatograph, and separated using a 60-m DB-23 capillary column (0.25 mm i.d. and 0.25 um film thickness, Agilent Technologies). Column oven temperature was programmed at 150-190°C at 10°C/min, 190-230°C at 4°C/min and held at 230°C for 20 min with a 10:1 split ratio. The injector and detector were maintained at 250°C. Helium was the carrier gas at a flow rate of 1 mL/min. Individual fatty acids were identified by comparison of retention times with standards (Nu-Chek Prep, Inc.) and quantified using the internal standard.

Determination of Lipid Oxidation

Lipid oxidative stability was evaluated by utilizing a thiobarbituric acid (TBA) reactive substance assay modified from Buege and Aust (1978). Lipid oxidative stability samples were removed from frozen storage and a 10-g sample was homogenized, within 1 h of removal from frozen storage, with 30 mL of distilled water. Approximately 4 mL of homogenate was combined with 8 mL of trichloracetic/thiobarbituric acid reagent and 100 μL of 10% butylatedhydroxyanisole. Samples were incubated in a 99°C water bath

for 15 min, allowed to cool in cold water for 10 min and spun at 2000 × *g* for 10 min. The absorbance of the supernatant was read against a blank containing like reagents at 531 nm. Malonaldehyde standards where constructed utilizing 1,1,3,3-tetraethoxypropane and thiobarbituric acid reactive substances were reported as mg/10g of meat.

Statistical Analysis

Average daily gain, carcass, shear, initial color and pH data were analyzed as a completely randomized design using the general linear models procedures of SAS (SAS Inst. Inc., Cary, NC). Initial lean and fat color measurements; 1, 24 and 48 h pH; individual FAME; TBA reactive substances; and Vitamin E were included in the model with treatment as a fixed variable. Sensory, retail and TBA data were analyzed for a completely randomized design, with a split plot repeated measures arrangement using the mixed models procedures as implemented in PROC MIXED (Littell et al., 1996). Initial and sustained tenderness, initial and sustained juiciness, flavor intensity, off flavor, visual color, lean uniformity, lean discoloration, lean browning, L*, a*, b*, Chroma, hue, myoglobin, oxymyoglobin, metmyoglobin and TBA values were included in the model with treatment, postmortem period, display day and all two- and three-way interactions as fixed effects. Display day was analyzed as a repeated measure within postmortem period. Steak was the subject of the repeated statement and based on the AICC criteria, first order autoregressive was chosen as the optimum covariance structure (Littell et al., 1996). Pen was used as experimental unit and significant ($P \leq 0.05$) treatment effect means were separated using Fisher's protected LSD.

RESULTS

Animal Performance and Carcass Traits

Finishing diet had no affect on ADG of steers during the entire finishing period ($P = 0.59$; Table 4) as ADG ranged from 1.07 – 1.14 kg/d^{-1} across all treatments. At harvest, steers receiving SHP supplement (RC and RTC) had higher dressing percentages ($P = 0.02$) when compared to remaining treatment regimen (RY and RT). Lean maturity, marbling score, PYG, APYG, LM area, HCWT and yield grade were all similar among treatments ($P > 0.21$).

Initial Color

Diet had no affect on L*, b*, chroma, hue, myoglobin, oxymyoglobin and metmyoglobin initial lean color attributes ($P > 0.10$; Table 5). Initial 48 h PM lean a* values tended ($P = 0.09$) to be higher for RTC carcasses, when compared to all other treatments. Subcutaneous fat L* and a* values were similar across treatments ($P = 0.60$ and 0.19; respectively). However, subcutaneous fat b* values tended ($P = 0.008$) to be higher (more yellow) in animals receiving SHP supplementation (RC and RTC) compared to animals receiving no SHP supplementation.

Sensory and Shear

No sensory attributes were affected by diet (Table 6; $P > 0.15$). Cook loss (CL) percentages tended to be greatest for RTC and lowest for RC steaks when compared to all other treatment regimen steaks ($P = 0.10$). With extended days of simulated retail display, initial and sustained juiciness decreased ($P = 0.004$), off-flavor increased ($P = 0.001$) and cook-loss increased ($P = 0.03$). All remaining sensory characteristics (IT, ST and FI) were unaffected by treatment ($P > 0.18$). Additionally, OF scores increased with

advanced PM aging ($P = 0.001$), but IJ, SJ, IT, ST, FI and CL were similar across treatments ($P > 0.11$).

Warner-Bratzler shear values, of steaks vacuum-packaged aged for 20 d PM, were not affected by treatment regimen ($P = 0.94$; Table 7). Moreover, proximate fat, moisture, protein and ash percentages were similar across treatments ($P = 0.63$, 0.69, 0.66 and 0.64; respectively).

Fatty Acid Profile

Fatty acids of C14 to C22 were not affected by finishing diets ($P > 0.16$; Table 8). However, all C14 thru C20:3 fatty acids, with the exception of C14:1, 15:1, 16:0, 17:1, 20:4 and 22:2 ($P > 0.05$), increased with increased postmortem aging ($P \leq 0.03$). Additionally eicosapentanoic acid (EPA), conjugated linoleic acid (CLA), saturated fatty acid (SFA), monounsaturated fatty acid (MUFA), polyunsaturated fatty acid (PUFA), omega-6 PUFA (n-6), PUFA:SFA ratio and total FA ($P > 0.05$;Table 9), were unaffected by diet. However, omega-3 PUFA (n-3) levels tended to decrease and the ratio of n-6:n-3 tended to increase if steaks were from animals supplemented with SHP when compared to RY and RT steaks ($P = 0.10$ and 0.06; respectively). The SFA, MUFA, PUFA, n-6 and n-3 levels across all dietary treatments increased with increased PM aging time ($P < 0.004$). Eicosapentanoic acid, CLA, n-6:n-3 ratio and total FA values were not affected by PM aging ($P > 0.14$); however, PUFA:SFA ratios tended ($P = 0.09$) to decrease with increased PM aging.

Retail Shelf-Life and Lipid Oxidation

All visual and instrumental measures of retail color attributes deteriorated over d of retail display (DD) within PM aging period as expected ($P = 0.001$; Montgomery et

al., 2001). Visual steak color analysis values for lean color, uniformity, discoloration and browning (Figures 1, 2, 3 and 4; respectively) were similar across treatments ($P > 0.05$) regardless of DD ($P > 0.05$) and PM ($P > 0.05$) exposure periods. Additionally, instrumental measures of lean color and shelf-life (L*, a*, b*, chroma, hue, oxymyoglobin and metmyoglobin; Figures 5 – 11, respectively) were unaffected by treatment regimens ($P > 0.05$) or the treatments within DD and PM interactions. However, myoglobin pigment equation values of steaks from RY steers were much higher when compared to all other diet regimen on d 5 of display regardless of postmortem ageing period ($P = 0.03$; Figure 10). Thiobarbituric reactive substances (TBA) levels were not affected by treatment ($P = 0.36$; Figure 12) nor DD and PM interactions ($P > 0.05$). TBA levels increased with extended DD exposure and vacuum-packaged PM aging ($P = 0.001$).

DISCUSSION

Animal Performance

Animal performance is perhaps one of the most important evaluation factors of live animal production. Most often, live animal weight gain is utilized as the performance measure criteria. Cattle finishing diet has profound effects on performance, measured by gain, and carcass characteristics (Mandell et al., 1998). Forage diets, typically low in energy in comparison to concentrate diets, generally produce carcasses with smaller HCW, decreased subcutaneous fat levels, lower USDA quality grades and smaller LM area. In the present study we found no differences due to finishing diet on any animal performance or carcass characteristics with the exception of dressing percentage (DP) at

harvest. Steers supplemented with SHP had higher DP when compared to non-supplemented treatments.

As previously discussed, protein-to-energy ratios of forage-finishing diets are commonly imbalanced and this disproportion causes inefficient nitrogen utilization and poor gain in comparison to balanced rations. Therefore, supplementing cattle, on forage-finishing diets, with high-energy feed-stuffs to increase performance and weight gain is routinely utilized and has been well investigated. However, in the present study SHP was utilized as a supplement which may have fallen short of supplying adequate levels of energy supplementation to accomplish optimum protein utilization in terms of increasing ADG and HCW. Additionally, no Tasco supplementation effect was present for any of the evaluated forage, animal performance and carcass characteristics. Steers receiving Tasco, in previous research, were supplemented at a rate of 2% of the diet on a DM basis (Braden et al., 2003). Steers in the current study received Tasco in a free-choice mineral at a rate of 12% of the mineral portion. Mineral consumption in finishing interval one was between 9.48 – 32.23 gm•hd•day and in interval six was approximately 40.53 g•hd^{-1}•day^{-1} resulting in Tasco consumption from approximately 3 to 5 g•hd^{-1}•day^{-}1. Tasco consumption in the present research was much lower when compared to previous research conducted by Braden et al. (2003). Tasco supplementation levels, in the present study, may have been below adequate levels necessary for significant Tasco treatment effects.

Initial Color, Sensory and Shear

Many factors such USDA carcass cutability and quality factors affect overall carcass value; however, carcass external fat color is of significant impact, and when

external carcass fat appears yellow in color a price de-valuation is realized (Strachan et al., 1993). Several researchers have found carcasses of forage-finished cattle to have a characteristic yellow fat and have contributed this occurrence mainly to carotenoids, of which β-carotene, in forages, is predominate (Knight et al., 1996). Correspondingly, Yang et al. (2002) and Kerth et al. (2006) found subcutaneous fat b* (measure of yellowness) values to increase as levels of forage increased in the finishing-diet. However, Bidner et al. (1986) found no differences due to finishing diets, of forage and/or concentrates on fat color. Subcutaneous fat b* values in the present study where generally unaffected by treatment; however, animals receiving SHP supplementation tended to have higher b* values, indicating a less yellow color, when compared to steers not receiving SHP supplementation.

Feed source has generally been implicated as the largest source of variation in sensory attributes due to environmental factors (Melton et al., 1990). Contrasting research findings exist for sensory characteristics of beef from a broad mix of forage, forage and concentrate or solely concentrate finishing diets. Simmone et al. (1996) found similar sensory characteristics between forage- and concentrate-finished beef. Sapp et al. (1999) and Mandell et al. (1998) found few differences in overall palatability; however, some evidence suggested forage-finished beef to have slightly less flavor and more off-flavor (Mandell et al., 1998). Some evidence suggests forage type to be a key variable in sensory differences in forage-finished beef (Larick and Turner, 1990), and high quality pastures may produce beef similar to traditional finishing systems (Melton et al., 1990). However, Reagan et al. (1977) found that most data will state that grain-fed beef is much

more desirable to the consumers than forage-fed beef, simply because of a more desirable flavor.

All sensory characteristics in the current study where similar across treatments. Braden et al. (2003), in concentrate-finished steers supplemented Tasco, found no affect of supplementation on any of the evaluated sensory characteristics of striploin steaks. Initial and sustained juiciness decreased with extended simulated retail display exposure. Correspondingly, cook-loss percentage increased with extended simulated retail display exposure. Braden et al. (2003) found no differences due to Tasco treatment in cook-loss; however, steaks were not exposed to simulated retail display conditions as in the current study. In the present study, extended retail display exposure increased moisture and purge loss of striploin steaks and hence decreased initial and sustained juiciness scores. Similarly, Jeremiah and Gibson, (2003) found decreased juiciness scores for steak that have been postmortem aged.

Postmortem ageing treatments are commonly used to increase beef tenderness scores and reduce overall variation in tenderness of beef steaks (Eilers et al., 1996; Jeremiah and Gibson, 2003). Postmortem aging of beef steaks has been shown to be significantly related to meat tenderness due to degradation of selected myofibrillar muscle protein structures (Parish et al., 1973). Jeremiah and Gibson, (2003) reported initial and overall tenderness improved with postmortem aging and Warner-Bratzler shear force values decreased. Wheeler et al. (1990) found continual improvements in tenderness measures up to 28 d postmortem; however, little improvements were noted after 28 d of aging. In the present study, we found no improvement in tenderness scores due to postmortem aging. Additionally, several factors related to product appearance and

shelf-life deteriorated with extended aging treatment and display. Eilers et al. (1996) found improvements in tenderness from 6 to 12 d postmortem, no changes in tenderness between 12 and 18 d postmortem and continual slow increases in tenderness from 18 to 24 d postmortem. At some point postmortem aging of beef steaks has diminishing tenderness gains, and increased product appearance deterioration. Postmortem aging treatments, designed to increase tenderness must be evaluated for feasibility in terms of product sensory properties (tenderness) while maintaining product shelf-life factors.

Fatty Acid Profile, Retail Display and Lipid Oxidation

The effects of a forage-based diet leading to higher concentrations of n-3 polyunsaturated fatty acids in body tissues and grain-based diets leading to higher concentrations of n-6 polyunsaturated fatty acids have been established and verified (Marmer et al., 1984; Mitchell et al., 1991). Supplementation of marine algae, a source of long chain (n-3) fatty acids will typically increase the level of n-3 fatty acid in ruminant animals. A majority of research has found decreased saturated fatty acid levels as well as greater polyunsaturated and more specifically DHA and CLA when compared to animals feed primarily concentrates (Franklin et al, 1999). Levels of DHA have been found to increase in cows fed marine algae when compared to control animals (Franklin et al., 1999). Marine algae allowed for decreased rumen biohydrogenation of DHA to the extent that allowed for more efficient incorporation of DHA (Franklin et al., 1999). However, no affect of treatment on fatty acid profile was evident in the current study. Postmortem aging generally increased fatty acid amounts and this may be due to moisture loss in subsequent aging treatments.

A number of factors can affect the retail display and shelf-life of beef products from forage-finishing systems; however, diet fed to the animal is perhaps one of the most important aspects (Kerry et al., 2000). According to O'Sullivan et al. (2003), diet has a tremendous effect on meat quality as it effects meat composition and therefore, shelf-life. However, several researchers have found mixed effects of forage diets on product retail attributes and an array of tissue level antioxidants and specific forage type factors were indicated as possible causative elements (Arnold et al., 1993; Gatellier et al., 2005). Reagan et al. (1977) found beef from forage-finishing systems to have similar retail shelf-life characteristics to beef from cattle finished on concentrates and was further evident when primal cuts were stored in vacuum-packaging less than 21 d. Gatellier et al. (2005) and Sapp et al. (1999) found retail color to deteriorate more rapidly if beef was from animals finished on grains. Inversely, Wheeling et al. (1995) found forage-finished beef to have greater surface discoloration, paler lean and lower consumer ratings when compared to concentrate-finished beef and Schroeder et al. (1980) found forage-finished beef retail color to decrease in acceptability more rapidly. Furthermore, Bidner et al. (1986) published evidence suggesting forage-finished beef to have darker lean color in comparison. Quite evidently, a mixed array of finding have been found for the retail display and shelf-life of forage-finished beef compared to common concentrate-finished beef and a number of production system and animal factors play crucial roles in development of retail characteristics. In the present study, finishing diet had no affect on any of the visual or instrumental measures of retail shelf life and lipid oxidation. This may be due to the lack of effective Tasco level ingestion on a common winter annual ryegrass based finishing diet.

IMPLICATIONS

Tasco meal supplementation, in a free-choice mineral affected few of the animal performance, forage, and product related characteristics examined in the present study. It would seem plausible to evaluate the amount of Tasco consumed, in terms of an effective supplementation level, when comparing to previous research conclusions with Tasco meal. To determine possible Tasco effects in forage-finishing diets future studies may need to determine effective intake levels.

Table. 1. Approximate composition[1] of Tasco-14, an Ascophyllum nodosum seaweed meal; from Allen et al., 2001a, p. E23

Item	Value
Crude Fiber, %	6.0
Carbohydrates, %	52.0
Ash, %	22.0
Moisture, %	12.0
Crude Protein, %	6.0

[1]Acadian Seaplants Limited, Dartmouth, Nova Scotia

Table 2. Body weight, ADG, and finishing interval mineral consumption of steers finished on winter annual ryegrass supplemented with or without Tasco and/or concentrate.

Finishing Interval		RY[1]	RT[1]	RC[1]	RTC[1]
Interval 1[2]	BW, kg	350.46	347.52	342.65	334.61
	ADG, kg	1.69	1.72	1.74	1.58
	ADMC[3]	32.23	9.48	21.67	16.14
	ADCC[4]	-	-	2.93	2.90
Interval 2[2]	BW, kg	383.76	379.19	376.74	370.93
	ADG, kg	1.18	1.21	1.12	1.32
	ADMC[3]	35.60	33.77	33.07	35.13
	ADCC[4]	-	-	3.42	3.34
Interval 3[2]	BW, kg	403.99	395.42	407.09	397.84
	ADG, kg	0.72	1.08	0.58	0.92
	ADMC[3]	32.84	31.69	33.44	38.73
	ADCC[4]	-	-	3.76	3.69
Interval 4[2]	BW, kg	445.56	428.53	453.29	428.31
	ADG, kg	1.15	1.28	0.91	0.78
	ADMC[3]	34.83	35.80	35.33	35.13
	ADCC[4]	-	-	4.07	3.97
Interval 5[2]	BW, kg	475.94	460.20	475.72	472.62
	ADG, kg	0.84	0.62	0.87	1.25
	ADMC[3]	40.53	40.53	40.53	40.53
	ADCC[4]	-	-	4.53	4.28
Interval 6[2]	BW, kg	501.28	494.97	487.76	491.11
	ADG, kg	0.90	0.98	0.68	0.67
	ADMC[3]	40.53	40.53	40.53	40.53
	ADCC[4]	-	-	4.75	4.72

[1] Diets consist of: ryegrass pasture (RY), ryegrass pasture + Tasco (RT), ryegrass pasture + concentrate (RC) and ryegrass pasture + Tasco + concentrate (RTC); n = 12, 11, 12 and 12; respectively for each mean

[2] Finishing intervals of approximately 28 days beginning in December and terminating in June

[3] Average daily mineral consumption (gm/head/day) in approximately 28 d intervals

[4] Average daily concentrate consumption (kg/head/day) in approximately 28 d intervals

Table 3. Availability (kg DM/ha) and quality attributes of winter annual ryegrass pastures grazed by steers being supplemented with or without Tasco and/or concentrate

Forage Attribute		Diet			
		RY[1]	RC[1]	RT[1]	RTC[1]
kg Dm ha^{-1}	January	1499	1683	1542	1716
	February	1461	1591	1401	1564
	March	1683	1949	1613	1927
	April	1835	2356	1878	2296
	May	1830	2671	1927	2535
	June	2177	2763	2291	2763
January Quality Attributes	NDF	38.99	40.99	32.69	39.72
	ADF	20.35	19.77	16.48	19.33
	CP	17.21	19.69	19.04	17.40
March Quality Attributes	NDF	40.26	38.55	36.33	34.89
	ADF	20.21	19.41	18.78	18.62
	CP	27.50	28.46	26.38	25.60
June Quality Attributes	NDF	37.22	36.90	35.75	39.39
	ADF	23.03	24.53	22.15	22.57
	CP	23.00	20.19	21.06	20.81

[1] Diets consist of: ryegrass pasture (RY), ryegrass pasture + Tasco (RT), ryegrass pasture + concentrate (RC) and ryegrass pasture + Tasco + concentrate (RTC)

Table 4. Least square means ± SEM for evaluated average daily animal gain and carcass traits of steers finished on winter annual ryegrass supplemented with or without Tasco and/or concentrate.

Attribute	R[1]	RT[1]	RC[1]	RTC[1]	P > F
ADG, kg/d	1.13±0.03	1.07±0.03	1.14±0.03	1.14±0.04	0.59
Dressing percentage	53.70[b]±0.67	53.57[b]±0.70	56.47[a]±0.67	56.26[a]±0.70	0.02
Lean maturity[2]	30.41±5.42	30.55±5.72	44.58±5.42	32.63±5.72	0.27
Marbling score[3]	355.41±18.43	353.33±19.43	378.75±18.43	394.86±19.43	0.41
PYG[4]	2.45±0.06	2.30±0.07	2.45±0.06	2.53±0.07	0.22
APYG[5]	2.55±0.07	2.39±0.07	2.58±0.07	2.58±0.07	0.31
LM area, cm^2	30.09±0.66	29.59±29.59	31.11±0.66	11.95±30.53	0.50
HCW, kg	269.68±11.06	260.61±11.06	280.27±11.06	277.06±11.66	0.64
Yield Grade	1.87±0.10	1.69±0.11	1.87±0.10	1.93±0.11	0.50

[1] Diets consist of: ryegrass pasture (R), ryegrass pasture + Tasco (RT), ryegrass pasture + concentrate (RC) and ryegrass pasture + Tasco + concentrate (RTC); n = 12, 11, 12 and 11; respectively for each mean

[2] Maturity score (100 = A^{00}, 200=B^{00})

[3] Marbling score (400=$Small^{00}$, 300=$Slight^{00}$

[4] Preliminary yield grade

[5] Adjusted preliminary yield grade

[a,b] Means with different superscript letters differ ($P < 0.05$)

Table 5. Least square means ± SEM for initial 48 hr postmortem color and subcutaneous fat instrumental color values from steers finished on winter annual ryegrass supplemented with or without Tasco and/or concentrate.

	Initial Lean Color					Initial Subcutaneous Fat Color				
	RY[1]	RT[1]	RC[1]	RTC[1]	P > F	RY[1]	RT[1]	RC[1]	RTC[1]	P > F
CIE L*,[2]	34.38±0.66	33.70±0.69	32.52±0.76	34.01±0.69	0.36	79.93±0.85	80.61±0.88	79.11±0.85	80.78±0.88	0.60
CIE a*,[3]	19.46±0.50	19.71±0.51	19.73±0.57	21.37±0.51	0.09	4.25±0.47	3.29±0.49	4.67±0.54	4.81±0.49	0.19
CIE b*,[4]	16.91±0.59	16.89±0.61	16.70±0.68	18.56±0.61	0.19	16.93±1.28	14.83±1.32	18.61±1.47	20.24±1.32	0.08
Chroma[5]	25.79±0.74	25.97±0.77	25.86±0.85	28.32±0.77	0.12	-	-	-	-	-
Hue[6]	40.91±0.48	40.50±050	40.17±0.56	40.88±0.50	0.73	-	-	-	-	-
Myoglobin, %	2.42±0.50	2.50±0.51	1.38±0.57	0.79±0.51	0.11	-	-	-	-	-
Oxymyoglobin, %	64.51±0.39	64.35±0.40	64.73±0.45	65.64±0.40	0.18	-	-	-	-	-
Metmyoglobin, %	33.05±0.27	33.13±0.27	33.88±0.31	33.56±0.27	0.22	-	-	-	-	-

[1] Diets consist of: ryegrass pasture (RY), ryegrass pasture + Tasco (RT), ryegrass pasture + concentrate (RC) and ryegrass pasture + Tasco + concentrate (RTC); n = 12, 11, 12 and 11; respectively for each mean
[2] L* instrumental value (positive = white, negative=black)
[3] a* instrumental value (positive = red, 0 = neutral, negative = green)
[4] b* instrumental value (positive = yellow, 0 = neutral, negative = blue)
[5] Chroma value (measure of color saturation; increasing value indicates increasing color saturation)

Table 6. Least square means ± SEM for sensory and cook-loss attributes for striploin steaks after postmortem ageing and simulated retail display exposure from steers finished on winter annual ryegrass supplemented with or without Tasco and/or concentrate.

Effect Mean		Sensory Attribute						
		IJ[2]	SJ[2]	IT[2]	ST[2]	FI[2]	OF[3]	CL[4]
Diet[5]	RY[1]	5.43±0.15	5.21±0.17	5.99±0.18	5.68±0.20	6.25±0.07	6.84±0.13	17.14±0.76
	RT[1]	5.42±0.15	5.11±0.17	5.96±0.18	6.05±0.20	6.19±0.07	7.12±0.13	17.93±0.76
	RC[1]	5.58±0.15	5.44±0.17	6.29±0.18	5.79±0.20	6.36±0.07	7.03±0.13	16.28±0.76
	RTC[1]	5.56±0.15	5.23±0.17	6.29±0.18	5.96±0.20	6.42±0.07	7.20±0.13	19.32±0.76
	P > F	0.80	0.60	0.42	0.59	0.16	0.29	0.10
Display Day[5]	1	5.70±0.09	5.45±0.10	6.20±0.10	5.92±0.12	6.35±0.05	7.59±0.08	18.62±0.55
	5	5.30±0.09	5.04±0.10	6.07±0.10	5.82±0.12	6.26±0.05	6.51±0.08	16.72±0.55
	P > F	0.005	0.004	0.19	0.35	0.23	0.001	0.03
Postmortem Ageing[5]	20	5.56±0.10	5.33±0.10	6.16±0.12	5.83±0.13	6.36±0.05	7.39±0.08	18.32±0.55
	34	5.44±0.10	5.16±0.10	6.11±0.12	5.90±0.13	6.25±0.05	6.71±0.08	17.01±0.55
	P > F	0.36	0.15	0.75	0.65	0.12	0.001	0.12

[1] Diets consist of: ryegrass pasture (RY), ryegrass pasture + Tasco (RT), ryegrass pasture + concentrate (RC) and ryegrass pasture + Tasco + concentrate (RTC) ; n = 12, 11, 12 and 11; respectively for each mean

[2] IJ = Initial tenderness, SJ = sustained juiciness, IT = initial tenderness, ST = sustained tenderness and FI = flavor intensity; 1=Extremely dry, tough and bland palatability attribute; 8=extremely juicy, tender, and intense palatability attribute

[3] OF = off-flavor; 1 = extreme off-flavor, 8 = none

[4] CL = Cook-loss percentage

[5] Treatment = treatment finishing regimen, Display Day = exposure to 1 or 5 days of simulated retail display and PM = days of postmortem ageing

Table 7. Least square means ± SEM for 48-h postmortem pH, Warner-Bratzler shear force and proximate attributes of striploin steaks from steers finished on winter annual ryegrass supplemented with or without Tasco and/or concentrate.

Attribute	RY[1]	RT[1]	RC[1]	RTC[1]	P > F
WB Shear, kg [2]	3.84±0.23	4.04±0.24	3.94±0.23	3.98±0.24	0.94
pH, 48 h	5.65±0.03	5.59±0.03	5.60±0.03	5.55±0.03	0.24
Proximate Fat, %	2.41±0.27	2.45±0.29	2.78±0.27	2.84±0.29	0.63
Proximate Moisture, %	72.14±1.13	74.03±1.19	73.48±1.13	73.54±1.19	0.69
Proximate Protein, %	24.21±1.11	22.50±1.17	22.60±1.11	22.52±1.17	0.66
Proximate Ash	1.22±0.11	1.00±0.12	1.13±0.11	1.08±0.12	0.64

[1] Diets consist of: ryegrass pasture (RY), ryegrass pasture + Tasco (RT), ryegrass pasture + concentrate (RC) and ryegrass pasture + Tasco + concentrate (RTC); n = 12, 11, 12 and 11; respectively for each mean
[2] Warner-Bratzler shear force

Table 8. Least square means ± SEM for longissimus muscle fatty acid composition (C14-C22) reported as mg /100 g of tissue from steers finished on winter annual ryegrass supplemented with or without Tasco and/or concentrate.

Fatty acid	Diet					Postmortem Ageing Treatment			
	RY[1]	RC[1]	RT[1]	RTC[1]	P > F	PM d 2[2]	PM d 20[2]	PM d 34[2]	P > F
14:0	192.79±39.36	187.221±39.36	181.98±40.37	247.32±40.37	0.65	108.19±25.83	215.02±25.83	283.25±25.83	0.001
14:1 cis-9	65.31±16.27	32.13±16.27	36.86±16.98	46.12±16.98	0.52	23.65±13.25	55.40±13.25	56.26±13.25	0.14
15:0	42.54±7.54	40.55±7.51	36.94±7.74	43.92±7.74	0.92	17.55±5.40	50.07±5.40	55.34±5.40	0.001
15:1 cis-9	83.53±30.86	26.21±30.86	37.04±32.21	34.60±32.21	0.57	22.25±27.06	75.34±27.06	38.43±27.06	0.38
16:0	1464.33±268.09	1512.22±268.09	1558.23±276.69	2007.20±276.69	0.46	982.72±209.90	1768.70±209.90	2180.28±209.90	0.40
16:1 trans-9	27.83±6.69	17.07±6.69	19.59±6.99	21.79±6.99	0.56	16.99±5.92	12.63±5.92	35.09±5.92	0.001
16:1 cis-9	167.41±37.51	160.41±37.51	181.46±38.61	232.47±38.61	0.71	98.58±23.18	183.03±23.18	274.70±23.18	0.03
17:0	76.96±14.79	80.64±14.79	75.76±15.09	94.55±15.09	0.80	41.53±10.38	89.51±10.38	114.89±10.38	0.001
17:1 cis-9	67.85±57.34	56.42±57.34	45.28±59.30	179.26±59.30	0.40	45.43±49.19	46.81±49.19	169.33±49.19	0.14
18:0	1044.48±208.40	1170.65±208.40	1096.88±213.98	1380.20±213.98	0.70	634.45±149.21	1360.12±149.21	1524.59±149.21	0.001
18:1 trans-9	21.11±7.18	17.64±7.18	13.98±7.50	23.11±7.50	0.74	2.81±6.36	24.58±6.36	31.74±6.36	0.01
18:1 cis-11	325.32±97.20	307.29±97.20	308.31±98.75	424.63±98.75	0.80	115.19±63.61	348.42±63.61	560.55±63.61	0.001
18:1 trans-7	81.29±12.58	88.67±12.58	84.06±12.96	102.01±12.96	0.68	51.95±8.56	94.44±8.56	120.64±8.56	0.001
18:1 cis-9	2208.76±420.64	2598.67±420.64	2494.72±434.02	2999.58±434.02	0.64	1480.71±283.86	2789.88±283.86	3455.70±283.86	0.001
18:2 trans-10,12	20.04±4.90	17.78±4.90	19.33±5.06	23.91±5.06	0.84	0.59±4.12	29.59±4.12	30.61±4.12	0.001
18:2 cis-9,12	143.54±18.06	189.63±18.06	169.20±18.61	205.51±18.61	0.17	120.48±13.22	186.35±13.22	223.90±13.22	0.001
18:3 cis-9,12,15	61.56±4.89	61.60±4.89	70.43±5.11	60.75±5.11	0.52	45.84±4.06	64.02±4.06	80.89±4.06	0.001
20:3 cis-8,11,14	10.21±2.66	16.44±2.66	11.43±2.78	11.38±2.78	0.41	6.68±2.36	19.86±2.36	10.56±2.36	0.003
20:4cis- 5,8,11,14	55.88±3.72	57.65±3.72	55.08±3.89	60.20±3.89	0.79	58.39±2.29	56.61±2.29	56.69±2.29	0.65
22:5cis-7,10,13,16,19	82.57±25.77	33.16±25.77	42.50±26.91	35.42±26.91	0.52	28.82±22.50	72.62±22.50	43.81±22.50	0.39

[1] Diets consist of: ryegrass pasture (RY), ryegrass pasture + Tasco (RT), ryegrass pasture + concentrate (RC) and ryegrass pasture + Tasco + concentrate (RTC); n = 12, 11, 12 and 11; respectively for treatment means and 46 for each postmortem ageing period mean

[2] Days of vacuum-packaged postmortem ageing at 4°C

[c,d,e] Means within the same row with different letters differ $P < 0.05$.

Table 9. Least square means ± SEM for longissimus muscle fatty acid composition (diet/health/summary factors) reported as mg /100 g of tissue from steers finished on winter annual ryegrass supplemented with or without Tasco and/or concentrate.

Fatty acid	Diet					Postmortem Ageing Treatment			
	RY[1]	RC[1]	RT[1]	RTC[1]	P > F	PM d 2[2]	PM d 20[2]	PM d 34[2]	P > F
EPA[3]	186.44±85.63	16.73±85.63	24.08±89.40	12.72±89.40	0.45	15.97±75.60	140.95±75.60	22.06±75.60	0.43
CLA[4]	144.46±41.00	68.03±41.00	76.52±42.78	76.55±42.78	0.55	34.05±35.17	128.52±35.17	111.61±35.17	0.15
SFA[4]	2893.04±534.36	2994.93±534.36	2962.45±547.69	3822.79±547.69	0.60	1788.76±377.36	3523.58±377.36	4192.55±377.36	0.002
MUFA[4]	2987.79±527.52	3480.05±527.52	3674.20±547.24	3705.51±547.24	0.76	1848.70±416.23	3914.98±416.23	4621.99±416.23	0.003
PUFA[4]	379.41±39.82	430.50±39.82	440.41±40.86	452.77±40.86	0.60	313.78±27.65	436.11±27.65	527.43±27.65	0.001
n-6[5]	196.12±20.95	250.96±20.95	224.79±21.58	264.37±21.58	0.18	187.81±15.60	246.55±15.60	267.81±15.60	0.002
n-3[5]	112.26±7.45	111.50±7.45	137.02±7.78	108.90±7.78	0.10	90.64±6.60	114.87±6.60	146.76±6.60	0.001
n-6:n-3	1.81±0.23	2.45±0.23	1.69±0.24	2.58±0.24	0.06	2.24±0.19	2.31±0.19	1.84±0.19	0.18
PUFA:SFA	0.15±0.04	0.19±0.04	0.19±0.04	0.23±0.04	0.66	0.26±0.03	0.16±0.03	0.15±0.03	0.09
Total FA[5]	6267.61±1124.71	6835.43±1124.71	7073.77±1159.28	8324.70±1159.28	0.48	3852.24±788.98	7948.98±788.98	9574.91±788.98	0.34

[1] Diets consist of: ryegrass pasture (RY), ryegrass pasture + Tasco (RT), ryegrass pasture + concentrate (RC) and ryegrass pasture + Tasco + concentrate (RTC); n = 12, 11, 12 and 11; respectively for treatment means and 46 for each postmortem ageing period mean

[2] Days of vacuum-packaged postmortem ageing at 4°C

[3] EPA: eicosapentanoic acid, 20:5 cis-5,8,11,14,17

[4] CLA: conjugated linoleic acid – 18:2 cis-9, trans-11, SFA: saturated fatty acids, MUFA: monounsaturated fatty acids, PUFA: polyunsaturated fatty acids.

[5] n-6 fatty acids include:18:2c10,12, 18:2c9,12, 20:2c11,14, 20:3c8,11,14, 20:4c5,8,11,14, 22:4c7,10,13,16. n-3 fatty acids include 183c0,12,15, 20:5c5,8,11,14,17, 22:5c7,10,13,16,19.

[6] Total FA includes fatty acids from figures 1, 2 and 3.

Figure 1. Least square means ± SEM for visual lean color of striploin steaks by retail display day within postmortem ageing days from steers finished on winter annual ryegrass supplemented with or without Tasco and/or concentrate. Diets consist of: ryegrass pasture (RY), ryegrass pasture + Tasco (RT), ryegrass pasture + concentrate (RC) and ryegrass pasture + Tasco + concentrate (RTC); n = 12, 11, 12 and 11; respectively for diet means. T = treatment regimen, DD = days of simulated retail display and PM = days of postmortem ageing. [1]Lean color (1 = extremely dark red; 8 = extremely bright cherry-red)

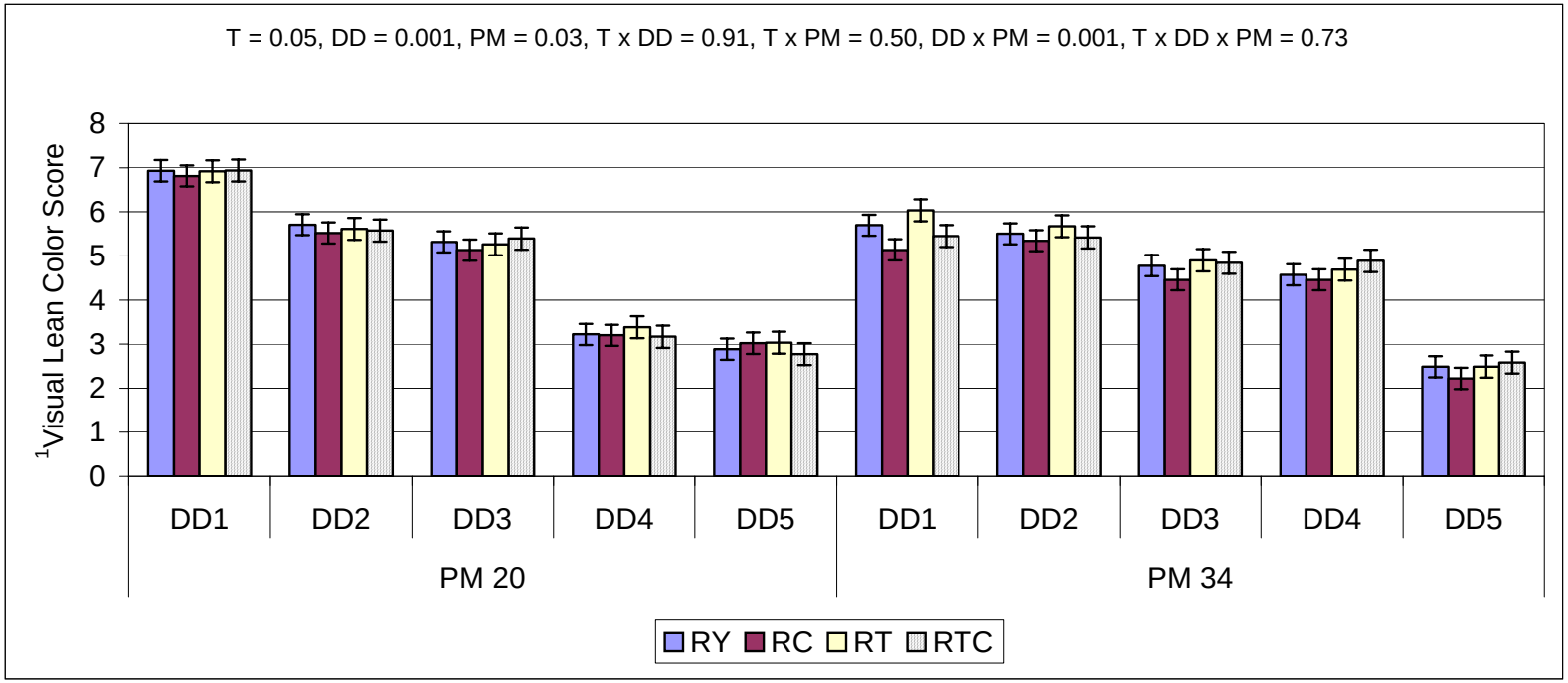


Figure 2. Least square means ± SEM for visual lean uniformity of striploin steaks by retail display day within postmortem ageing days from steers finished on winter annual ryegrass supplemented with or without Tasco and/or concentrate. Diets consist of: ryegrass pasture (RY), ryegrass pasture + Tasco (RT), ryegrass pasture + concentrate (RC) and ryegrass pasture + Tasco + concentrate (RTC); n = 12, 11, 12 and 11; respectively for diet means. T = Treatment, DD = days of simulated retail display and PM = days of postmortem ageing [1]Lean color uniformity (1 = uniform; 5 = extreme two-toning)

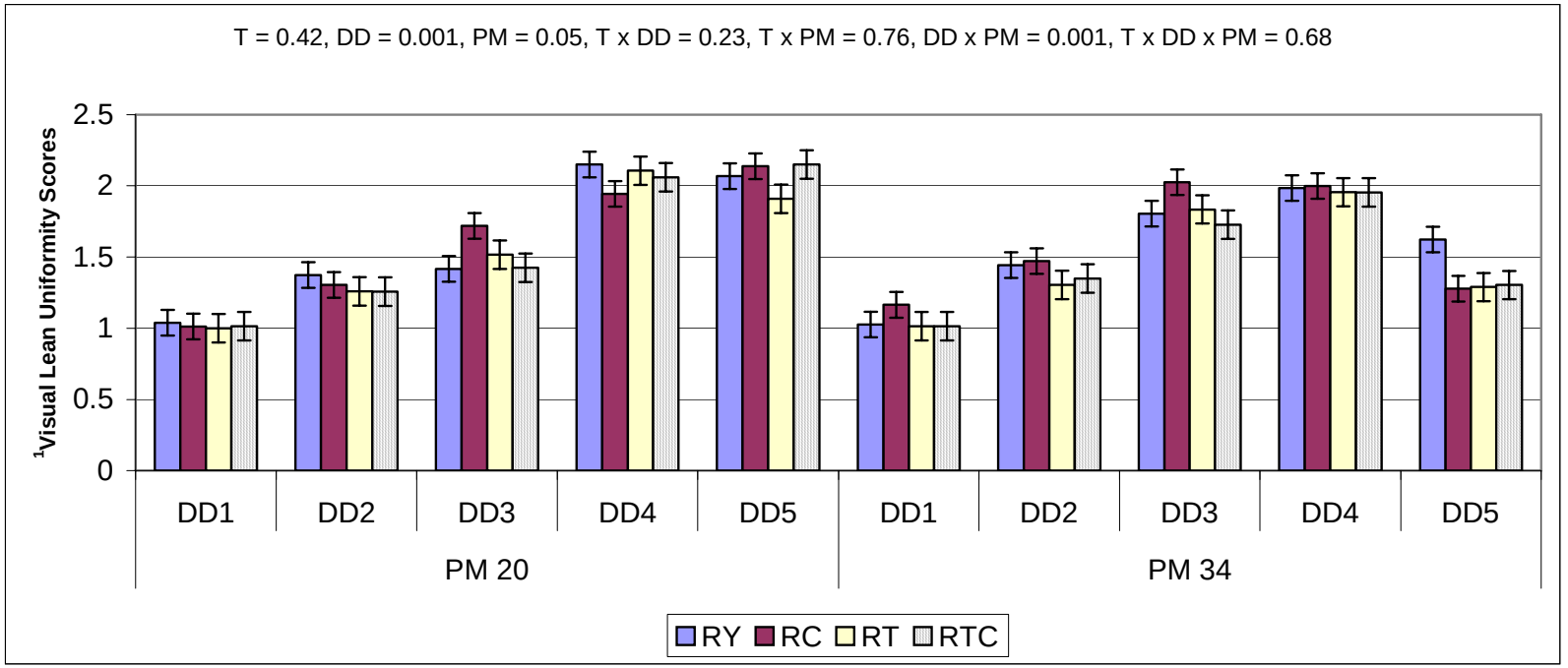


Figure 3. Least square means ± SEM for visual lean discoloration of striploin steaks by retail display day within postmortem ageing days from steers finished on winter annual ryegrass supplemented with or without Tasco and/or concentrate. Diets consist of: ryegrass pasture (RY), ryegrass pasture + Tasco (RT), ryegrass pasture + concentrate (RC) and ryegrass pasture + Tasco + concentrate (RTC); n = 12, 11, 12 and 11; respectively for diet means. T = Treatment, DD = days of simulated retail display and PM = days of postmortem ageing; [1]Lean discoloration (1 = none; 7 = total discoloration)

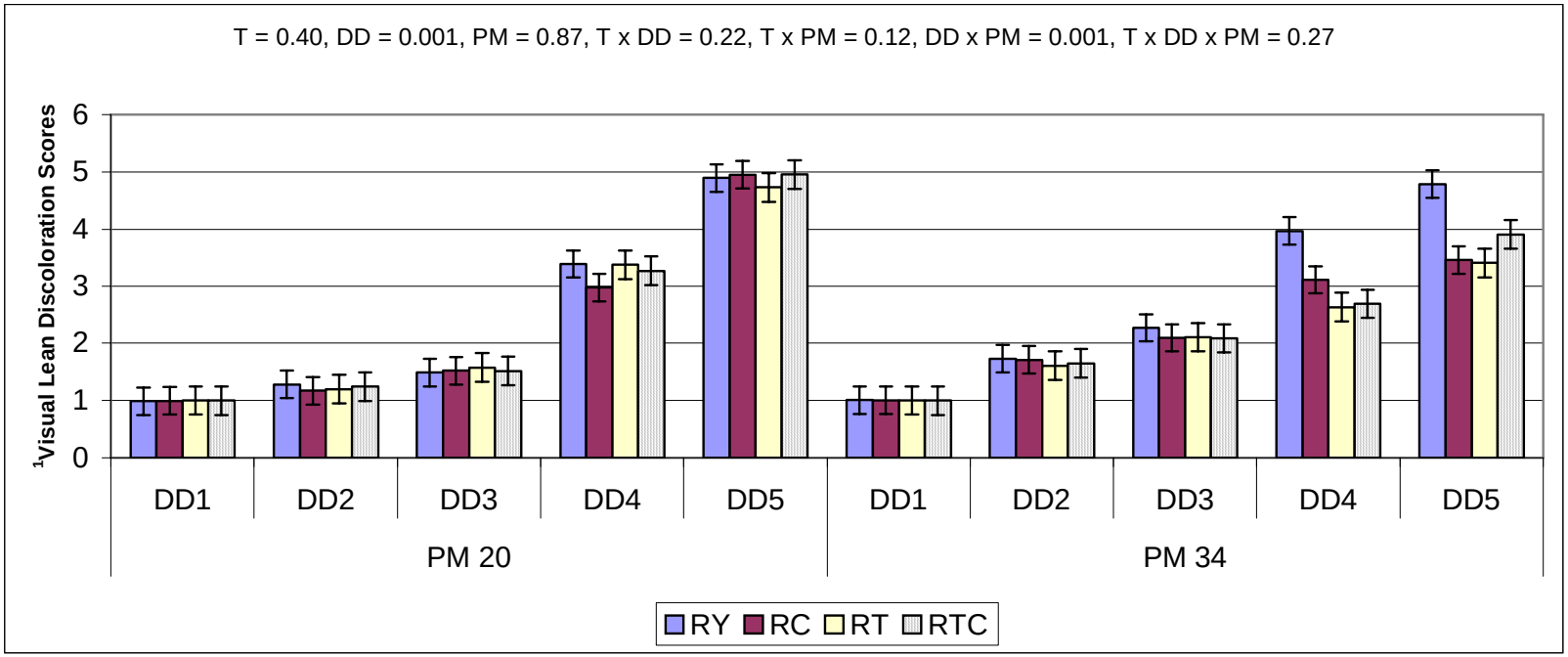


Figure 4. Least square means ± SEM for visual lean browning of striploin steaks by retail display day within postmortem ageing days from steers finished on winter annual ryegrass supplemented with or without Tasco and/or concentrate. Diets consist of: ryegrass pasture (RY), ryegrass pasture + Tasco (RT), ryegrass pasture + concentrate (RC) and ryegrass pasture + Tasco + concentrate (RTC); n = 12, 11, 12 and 11; respectively for diet means. T = Treatment, DD = days of simulated retail display and PM = days of postmortem ageing; [1]Lean browning (1 = none; 8 = dark brown)

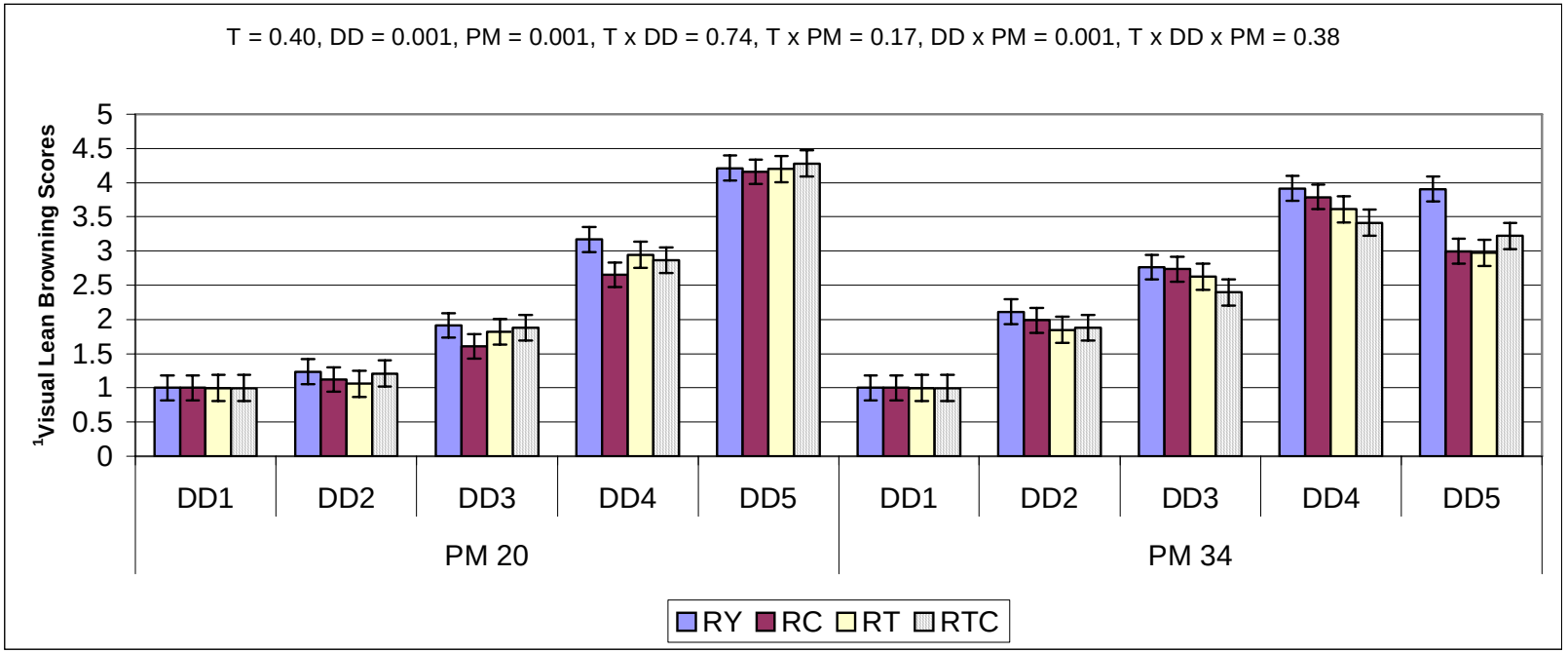


Figure 5. Least square means ± SEM for CIE L* instrumental values of striploin steaks by retail display day within postmortem ageing days from steers finished on winter annual ryegrass supplemented with or without Tasco and/or concentrate. Diets consist of: ryegrass pasture (RY), ryegrass pasture + Tasco (RT), ryegrass pasture + concentrate (RC) and ryegrass pasture + Tasco + concentrate (RTC); n = 12, 11, 12 and 11; respectively for diet means. T = Treatment, DD = days of simulated retail display and PM = days of postmortem ageing; [1]CIE L* Value (increasing value indicates a lighter color)

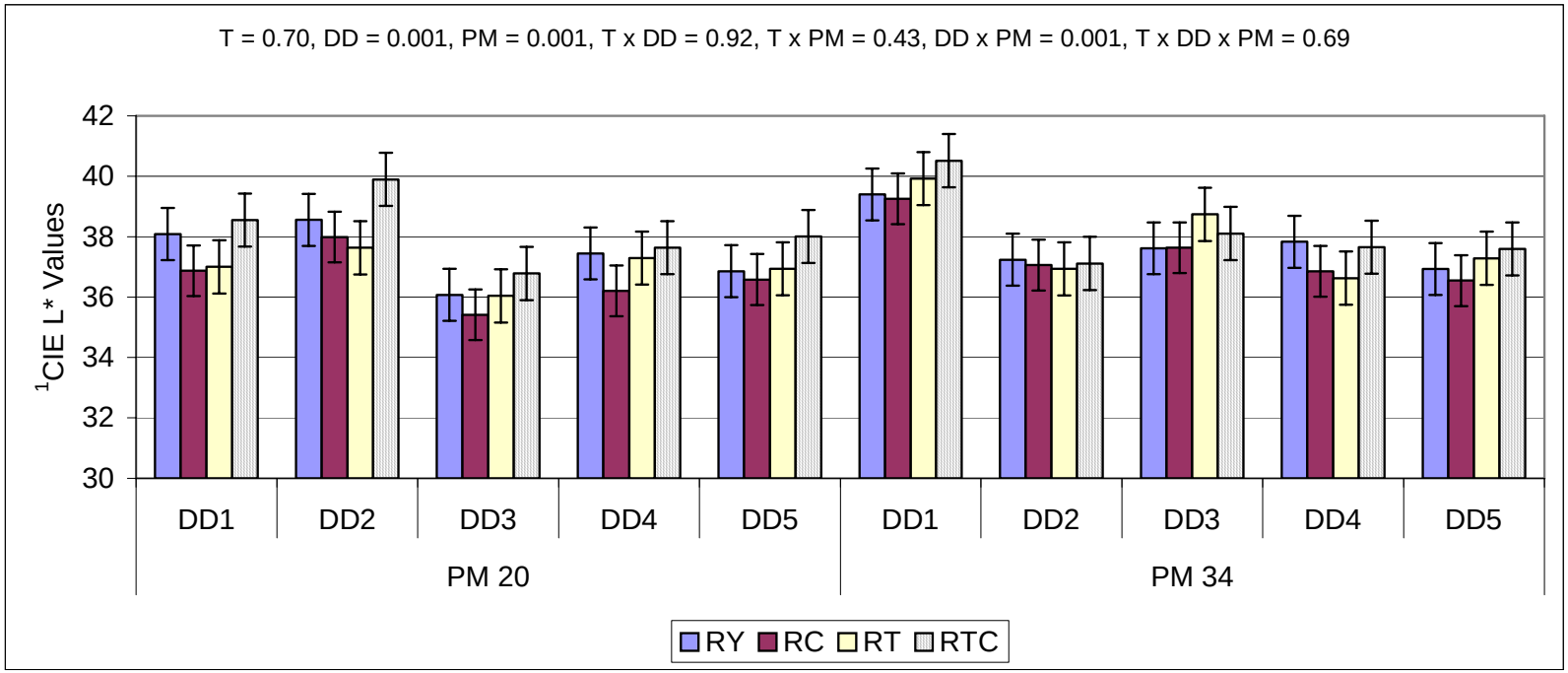


Figure 6. Least square means ± SEM for CIE a* instrumental values of striploin steaks by retail display day within postmortem ageing days from steers finished on winter annual ryegrass supplemented with or without Tasco and/or concentrate. Diets consist of: ryegrass pasture (RY), ryegrass pasture + Tasco (RT), ryegrass pasture + concentrate (RC) and ryegrass pasture + Tasco + concentrate (RTC); n = 12, 11, 12 and 11; respectively for diet means. T = Treatment, DD = days of simulated retail display and PM = days of postmortem ageing; [1]CIE a* Value (positive = red, 0 = neutral, negative = green)

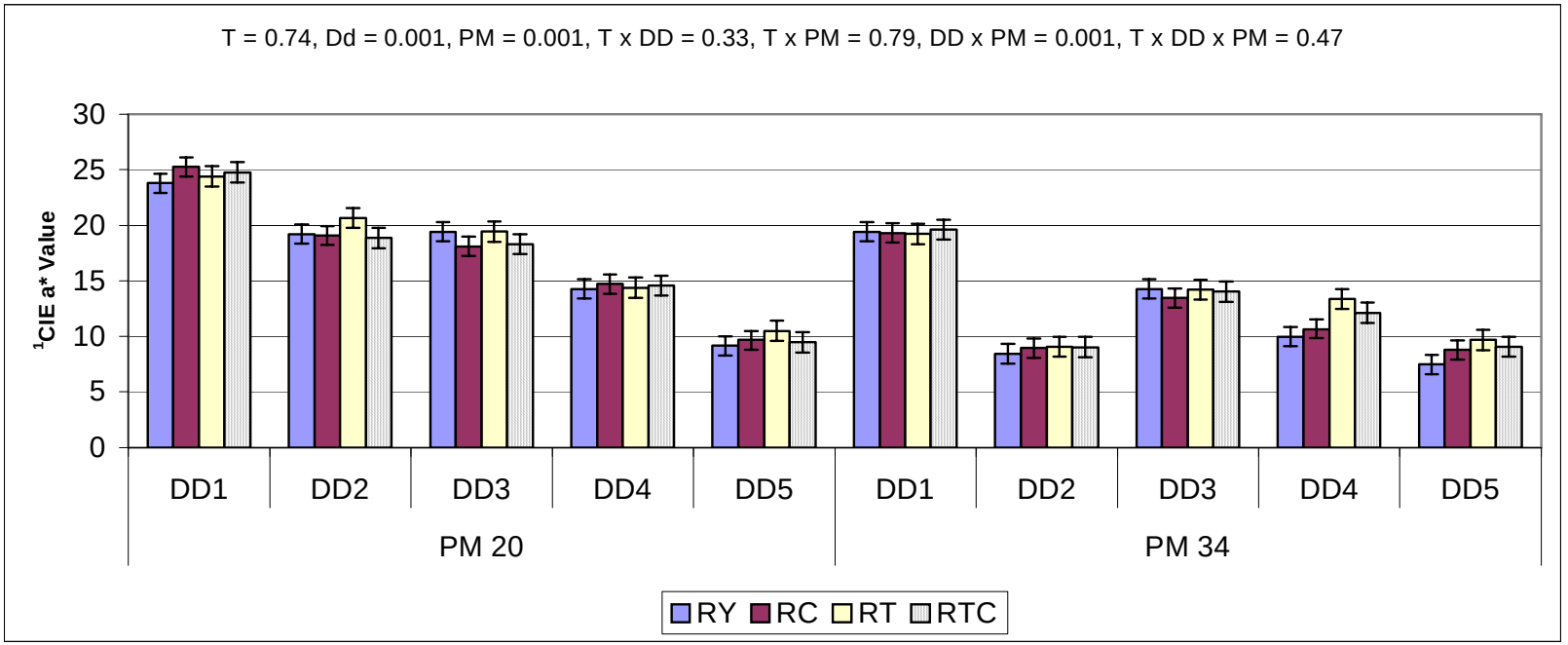


Figure 7. Least square means ± SEM for CIE b* instrumental values of striploin steaks by retail display day within postmortem ageing days from steers finished on winter annual ryegrass supplemented with or without Tasco and/or concentrate. Diets consist of: ryegrass pasture (RY), ryegrass pasture + Tasco (RT), ryegrass pasture + concentrate (RC) and ryegrass pasture + Tasco + concentrate (RTC); n = 12, 11, 12 and 11; respectively for diet means. T = Treatment, DD = days of simulated retail display and PM = days of postmortem ageing; [1]CIE b* Value (positive = yellow, 0 = neutral, negative = blue)

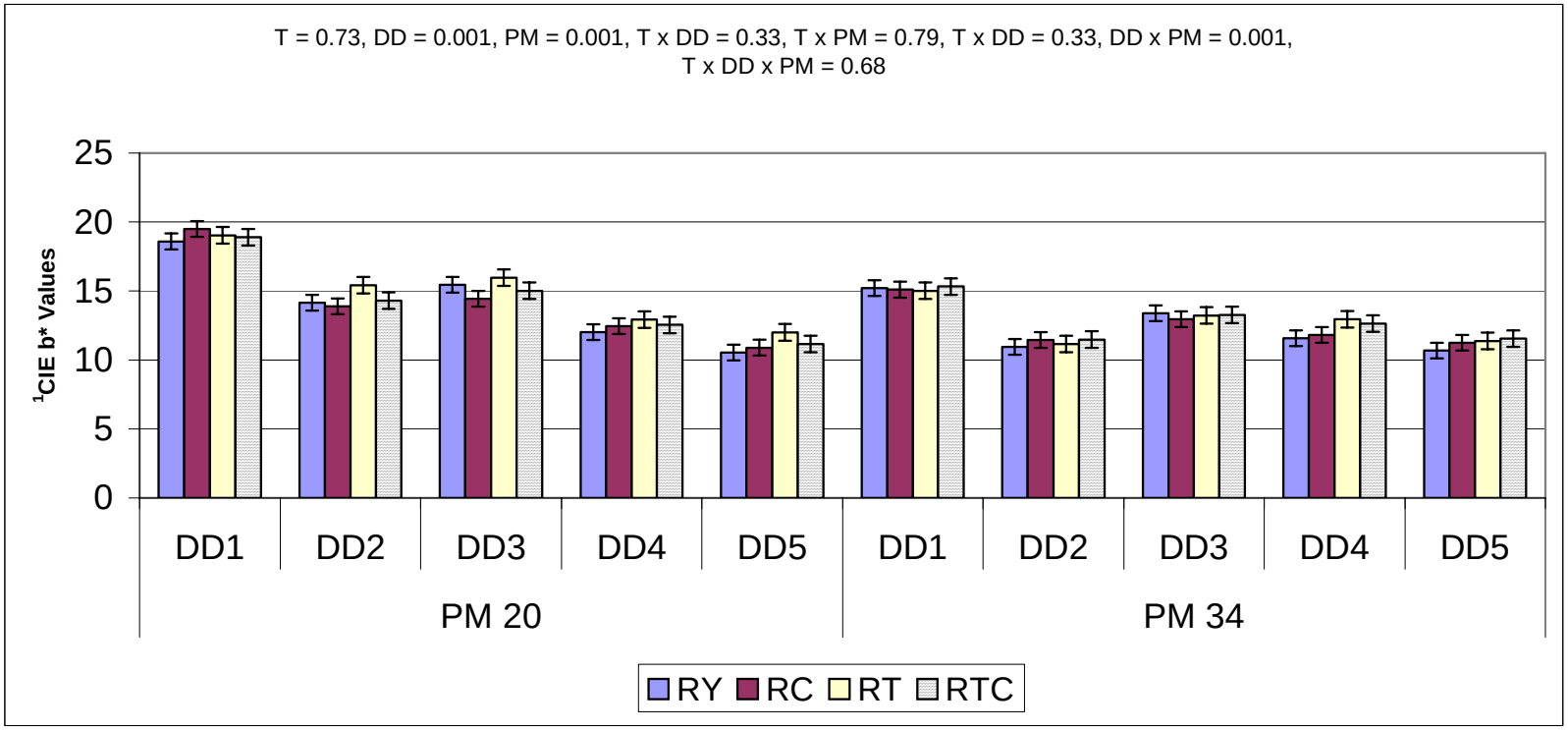


Figure 8. Least square means ± SEM for lean Chroma instrumental values of striploin steaks by retail display day within postmortem ageing days from steers finished on winter annual ryegrass supplemented with or without Tasco and/or concentrate. Diets consist of: ryegrass pasture (RY), ryegrass pasture + Tasco (RT), ryegrass pasture + concentrate (RC) and ryegrass pasture + Tasco + concentrate (RTC); n = 12, 11, 12 and 11; respectively for diet means. T = Treatment, DD = days of simulated retail display and PM = days of postmortem ageing; [1]Lean Chroma Value (numerically increasing color saturation)

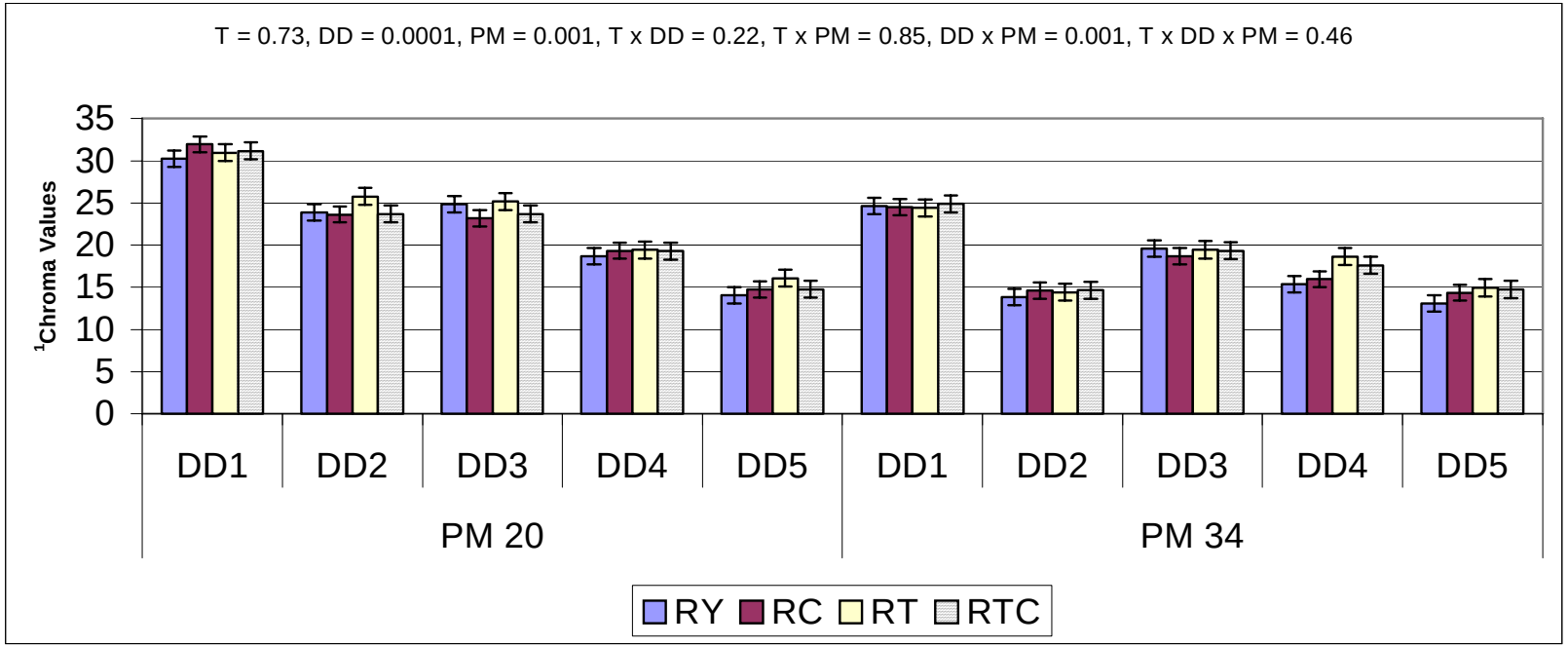


Figure 9. Least square means ± SEM for lean Hue instrumental values of striploin steaks by retail display day within postmortem ageing days from steers finished on winter annual ryegrass supplemented with or without Tasco and/or concentrate. Diets consist of: ryegrass pasture (RY), ryegrass pasture + Tasco (RT), ryegrass pasture + concentrate (RC) and ryegrass pasture + Tasco + concentrate (RTC); n = 12, 11, 12 and 11; respectively for diet means. T = Treatment, DD = days of simulated retail display and PM = days of postmortem ageing; [1]Lean Hue Value (numerically increasing true red color)

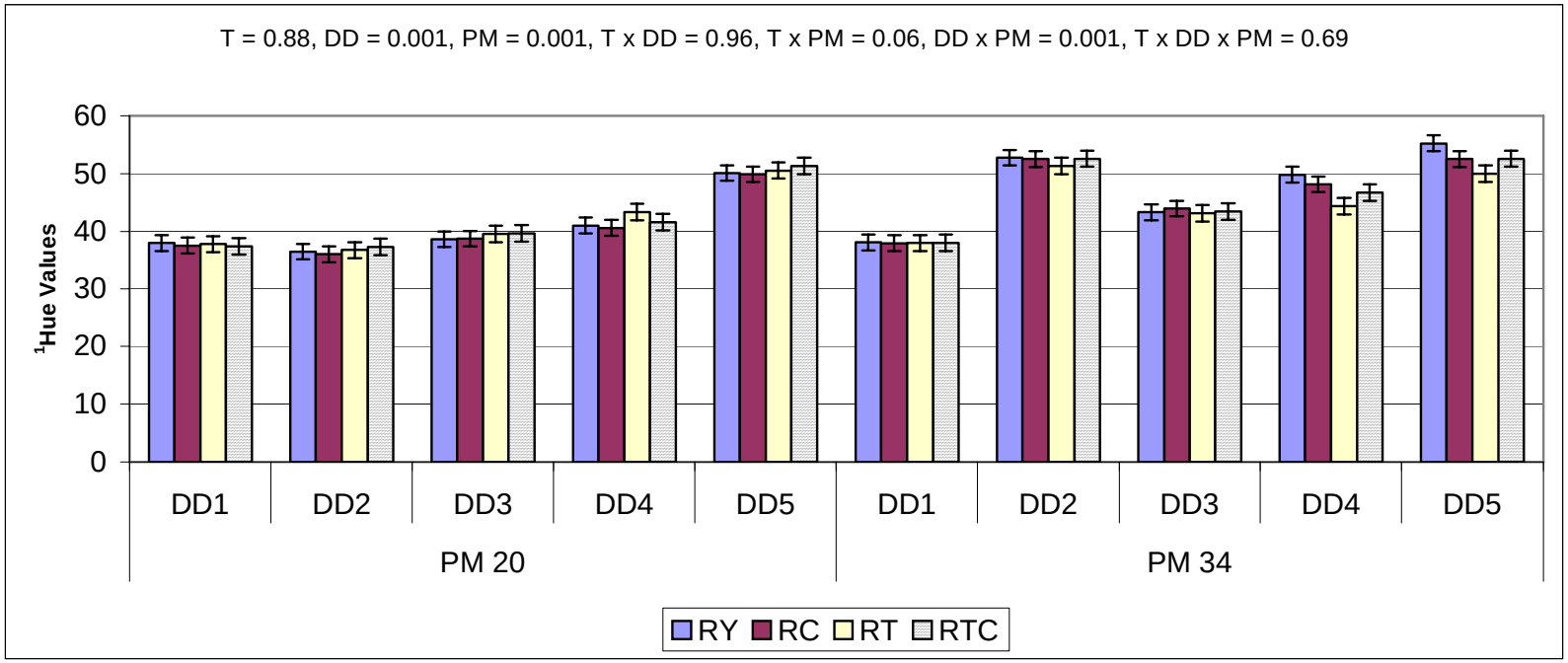


Figure 10. Least square means ± SEM percent myoglobin instrumental values of striploin steaks by retail display day within postmortem ageing days from steers finished on winter annual ryegrass supplemented with or without Tasco and/or concentrate. Diets consist of: ryegrass pasture (RY), ryegrass pasture + Tasco (RT), ryegrass pasture + concentrate (RC) and ryegrass pasture + Tasco + concentrate (RTC); n = 12, 11, 12 and 11; respectively for diet means. T = Treatment, DD = days of simulated retail display and PM = days of postmortem ageing; [1]Myoglobin percentage (fresh muscle pigment)

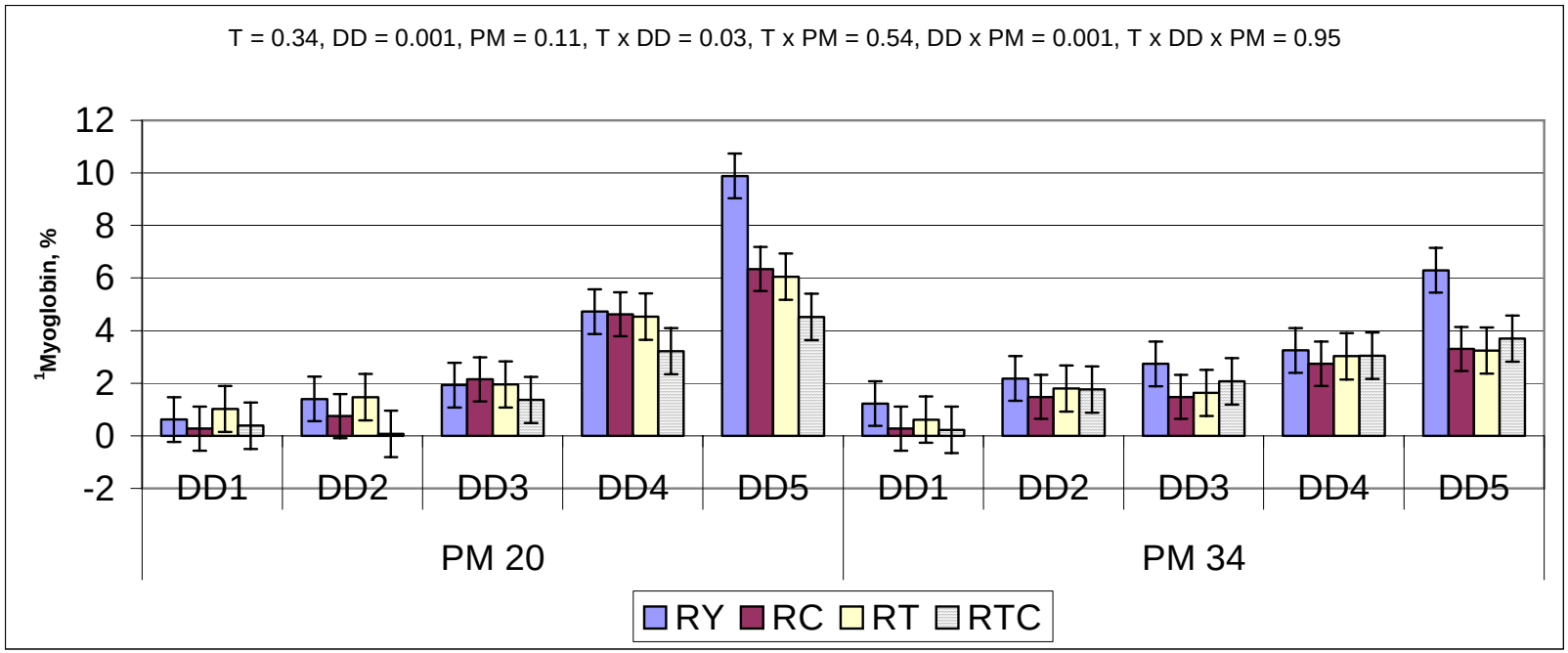


Figure 11. Least square means ± SEM for lean oxymyoglobin instrumental values of striploin steaks by retail display day within postmortem ageing days from steers finished on winter annual ryegrass supplemented with or without Tasco and/or concentrate. Diets consist of: ryegrass pasture (RY), ryegrass pasture + Tasco (RT), ryegrass pasture + concentrate (RC) and ryegrass pasture + Tasco + concentrate (RTC); n = 12, 11, 12 and 11; respectively for diet means. T = Treatment, DD = days of simulated retail display and PM = days of postmortem ageing; [1]Oxymyoglobin percentage (oxygenated myoglobin pigment)

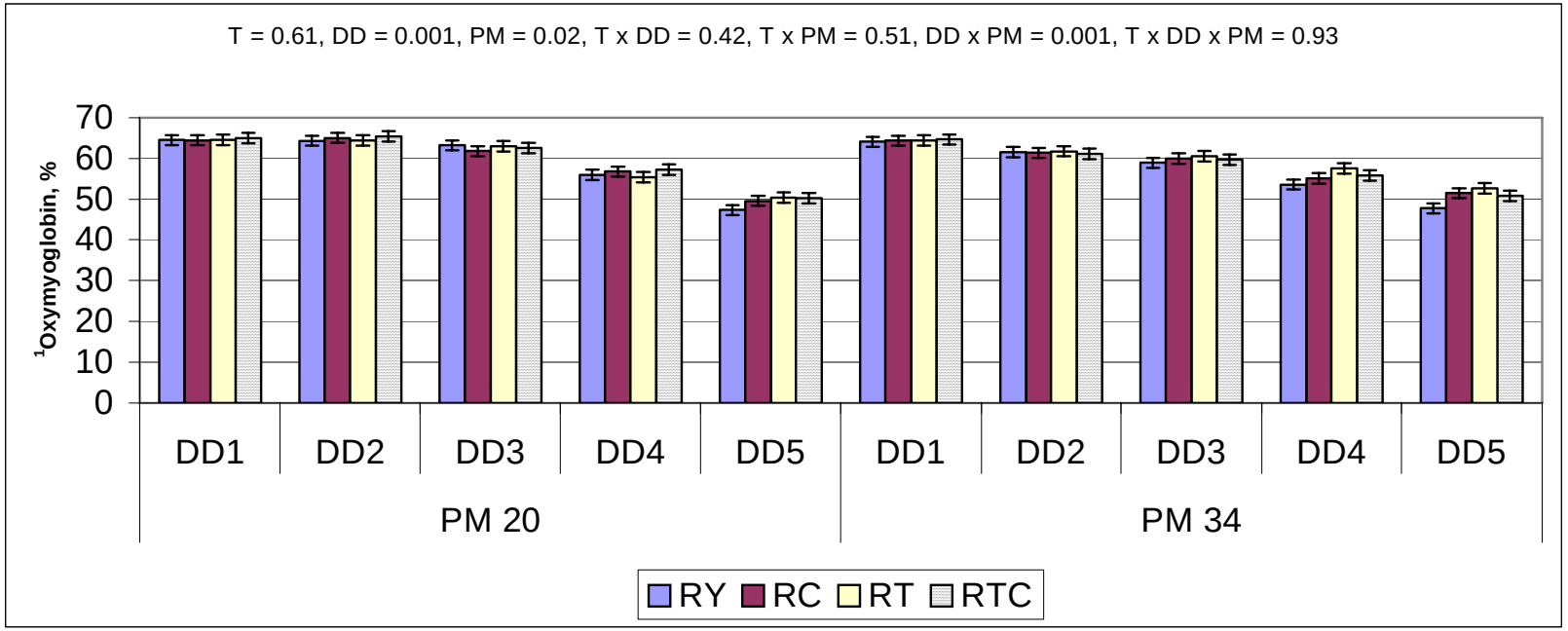


Figure 12. Least square means ± SEM for lean metmyoglobin instrumental values of striploin steaks by retail display day within postmortem ageing days from steers finished on winter annual ryegrass supplemented with or without Tasco and/or concentrate. Diets consist of: ryegrass pasture (RY), ryegrass pasture + Tasco (RT), ryegrass pasture + concentrate (RC) and ryegrass pasture + Tasco + concentrate (RTC); n = 12, 11, 12 and 11; respectively for diet means. T = Treatment, DD = days of simulated retail display and PM = days of postmortem ageing; [1]Metmyoglobin percentage (oxidized myoglobin pigment)

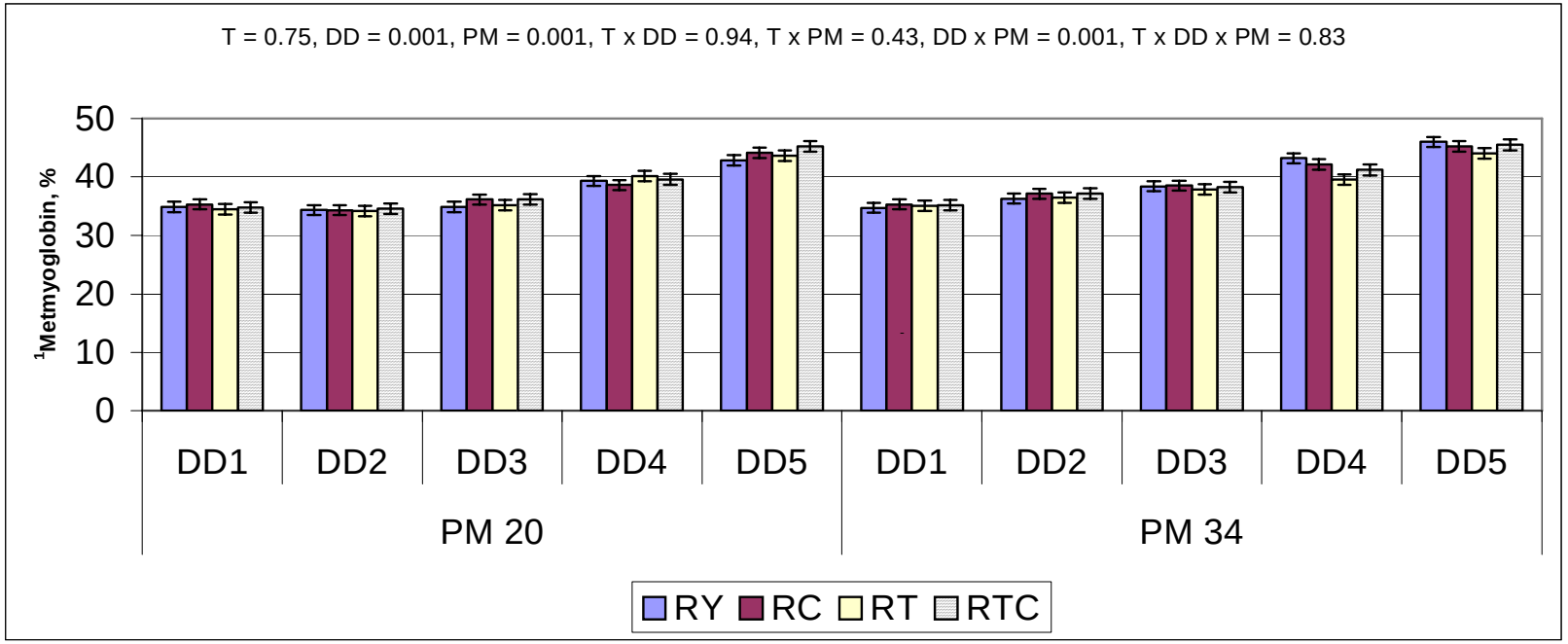
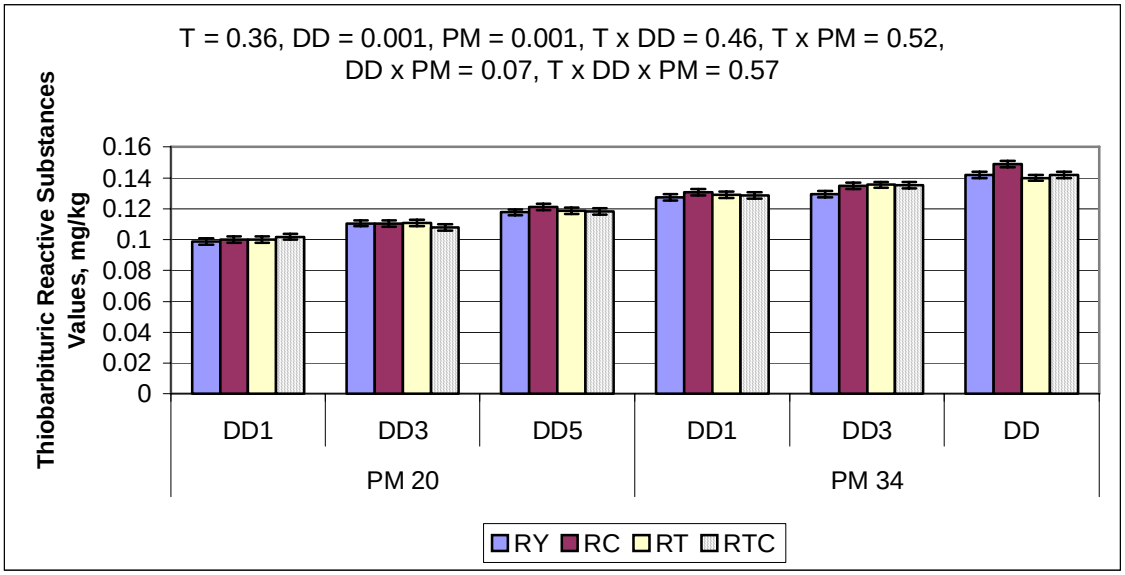


Figure 13. Least square means ± SEM for thiobarbituric reactive substance values of striploin steaks by retail display day within postmortem ageing days from steers finished on winter annual ryegrass supplemented with or without Tasco and/or concentrate. Diets consist of: ryegrass pasture (RY), ryegrass pasture + Tasco (RT), ryegrass pasture + concentrate (RC) and ryegrass pasture + Tasco + concentrate (RTC). T = Treatment, DD = days of simulated retail display and PM = days of postmortem ageing; n = 12, 11, 12 and 11; respectively for diet means



V. CONCLUSION AND IMPLICATIONS

Forage-finishing strategies have been examined as an alternative means for finishing and producing beef since the late 1960s and has meet with little sustainable success. However, the emergence of specific niche markets for products with a functional food claim in terms of production and product characteristics may increase the demand for beef produced in forage systems. Several consumer surveys have indicated a moderate demand for forage-finished beef. Consumers, preferring forage-finished beef, were willing to pay a premium to purchase products produced in a forage-based system.

Finishing-diet composition significantly affects animal performance, product quality, product color, and dietetic quality of beef. A number of production and product attribute barriers are commonly associated with forage-finished beef production. Forage-finished beef has generally been found to have an undesirable affect on animal performance, product palatability, retail shelf-life and lipid stability. However, in response to a number of consumer concerns and demand, forage-finished beef has re-emerged as a niche market alternative. Beef from forage-based finishing systems has a higher amount of polyunsaturated fatty acids (PUFA), more specifically *n*-3 PUFA, compared with concentrate-finished beef and the targeted ratio of *n*-6/*n*-3 PUFA is commonly attained in forage-finished beef (Enser et al., 1998). Appropriate *n*-6/*n*-3

PUFA ratios (below 4) and increased CLA intake have been shown to prevent human disease (Gatellier et al., 2005; Simopoulous, 1991).

Lipids from forage-finished beef contain high levels of PUFA which are more prone to being attacked by free radicals. The oxidation of lipids in meat is one of the most significant aspects of loss in flavor quality and the formation of rancid and lean discoloration characteristics.

Negative animal and carcass attributes associated with forage-finishing could prove detrimental to forage-finishing strategies. A method to improve forage-finished beef carcass and product quality would serve to improve the efficiency and sustainability of forage-finishing systems. Tasco, a proprietary product derived from the dried brown seaweed *Ascophyllum nodosum* has been shown in various instances to increase marbling score and certain measures of retail display shelf life

The results of this study indicate that finishing steers on winter annual ryegrass with added supplemental concentrate increases fat b* values (yellowness) when compared to animal fed all or increasing amounts of concentrate. Finishing steers on a forage based diet produced beef with increased health aspects of fatty acids such as omega 3, omega 6:omega 3 ratio and conjugated linoleic acid. Finishing cattle on winter annual ryegrass increased shelf-life and decreased measures of lipid oxidation regardless of supplementation. Therefore, finishing steers on forages with added concentration may be employed as an alternative finishing system without negatively impacting, or possible increasing, measures of fatty acid profile, retail shelf-life or lipid stability.

Additionally, Tasco meal supplementation, in a free-choice mineral affected few of the animal performance, forage, and product related characteristics examined in the

present study. It would seem plausible to evaluate the effective supplementation level and delivery method of Tasco in a forage-finishing diet by when comparing to previous research conclusions with Tasco meal. To determine possible Tasco effects in forage-finishing diets future studies may need to determine effective intake levels.

LITERATURE CITED

Abdullah, M., T. D. Bidner, J. C. Carpenter, Jr., A. R. Schupp, J. E. Pontif and K. L. Koonce. 1979. Forage-Fed Versus Short-Fed Beef as Influenced by Breed Type. Livestock Producers' Day Report. Louisiana State University. Vol. 19:146-151

Allen, V. G., J. P. Fontenot, R. F. Kelly and D. R. Notter. 1996. Forage Systems for Beef Production from Conception to Slaughter: III. Finishing Systems. J. Anim. Sci. 74:625-638

Allen, V. G., K. R. Pond, K. E. Saker, J. P. Fontenot, C. P. Bagley, R. L. Ivy, R. R, Evans, R. E. Schmidt, J. H. Fike, X. Zhang, J. Y. Ayad, C. P. Brown, M. F. Miller, J. L. Montgomery, J. Mahon, D. B. Wester and C. Melton. 2001a. Tasco: Influence of a brown seaweed on antioxidants in forages and livestock – A review. J. Anim. Sci. 79(E. Suppl.):E.21-31

Allen, V. G., K.R. Pond, K.E. Saker, J.P. Fontenot, C.P. Bagley, R.L. Ivy, R.R. Evans, C.P. Brown, M.F. Miller, J.L. Montgomery, T.M. Dettle and D.B. Wester. 2001b. Tasco-Forage: III. Influence of a seaweed extract on performance, monocyte immune cell response, and carcass characteristics in feed-lot finished steers. J. Anim. Sci. 79:1032-1040.

AMSA. 1991. Guidelines for meat color evaluation. Proc. Reciprocol Meat Conference.,

AMSA. 1995. Research guidelines for cookery, sensory evaluation and instrumental tenderness measurement of fresh meat. National Livestock and Meat Board, Chicago, IL.

AOAC. 1998. Official methods of analysis. 15th ed. Assoc. Offic. Anal. Chem., Arlington, VA

Arnold, R. N., S. C. Arp, K. K. Scheller, S. N. Williams and D. M. Schaefer. 1993. Tissue equilibration and subcellular distribution of vitamin E relative to myoglobin and lipid oxidation in displayed beef. J. Anim. Sci. 71:105-118.

Arnold, R. N., K. K. Scheller, S. C. Arp, S. N. Williams and D. M. Schaefer. 1993. Dietary alpha-tocopherol acetate enhances beef quality in Holstein and beef breed steers. J. Food Sci. 58:28.

Ayad, J. Y. 1998. The effect of seaweed (Ascophyllum nodosum) extract on antioxidant activities and drought tolerance of tall fescue (Festuca arundinacea Schreb.). Ph.D. dissertation. Texas Tech University, Lubbock.

Bagley, C. P., and J. I. Feazel. 1987. Production, economics and acceptability of forage-fed beef. La. Agric. Exp. Sta. Bull. 295-301.

Bagley, C. P., G. M. Hill, J. W. Knox, D. F. Coombs, W. M. Oliver, A. F. Loyacano, W. E. Wyatt, D. C. Huffman, K. W. McMillin, and T .D. Binder. 1988. Using forages to produce stocker and finished beef year-round. La Agric. Exp. Sta. Bull. 17-19.

Bagley, C. P., G. M. Hill, J. W. Knox, D. F. Coombs, W. M. Oliver, A. F. Loyacano, W. E. Wyatt, D. C. Huffman, K. W. McMillin, T. D. Bidner and A. M. Saxton. 1990. Year-Round Production of Beef Using Maximum Levels of Forages. I. Stocker Phase. App. Agric. Res. Vol. 5 No. 4:309-314

Bastian, C. 2002. The New Beef Industry: What Will It Mean To Feeder Cattle Producers? *Managing For Today's Cattle Market*. Published jointly by University of Wyoming Cooperative Extension, Utah State University Cooperative Extension, University of Nebraska Cooperative Extension and Farm Foundation. Laramie, Wyoming. 1996. Web address: http://agecon.uwyo.edu/marketing/mngtcmkt/default

Baumann, D.E., Baumgard, L.H., Corl, B.A., and J.M. Griinari. 1999. Biosynthesis of conjugated linoleic acid in ruminants. Proc. ASAS

Bennett, L. L., A. C. Hammond, M. J. Williams, W. E. Kunkle, D. D. Johnson, R. L. Preston and M. F. Miller. 1995. Performance, carcass yield, and carcass quality characteristics of steers finished on rhizome peanut (Arachis glabrata)-tropical grass pasture or concentrate. J. Anim. Sci. 73:1881-1887.

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.

Bidner, T. D., A. R. Schupp, R. E. Montgomery and J. C., Jr. Carpenter. 1981. Acceptability of beef finished on all-forage, forage-plus-grain or high energy diets. J. Anim. Sci. 53:1181-1187.

Bodine, T. N., and H. T. Purvis II. 2003. Effects of supplemental energy and/or degradable intake protein on performance, grazing behavior, intake, digestibility, and fecal and blood indices by beef steers grazed on dormant native tallgrass prairie. J. Anim. Sci. 81:304-317.

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. J. Anim. Sci. 46:333-340.

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

Braden, K.W.B. 2003. Effects of 2% Ascophyllum nodosum on Carcass Characteristics, Retail Display and Microbial Loads of Feedlot Steers. M.S. Thesis. Texas Tech Univ., TX

Bransby, D. I., A. G. Matches, and G. F. Krause. 1977. Disk meter for rapid estimation of herbage yield in grazing trials. Agron. J. 69:393-396.

Bransby, D. I., M. Pegues, and R. Rawls. 1997. Marshall ryegrass dramatically superior under grazing. Highlights of Agric. Res. (Alabama Agric. Exp. Stn.) 44 (No. 2):12-14.

Brown, H. G., S. L. Melton, M. J. Riemann and W. R. Backus. 1979. Effects of energy intake and feed source on chemical changes and flavor of ground beef during frozen storage. J. Anim. Sci. 48:338.

Brown, W. L. 1954. Beef carcass characteristics as influenced by grass and other roughages. Proc. Recip. Meat Conf. 7:199.

Bryant, H. T., R. C. Hammes, Jr., R. E. Blaser and J. P. Fontenot. 1965. Effects of feeding grain to grazing steers to be fattened in drylot. J. Anim. Sci. 24:676.

Buckley, D. J., J. J. Gray, A. Asghar, J. F. Price, R. L. Crackel, A. M. Booren, A. M. Pearson and E. R. Miller. 1989. Effects of dietary antioxidants and oxidized oil on membranal lipid stability and pork product quality. J. Food Sci. 54:1193-1197.

Buege, J. A. and S. D. Aust. 1978. Assay of lipid oxidation in muscle samples. Methods in Enzymol. 52:305, AP

Buege, J. A. and S. D. Aust. 1978. Assay of lipid oxidation in muscle samples. Methods in Enzymol. 52:305, AP

Burriss, W. R., C. H. Hovermale and W. E. Brown. 1979. Wheat, rye or oats with ryegrass and crimson clover for winter grazing steer calves. Mississippi Agric. Forestry Exp. Sta. Res. Highlights 42:11.

Buttriss, J. L. and A. T. Diplock. 1984. High-performance liquid chromatography methods for vitamin E in tissues. Meth. Enzym. 105:131-138.

Camfield, P. K., A. H. Brown, Jr., Z. B. Johnson, C. J. Brown, P. K. Lewis, and L. Y. Rakes. 1999. Effects of growth type on carcass traits of pasture- or feedlot-developed steers. J. Anim. Sci. 77:2437-2443.

Campion, D. R., J. D. Crouse, and M. E. Dikeman. 1975. Predictive value of USDA beef quality grade factors for cooked meat palatability. J. Food Sci. 40:1225-1228.

Cassens, R. G., C. Faustman, and F. Jimenez-Colmenero. 1988. Modern Developments in research on colour of meat. In B. Krut, P. VanRoon and J. Houben (Eds.), Trends in modern meat technology 2 (pp. 2-11) Wageningen, The Netherlands:Pudoc.

Chan, W. K. M., K. Hakkarainen, C. Faustman, D. M. Schaefer, K. K. Scheller and Q. Liu. 1996. Dietary vitamin E effect on color stability and sensory assessment of spoilage in three beef muscles. Meat Sci. 42:387-399.

Chapman, V.J. 1950. Seaweeds and their uses. Methuen and Co., Ltd., London.

Chapman, V.J., and D.J. Chapman. 1980. Seaweeds and their uses. Chapman and Hall, London.

Chouinard, P. Y., Corneau, L., Baumann, D. E., Butler, W. R., Chillard, Y. and J. K. Drackley. 1998. Conjugated linoleic acid content of milk from cows fed different sources of dietary fat. J. Dairy Sci. 81(Suppl. 1):223 (Abstr.).

Church, D. C. 1988. The Ruminant Animal. Waveland Press, Inc., Prospect Heights, IL

Clydesdale, R. M. 1991. Color perception and food quality. J. Food Quality. 14:61-74.

Coombs, D. F., C. P. Bagley, G. M. Hill, J. W. Knox, A. F. Loyacano, W. M. Oliver, W. E. Wyatt, D. C. Huffman, K. W. McMillin, T. D. Bidner and A. M. Saxton. 1990. Year-round production of beef using maximum levels of forages. II. Finishing phase. Appl. Agric. Res. 5:315.+

Cox, R. B., C. R. Kerth, J. G. Gentry, J. W. Prevatt, K. W. Braden and W. R. Jones. 2006. Determining acceptance of domestic forage- or grain-finished beef by consumers from three southeastern USA states. J. Food Sci. Volume 71

Cross, H. R., R. Moen, and M. Stanfield. 1978. Guidelines for training and testing judges for sensory analysis of meat quality. Food Tech. 32:48.

Crouse, J. D., and S.C. Seideman. 1984. Effect of high temperature conditioning on beef from grass and grain fed cattle. J. Food Sci. 49:157-161.

Crouse, J. D., and G. M. Smith. 1978. Relationship of selected beef carcass traits with meat palatability. J. Food Sci. 43:152-157.

Dhiman, T. R. et al. 2005. Influence of Feeding Soybean Oil on Conjugated Linoleic Acid Content in Beef. J Agric. Food Chem. 53:684-389

Dinius, D. A., and H. R. Cross. 1978. Feedlot performance, carcass characteristics and meat palatability of steers fed concentrate for short periods. J. Anim. Sci. 47:1109-1113.

Duckett, S. K., D. G., Wagner, L. D. Yates, H. G. Dolezal and S. G. May. 1993. Effects of time on feed on beef nutrient composition. J. Anim. Sci. 71:2079-2088.

Eilers, J.D., J.D. Tatum, J.B. Morgan and G.C. Smith. 1996. Modification of Early-Postmortem Muscle pH and Use of Postmortem Aging to Improve Beef Tenderness. J Anim. Sci. 74:790-798.

Elmore, J.S., D.S. Mottram, M. Enser, J.D. Wood. 1999. Effect of the polyunsaturated fatty acid composition of beef muscle on the profile of aroma volatiles. J. Agric. Food Chem. 47:1619-1625.

Enser, M. 2000. Producing meat for healthy eating. (pp. 124-127) In Proc. 46th International Congress of Meat Science and Technology. 2.II-L4. Argentina, Buenos Aires

Enser, M., K. G. Hallett, B. Hewett, G. A. J. Fursey, J. D. Wood and G. Harrington. 1998. Fatty acid content and composition of UK beef and lamb muscle in relation to production systems and implications for human nutrition. Meat Sci. 49:329-341.

Faustman, C., R. G. Cassens, D. M. Schaefer, D. R. Buege, and K. K. Sheller. 1989. Vitamin E. supplementation of Holstein steer diets improves sirloin steak values. J. Food Sci. 54:485.

Faustman, C., W. K. M. Chan, P. M. Schaefer, and A. Havens. 1998. Beef color update: The role for vitamin E. J. Anim. Sci. 76:1019-1026.

Fiems, L. O., S. DeLampaneere, D. DeSmet, G. Van de Vaurde, J. M. Vanacker, and C. V. Baueque. 2000. Relationship between fat depots in carcasses of beef bulls and effect on meat carcasses and tenderness. Meat Science. 56:41-47.

Fike, J. H., V. G. Allen, R. E. Schmidt, X. Zhang, J. P. Fontenot, C. P. Bagley, R. L. Ivy, R. R. Evans, R. W. Coelho, and D. B. Wester. 2001. Tasco-Forage: I. Influence of a seaweed extract on antioxidant activity in tall fescue and in ruminants. J. Anim. Sci. 79:1011-1021.

Folch, J., M. Lees and G. H. Sloane-Stanley. 1957. A simple method for the isolation and purification of total lipids from animal tissues. J. Biol. Chem. 226:497-509.

Fontenot, J.P., V.G. Allen and F.P. Horn. 1985. Forages and slaughter cattle. In: M.E. Heath, R.F. Barnes and D.S. Metcalfe (ed.). Forages: The Science of Grassland Agriculture. p. 570. Iowa State University Press, Ames.

Fortin, A, D. M. Verio, D. A. Froehlich, G. Butler, and J. E. Proulx. 1985. Carcass Characteristics and Sensory properties of Hereford X Shorthorn bulls and steers fed different levels of grass silage and high moisture barley. J. Anim. Sci. 60:1403-1411.

Franklin, S. T., Martin, K. R., Baer, R. J., Schingoethe, D. J. and A. R. Hippen. 1999. Dietary marine algae (Schizochytrium sp.) increases concentrations of conjugated linoleic, docosahexaenoic and transvaccenic acids in milk of dairy cows. Amer. Soc. Nutr. Sci.

French, E. G., F. J. O'Riordan, F. J. Monahan, P. J. Caffery, M. Vidal, M. T. Mooney, D. J. Troy and A. P. Moloney. 2000. Meat quality of steers finished on autumn grass, grass silage, or concentrate-based diets. Meat Sci. 56:173-180.

French, E. G., F. J. O'Riordan, F. J. Monahan, P. J. Caffery, M. T. Mooney, D. J. Troy and A. P. Mooney. 2001. The eating quality of meat of steers fed grass and/or concentrates. Meat Sci. 57:379-386.

Gatellier, R., Y. Mercier, H. Juin, and M. Renerre. 2005. Effect of finishing mode (pasture-or mixed-diet) on lipid composition, colour stability and lipid oxidation in meat from Charolais cattle. Meat Sci. 69:175-186.

Goetsch, A. L., G. E. Murphy, E. W. Grant, L. A. Forster, Jr, Sr., D. L. Galloway, C. P. West, and Z. B. Johnson. 1991. Effects of animal and supplement characteristics on average daily gain of grazing beef cattle. J. Anim Sci. 69:433-442.

Gonzalez, M. A., M. A. Hussey, and B. E. Conrad. 1990. Plant height, disk, and capacitance meters used to estimate bermudagrass herbage mass. Agron. J. 82:861-864.

Greathead, K. D., J. Wallace, and J. N. Boultwood. 1987. The nature of the relationship of electronic capacitance meter readings to pastures on offer in short swards. Grass Forage Sci. 42:161-167.

Griebenow, R. L., F. A. Martz, and R. E. Morrow. 1997. Forage-based beef finishing

Griinari, J. M., P.Y. Chouinard, and D.E. Baumann. 1997. Trans fatty acid hypothesis in milk fat depression revised. In: Proc. Cornell Nutr. Conf. Ithaca, NY. Pp208-216.

Griinari, J. M., D. A. Dwyer, M. A. McGuire, D.E. Baumann, D. L. Palmquist, and D. V. V. Nurmela. 1998. Trans-octadecenoic acids and milk fat depression in lactating diary cows. J. Dairy Sci. 81:1251-1261.

Guerreo, J. N., B. E. Conrad, E. C. Holt, and H. Wu. 1984. Prediction of animal performance on burmudagrass pastures from available forage. Agron. J. 76:577-580.

Harfoot, C. G., and C. P. Hazlewood. 1988. Lipid metabolism in the rumen. In: P.N. Hobson (Ed.) The Rumen Microbial Ecosystem. Pp. 285-322. Elsevier Applied Science Publishers, London.

Harfoot, C. G., R. C. Noble, and J. H. Moore. 1973. Factors influencing the extent of biohydrogentation of linoleic acid by rumen micro-organisms in vitro. J. Sci. Food Agric. 24:961-970.

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.

Hendrick, H. B., J. A. Patterson, 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.

Hendrix, K. S. 1975. Feeding grain to cattle on pasture. Beef Forage Res. Day. Indiana Agric. Exp. Stn., West Lafayette.

Hoke, K. E., and H. B. Hedrick. 1969. Maturity and carcass grade effects on palatability of beef. Food Technology. 23:330-332.

Hoveland, C. S. and W. B. Anthony. 1977. Existing and potential systems of finishing cattle on forages or limited grain rations in the Piedmont regions of the South. In: J.A. Stuedeman (ed.). Forage-Fed Beef: Production and Marketing Alternatives in the South. p. 377. So. Coop. Series Bull. 220.

Huber, D. A., G. O. Mott, T. W. Perry, C. L. Rhykerd, R. W. Taylor. 1967. Feeding grain to beef cattle on pasture. Proc. Annu. Indiana Cattle Feeders Day. Indiana Agric. Exp. Stn., West Lafayette. p. 14.

Hunt. M. C. 1980. Meat color measurements. Pages 41-46 in Proc. Reciprocol Meat Conference, Volume 33. Savoy, IL.

Institute of Medicine, National Academy of Science. 1994. Opportunities in the Nutrition and Food Sciences (Thomas, P.R. & Earl, R., eds.), p. 109. National Academy Press, Washington, DC.

Jenkins, T. C. 1993. Symposium: Advances in Ruminant Lipid Metabolism. J. Dairy Sci. 76:3851-3863

Jeremiah, L.E. and L.L. Gibson. 2003. The effects of postmortem handling and aging time on beef palatability. Food Resrch. Inter. 36:929-941.

Jones, S. D. M., L. E. Jeremiah, A. K. W. Tong, S. Lutz, and W. M. Robertson. 1991. The effects of marbling level, electrical stimulation and postmortem aging on the cooking and palatability properties of beef rib-eye steaks. Canadian Journal of Animal Science. 71:1037-1043.

Kelly, M. L., J. R. Berry, D. A. Dwyer, J. M., Griinari, P. Y., Chouinard, M. E. Van Amburgh, and D. E. Baumann. 1998. Dietary fatty acid sources effect conjugated linoleic acid concentrations in milk from lactating dairy cows. J. Nutr. 128:881-885.

Kerry, J. P., D. J. Buckley and P.A. Morrissey. 2000. Improvement of oxidative stability of beef and lamb with vitamin E. In E. Decker, C. Faustman & C.J. Lopez-Bote

(Eds.), Antioxidants in muscle foods, nutritional strategies to improve quality (pp. 229-261). United States: John Wiley & Sons.

Kerth, C.R., L.K. Blair-Kerth and W.R. Jones. 2003. Warner-Bratzler Shear Force Repeatability in Beef Longissimus Steaks Cooked With a Convection Oven, Broiler, or Clam-shell Grill. J Food Sci. Vol. 68. 2:668-670

Kerth C. R., K. W. Braden, R. Cox, L. K. Kerth and D. R. Rankins, Jr. 2006. Carcass, sensory, subcutaneous fat color, and consumer acceptance characteristics of Angus-cross steers finished on ryegrass (*Lolium multiflorum*) forage or on a high-concentrate diet. Meat Science. Accepted

Kim, C. J., and E. S. Lee. 2002. Effects of quality grade on the chemical, physical, and sensory characteristics of Hanwoo (Korean native cattle) beef.

Knight T. W., A. F. Death, P. D. Muir, M. Ridland and T. K. Wyeth. 1996. Effect of dietary vitamin A on plasma and liver carotenoid concentrations and fat colour in Angus and Angus crossbred cattle. *New Zealand Journal of Agricultural Research*. 39:281-288.

Kris-Etherton, P. M., W. S. Harris and L. J. Appel. 2002. Fish consumption, fish oil, omega-3 fatty acids, and cardiovascular disease. Circulation. 106:2747-2757.

Kropf, D. H. 1980. Effects of retail display conditions on meat color. In Proc. Reciprocol Meat Conf. 33, 15.

Lake, R. P., R. L. Hildebrand, D. C. Clanton, L. E. Jones. 1974. Limited energy supplementation of yearling steers grazing irrigated pasture and subsequent feedlot performance. J. Anim. Sci. 39:827-833.

Lanari, M. C., M. Brewster, A. Yang and R. K. Tume. 2002. Pasture and grain finishing affect the color stability of beef. J. Food Sci. 67:2467-2473.

Larick, D. K. and B. E. Turner. 1989. Influence of finishing diet on the phospholipids composition and fatty acid profile of individual phospholipids in lean muscle of beef cattle. J. Anim. Sci. 67:2282-2293.

Larick D. K., and B. E. Turner. 1990. Flavor characteristics of forage and grain-fed beef as influenced by phospholipid and fatty acid compositional differences. J. Food Sci. 55:312-317

Larick, D. K., H. B. Hedrick, G. B. Garner, M. E. Bailey, J. E. Williams, D. L. Hancock, and R. E. Morrow. 1987. Flavor constituents of beef as influenced by forage and grain-feeding. J. Food Sci. 52:245-251.

Leat, W. M. F., P. Kemp, R. J. Lysons, and T. J. L. Alexander. 1977. Fatty acid composition of depot fats from gnotobiotic lambs. J. Agric. Sci. 88:175-176.

Littell, R. C., G. A. Milliken, W. W. Stroup and R. D. Wolfinger. 1996. SAS System for Mixed Models. SAS Institute Inc., Cary, NC. USA.

Mandell, I. B., J. G. Buchanan-Smith and C. P. Campbell. 1998. Effects of forage vs. grain feeding on carcass characteristics, fatty acid composition and beef quality in Limousin-cross steers when time on feed is controlled. J. Anim. Sci. 76:2619-2630.

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 fed alfalfa silage and(or) high concentrate diets. Can. J. Anim. Sci. 77:109-121.

Marmer, W. N., R. J. Maxwell and J. E. Williams. 1984. Effects of dietary regimen and tissue site on bovine fatty acid profile. J. Anim. Sci. 59:109-121.

Matches, A. G., F. A. Martz and G. B. Thompson. 1974. Multiple assignment tester animals for pasture-animal systems. Agron. J. 66:719.

McKenna, D. R., D. L. Roeber, P. K. Bates, T. B. Schmidt, D. S. Hale, D. B. Griffin, J. W. Savell, J. C. Brooks, J. B. Morgan, T. H. Montgomery, K. E. Belk, G. C. Smith. 2002. National Beef Quality Audit-2000: Survey of targeted cattle and carcass characteristics related to quality, quantity, and value of fed steers and heifers. J. Anim. Sci. 2002.80:1212-1222.

McMillin, K. W., T. D. Binder, G. M. Hill, C. P. Bagley, J. W. Knox, D. F. Coombs, A. F. Loyacano and W. M. Oliver. 1984. Carcass traits of slaughter beef finished on forage diets. Livestock Producers' Day Report. Louisiana Agric. Exp. Stn., Baton Rouge.

McMillin, K. W., T. D. Binder, G. M. Hill, D. F. Coombs, C. P. Bagley, J. W. Knox, A.F.Loyacano, W.M. Oliver, D.C. Huffman, W.E. Wyatt, and A.M. Saxton. 1990. Year-round production of beef using maximum levels of forages. III. Carcass Evaluation. Appl. Agri. Research. 5:321-326.

Melton S. L. 1990. Effects of feeds on flavor of red meat: a review. J. Anim. Sci. 68:4421-4435.

Melton, S. L., N. Amiri, G. W. Davis and W. R. Backus. 1982. Flavor and chemical characteristics of ground beef from grass-‘ forage-grain-, and grain-finished steers. J. Anim. Sci. 55:77-87.

Menkhaus, D. J., D. P. M. Colin, G. D. Whipple, R. A. Field. 1993. The effects of perceived product attributes on the perception of beef. Agribusiness. 9:1:57-63.

Mikkelsen, A., L. Sosniecke, and L.H. Skibstead. 1992. Myoglobin catalysis in lipid oxidation. Zeitschrift fur Lebensmittel Untersuchung und Forshung. 195:228-234.

Miller, G. J., M. L. Masor and M. L. Riley. 1981. Intramuscular lipids and triglyceride structures in range and feedlot steers. J. Food Sci. 46:1333-1335.

Miller, G. H., T. R. Varnell and R. W. Rice. 1967. Fatty acid composition of certain ovine tissues as affected by maintenance level rations of roughage and concentrate. J. Anim. Sci. 26:41.

Miller, M. F., C. R. Kerth, J. W. Wise, J. L. Lansdell, J. E. Stowell, and C. B. J. Ramsey. 1997. Slaughter plant location, USDA quality grade, external fat thickness, and aging time effects on sensory characteristics of beef loin stripsteaks. J. Anim. Sci. 75:662-667.

Mills, E. W., J. W. Comerford, R. Hollender, H. W. Harpster, B. House and W. R. Henning. 1992. Meat composition and palatability of Holstein and beef steers as influenced by forage type and protein source. J. Anim. Sci. 70:2446-2451.

Milner, J.A. 1999. Functional Foods and Health Promotion. American Society for Nutritional Sciences. Supplement 99:0022-3166

Mitchell, G. E., A. W. Reed and S. A. Rogers. 1991. Influence of feeding regimen on the sensory qualities and fatty acid contents of beef steaks. J. Food Sci. 56:1102-1103.

Mitsumoto, M., R. N. Arnold, D. M. Schaefer and R. G. Cassens. 1993. Dietary versus post-mortem supplementation of vitamin E on pigment and lipid stability in ground beef. J. Anim. Sci. 71:1812-1816.

Mitsumoto, M., R. N. Arnold, D. M. Schaefer and R. G. Cassens. 1995. Dietary Vitamin E Supplementation shifted weight loss from drip to cooking loss in fresh longissimus during display. J. Anim. Sci. 73:2289-2294.

Mitsumoto, M, R. G. Cassens, D. M. Schaefer, R. N. Arnold, and K. R. Scheller. 1991. Improvement of color and lipid stability in beef longissimus with dietary vitamin E and vitamin C dip treatment. J. Food Sci. 56:1489-1492.

Mitsumoto, M., S. Ozawa, T. Mitsuhashi, and K. Koide. 1997. Effect of Dietary Vitamin E Supplementaiton for one week before slaughter on Drip, Color, and Lipid Stability During Display in Japanese Black Steer Beef. Meat Science. 49:165-174.

Monahan, F. J., D. J. Buckley, J. I. Gray, P. A. Morrissey, A. Ashgar, T. J. Hanrahan, and P. B. Lynch. 1990. Effect of Dietary vitamin E on the stability of raw and cooked pork. Meat Sci. 27:99.

Montgomery, J. L., V. G. Allen, K. R. Pond, M. F. Miller, D. B. Wester, C. P. Brown, R. Evans, C. P. Bagley, R. L. Ivy, and J. P. Fontenot. 2001. Tasco-Forage: IV. Influence of a seaweed extract applied to tall fescue pastures on sensory characteristics, shelf-life, and vitamin E status in feedlot-finished steers. J. Anim. Sci. 79:884-894.

Montgomery, R. E., K. W. McMillin, T. D. Bidner and M. H. Stanley. 1982. Effect of nutritional regime on the palatability of ground beef and rib steaks. Livestock

Producers' Day Report. Animal Science Department, Louisianan State University, Baton Rouge.

Morrissey, P. A., D. J. Buckley, P. J. A. Sheehy and F. J. Monahan. 1994. Vitamin E and meat quality. *Proceedings of the Nutrition Society*. 53:289-295.

Mottram, D. S. 1998. Flavour formation in meat and meat products. Food Chem. 62:4:415-424.

O'Sullivan, A. O., K. Galvin, A. P. Moloney, D. J. Troy, K. O. Sullivan and J. P. Kerry. 2003. Effect of pre-slaughter rations of forage and/or concentrates on the composition and quality of retail packaged beef. Meat Sci. 63:279-286.

Pariza, M. W. 2004. Perspective on the safety and effectiveness of conjugated linoleic acid. Am. J. Clin. Nutr. 79(suppl):1132S-6S

Park, B. Y., S. H. Cho, Y. M. Yoo, J. H. Kim, J. M. Lee, S. K. Joon, and J. K. Kim. 2000. Effect of intramuscular fat contents on the physiochemical properties of beef longissmus dorsi from Hanwoo. J. Anim. Sci. and Technology (Korean). 42:189-194.

Park, P. W., and R. E. Goins. 1994. In Situ preparation of FAME for analysis of fatty acid composition in foods J. Food Sci. 59:1262-1266.

Platter W. J., J. D. Tatum, K. E. Belk, P. L. Chapman, J. A. Scanga, and G. C. Smith. 2003. Relationships of consumer sensory ratings, marbling score, and shear force value to consumer acceptance of beef strip loin steaks. J Anim Sci. 81:11:2741-50.

Priolo, A., D. Micol, and J. Agabriel, 2001. Effects of grass feeding systems on ruminant meat colour and flavour. A review. Anim. Res. 50:185-200.

Raes, K., A. Balcaen, P. Dirinck, A. DeWinne, E. Claeys, D. Demeyer and S. DeSmet. 2003. Meat quality, fatty acid composition and flavour analysis in Belgian retail beef. Meat Science. 65:1237-1246.

Reagan, J. O., J. A. Carpenter, F. T. Bauer, and R. S. Lawry. 1977. Packaging and palatability characteristics of grass and grass-grain fed beef. J. Anim. Sci. 45:716.

Reagan, J. O., K. V. Stribling, J. A. Carpenter and D. R. Campion. 1977. Packaging and palatability characteristics of grass- and grain-fed beef. J. Anim. Sci. 46:716-721.

Reagan, J. O., K. V. Stribling, J. A. Carpenter, and D. R. Champion. 1981. Microbiological, vacuum packaging and palatability attributes of beef produced at varied levels of forages and grains. J. Anim. Sci. 53:1482-1488.

Redfearn, D. D., B. C. Venuto, W. D. Pitman, M. W. Alison, and J. D. Ward. 2002. Cultivar and environmental effects on annual ryegrass forage yield, yield distribution, and nutritive value. Crop. Sci. 42:2049-2054.

Renerre, M. 2000. Oxidative process and myoglobin. In E. Decker, C. Faustman and C. Lopez-Bote (Eds.)., Antioxidants in muscle foods (pp. 113-135). New York: Wiley and Sons.

Resurreccion, A. V. A. 2003. Sensory Aspects of consumer choices for meat and meat products. Meat Science. 66:11-20.

Reverte, D., Y. L. Xiong and W. G. Moody. 2003. Properties of restructured beef steaks from forage- and grain-fed cattle as affected by antioxidant and flavouring agents. Meat Sci. 65:539-546.

Rice, D., and S. Kennedy. 1988. Vitamin E function and effects of deficiency. Dr. Vet . J. 144:482-496.

Ritzenthaler, K.L. et al. 2001. Estimation of Conjugated Linoleic Acid Intake by Written Dietary Assessement of Methodologies Underestimates Actual Intake Evaluated by Food Duplicate Methodolgy. Nutrient Req. 0022-3166/01:1548-1554

Roberts, S. D. 2005. Forage Quality, Animal Performance and Carcass Traits of Steers Finished on Winter Annual Ryegrass (Lolium multiflorum Lam.) Pasture with Varying Levels of Corn Supplementation. M.S. Thesis. Auburn Univ., AL

Saker, K. E., V. G. Allen, J. P. Fontenot, C. P. Bagley, R. L. Ivy, R. R. Evans, and D. B. Wester. 2001. Tasco-Forage: II. Monocyte immune cell response and performance of beef steers grazing tall fescue treated with a seaweed extract. J. Anim. Sci. 79:1022-1031.

Sapp, P. H., S. E. Williams and M. A. McCann. 1999. Sensory attributes and retail display characteristics of pasture- and/or grain-fed beef aged 7, 14 or 21 days. J Food Quality. 22:257-274.

Savell, J. W., R. E. Branson, H. R. Cross, D. M. Stiffler, J. W. Wise, D. B. Griffin, and G. C. Smith. 1987. National Consumer Retail Beef Study: Palatability evaluations of beef loins steaks that differed in marbling. J. Food Sci. 52:517-219, 532.

Schaake, S. L., G. C. Skelley, E. Halpin, L. W. Grimes, R. B. Brown, D. L. Cross, C. E. Thompson. 1993. Carcass and meat sensory traits of steers finished on fescue and clover, summer forage, or for different periods in drylot. J. Anim. Sci. 71: 3199-3205.

Schaefer, D. M., Q. Liu, C. Faustman, and M. C. Yin. 1995. Supranutritional administration of vitamin E and C improves antioxidant status of beef. J. Nutr. 125:1792.

Schmidt, R. E., and X. Zhang. 1997. Influence of seaweed on growth and stress tolerance of grasses. In: M.J. Williams (ed.) Proc. Am. Forage Grassl. Council. vol. 6. Ft. Worth, TX. 158-162.

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

Schroeder, T. C. and J. Kovanda. 2003. Beef Alliances: Motivations, Extents, and Future Prospects. The Veterinary Clinics of North America Food Animal Practice. 19:397-417.

Schupp, A. R., T. D. Bidner, and N. C. Clark. 1980. Consumer acceptance of beef produced under alternative feeding systems. Southern J. Agric. Econ. 31-35.

Seideman, S. C., M. Koohmaraie, and J. D. Crouse. 1987. Factors associated with tenderness in young beef. Meat Science. 20:281-291.

Sheehy, P. J., P. A. Morrissey and A. Flynn. 1994. Consumption of thermally-oxidized sunflower oil by chicks reduces alpha-tocopherol status and increases susceptibility of tissues to lipid oxidation. Br. J. Nutr. 71(1):53-65.

Simonne, A. H., N. R. Green, and D. I. Bransby. 1996. Consumer acceptability and beta-carotene content of beef as related to cattle finishing diets. J. Food Sci. 61:1254.

Simopoulos, A. P. 1991. Omega-3 fatty acids in health and disease and in growth and development. Amer. J. Clin. Nutr. 54:438-463.

Smith, G. M., J. D. Crouse, R. W. Mandigo, and K. L. Neer. 1977. Influence of feeding regime and biological type on growth compensation and palatability of steers. J. Anim. Sci. 45:236-253.

Smith, G. C., J. B. Morgan and J. D. Tatum. 1993. Marketing vitamin E for meat-quality enhancement in the USA, Proc. Roche Vitamin E Workshop, Huffman. La Roche, AG, Luzern, Switzerland. pp. 1-7.

Smith, G. C., J. B. Morgan, J. N. Sofos, and J. D. Tatum. 1996. Supplemental vitamin E in beef cattle diets to improve shelf-life of beef. Anim. Food Sci. Tech. 59:207-214.

Srinivasan, S., Y. L. Xiong, S. P. Blanchard and W. G. Moody. 1998. Proximate, mineral and fatty acid composition of semimembranosus and cardiac muscles from grass- and grain-fed and zeranol-implanted cattle. Food Chem. 63:543-547.

Strachan D. B., A Yang and R. D. Dillon. 1993. Effect of grain feeding o fat colour and other carcass characteristics in previously grass-fed *Bos indicus* steers. Australian J. Exp. Agri. 33:269-273.

systems: A review. J. Prod. Agric., Vol.10, no.1

Tatum, J. D., G. C. Smith, B. W. Berry, C. E. Murphey, F. L. Williams, and Z. L. Carpenter. 1980. Carcass characteristics. Time-on-feed and cooked beef palatability attributes. J. Anim. Sci. 50:833-840.

Tatum, J. D., G. C. Smith, and Z. L. Carpenter. 1982. Interrelationships between marbling, subcutaneous fat thickness, and cooked beef palatability. J. Anim. Sci. 34:777-784.

Umberger, W. J., D. M. Feuz, C. R. Calkins, and K. Killinger-Mann. 2002. U.S. consumer preference and willingness-to-pay for domestic corn-fed beef versus international grass-fed beef measured through an experimental auction. Agribusiness. 18:491-504.

USDA. 1989. Agricultural Statistics. U.S. Government Printing Office. Washington, DC.

USDA. 1997. United States standards for grades of carcass beef. AMS, USDA, Washington, DC.

Utley, P. R., R. E. Hellwig, and W. C. McCormick. 1975. Finishing beef cattle for slaughter on all-forage diets. J. Anim. Sci. 40:1034.

Van Soest, P. J. 1994. Nutritional Ecology of the Ruminant. O&B Books, Inc., Corvallis, OR

Walker, P. J., R. D. Warner, and C. G. Winfield. 1990. Sources of variation in subcutaneous fat colour of beef carcasses. Proceedings of the Australian Society of Animal Production. 18:416-419.

Westerling, D. A., and H. B. Hedrick. 1979. Fatty acid composition of bovine lipids as influenced by diet, sex and anatomical location and relationship to sensory characteristics. J. Anim. Sci. 48:1343.

Wheeler, T. L., and S. D. Shackelford. 1999. Tenderness Classification of Beef: IV. Effects of USDA Quality Grade on the palatability of "Tender" Beef Longissimus When Cooked Well done. J. Anim. Sci. 77:882-888.

Wheeler, T.L., J.W. Savell, H.R. Cross, D.K. Lunt and S.B. Smith. 1990. Mechanisms Associated with the Variation in Tenderness of Meat from Brahman and Hereford Cattle. J. Anim. Sci. 68:4206-4220.

Wheeling, M. R., B. W. Berry, and J. A. Carpenter, Jr. 1975. Effects of breed and forage vs. grain feeding on beef palatability and shelf-life. Proc. West. Sect. Am. Soc. Anim. Sci. V-26.

Whigham, L. D. et al. 2000. Conjugated linoleic acid: Implications for human health. Pharmacological Res. 42:503-510.

Whitney, A. S. 1974. Measurements of foliage height and its relationship to yield by the double sampling method. Agron. J. 36:194-203.

Williams, S. N., T. M. Frye, M. Frigg, D. M. Schaefer, K. K. Scheller, and Q. Liv. 1992. Vitamin E. Meat International. 3(2):22.

Wood, J. D., R. L. Richardson, G. R. Nute, A. V. Fisher, M. M. Campo, E. Kasapidou, P. R. Sheard., et al. 2004. Effects of fatty acids on meat quality: a review. Meat Sci. 66:21-32.

Wyatt, W. and A. Granger. 2001. Does ryegrass variety matter in a beef stocker program? 2001 Beef Cattle Research Report, Louisiana Agric. Exp. Stn., Baton Rouge. p. 35-37.

Yamashita, T. et al. 2005. Varying the ratio of dietary n-6/n-3 polyunsaturated fatty acid alters the tendency to thrombosis and progress of atherosclerosis in apoE$^{-/-}$ LDLR$^{-/-}$ double knockout mouse. Thrombosis Research. 116:393-401.

Yang, A., M. G. Brewster, M. C. Lanari and R. K. Tume. 2002a. Effect of vitamin E supplementation on α-tocopherol and β-carotene concentrations in tissues from pasture-and grain-fed cattle. Meat Sci. 60:35-40.

Yang, A., M. C. Lanari, M. Brewster and R. K. Tume. 2002b. Lipid stability and meat colour of beef from pasture- and grain-fed cattle with or without vitamin E supplement. Meat Sci. 60:41-50.

Young O.A. and B.M.B. Baumeister. 1999. The effect of diet on flavour of cooked beef and the odour compounds in beef fat. N. Z. J. Agric. Res. 42:297-304.

Zhang, X., and R. E. Schmidt. 1999. Antioxidant response to hormone-containing product in Kentucky Bluegrass subjected to drought. Crop Sci. 39:545-551.

Zinn, D. W., C. T. Gaskins, G. L. Gann, and H. B. Hedrick. 1970. Beef muscle tenderness as influenced by days on feed, sex, maturity, and anatomical location. J. Anim. Sci. 31:307.

APPENDICES

APPENDIX A

RETAIL DISPLAY SHELF-LIFE VISUAL EVALUATION

Retail Display Shelf-Life Visual Evaluation

1. Obtain desired cut for retail display from harvest facility, vacuum package and quickly transport to evaluation facilities and store at -2 C.

2. Select postmortem days so as the first of each postmortem period fall on the first of the week

3. At each postmortem day remove cuts from packaging and fabricate into one 2.54-cm steak for visual and instrumental retail display measurement.

4. Following each fabrication day postmortem, re-package the cuts and store at -2°C until the following postmortem period.

5. At each postmortem period steaks should be placed into simulated retail display conditions.

6. Place each steak on styrofoam trays, and cover with polyvinyl chloride film (PVC), and place in retail display conditions.

7. In this study a Tyler (Model NM, Niles, MI) retail display case (coffin) were utilized.

8. Steaks should be allowed to remain in retail display case at 2 C for 5 days and should be subjected to 24h exposure to retail display lighting (illumination intensity at surface of the steaks should be near 1,000 lx).

9. During each 5 day postmortem period steaks should be evaluated by a trained panel, consisting of at least six members, for beef color, color uniformity, surface discoloration, and lean browning according to AMSA (1991) color guidelines.

10. Procedures shown here have been adapted from Montgomery et al. (2001).

APPENDIX B

INSTRUMENTAL COLOR EVALUATION

Instrumental Color Evaluation

1. Obtain meat desired cut for retail display from harvest facility, vacuum package and quickly transport to evaluation facilities and store at -2 C.

2. Select postmortem days so as the first of each postmortem period fall on the first of the week

3. At each postmortem day remove cuts from packaging and fabricate into one 2.54-cm steak for subjective retail display measurement.

4. Following each fabrication day postmortem, re-package the cuts and store at -2 C until the following postmortem time.

5. At each postmortem period steaks should be placed into simulated retail display conditions.

6. Place each steak on styrofoam trays, and cover with polyvinyl chloride film (PVC), and place in retail display conditions.

7. In this study a Hussmann (Model M1 and M3, Hussmann Corporation, Bridgeton, MO) retail display case (coffin and three tier) were utilized.

8. Steaks should be allowed to remain in retail display case at 2 C for 5 days and should be subjected to 24h exposure to retail display lighting (illumination intensity at surface of the steaks should be near 1,900 lx).

9. Commission Internationale de l'Eclairage (CIE) L* (muscle lightness), a* (muscle redness), and b* (muscle yellowness) values were determined daily, through the over-wrap for each postmortem day X display day combination from two random readings on each steak with a Hunter Miniscan XE Plus (Hunter laboratories Model MSXP-4500, Reston, VA).

10. Procedures shown here have been adapted from Montgomery et al. (2001).

APPENDIX C

SENSORY EVALUATION

Sensory Evaluation

1. Steaks should have an internal temperature of 2-5°C before cooking. It is common to thaw steaks before cooking at 2-5°C for 12 hours

2. Take care and maintain sample identity throughout process.

3. Pre-heat sample holding containers and pans. Pans with separate suspended compartments can be utilized, with the addition of sand below to maintain temperature.

4. Internal temperature of each steak should be taken in the geometric center of the steak and recorded. Temperatures should be in the range of 2-5°C.

5. Weigh each steak in grams before cooking and record

6. Place steak on cooking surface and cook until a medium degree of doneness. The internal temperature of steaks should be approximately 71°C.

7. Weight and temperature of each steak should be recorded immediately after cooking utilizing same procedure as before cooking.

8. Cut all four sides of the steak in a fashion that produces a square or rectangle out of the steak, while removing fat and connective tissue.

9. Cut the remaining portion of the steak into 1 cm^3 pieces. Take care that all samples are devoid of fat and connective tissue

10. Place all pieces of sample in designated sample holding containers and maintain identity.

11. Panel room should be prepared before cooking to facilitate efficient panel time and minimize period after cooking until panel evaluations.

12. Panel set-up and evaluations should be according to Cross et a., 1978.

13. Record all sensory data for analysis.

APPENDIX D

WARNER-BRATZLEAR SHEAR FORCE DETERMINATION

Warner-Bratzlear Shear Force Determination

1. Steaks should be thawed, prepared, and data recorded at prescribed in APPENDIX D steps 1 thru 7.

2. All data should be recorded in fashion similar to APPENDIX P.

3. Immediately after cooking steaks should be over-wrapped with poly-vinyl chloride (PVC) film with sample identity intact and placed in cold storage for 24hr.

4. Set up Warner-Bratzler Shear machine or similar apparatus that utilizes an Warner-Bratzler Shear design.

5. A TA can be utilized and set to measure tension in kg, linear measurement = mm, cycling = 1 × 40 mm, test speed = 200 mm/min, and return = 1000mm/min.

6. A sample core knife should be obtained along with data form.

7. Take 6 cores from each steak parallel to the muscle fibers! Check each core to assess that they are devoid of connective tissue or fat.

8. Record degree of doneness.

9. Shear each of the six cores and record values. Be sure to re-set the shear apparatus to starting position before each core is sheared.

10. Enter data and evaluate for accuracy of six replicates.

APPENDIX E

LIPID EXTRACTION for FAME ANALYSIS

Lipid Extraction for FAME Analysis

Prior to Extraction:

1. Solutions
    a. 2:1 Chloroform:Methanol+BHT
    b. 0.58% $NaCl_2$
    c. Upper Phase Solvent
2. Amber vials
    a. Wrap top thread of each amber vial with Teflon tape
    b. Place label tape/film on each vial corresponding to sample
3. Glass test tube
    a. Place a generous amount of 10 ml glass test tubes in desiccate at least 24 hr prior to extraction procedure
4. Desiccate preparation
    a. Place desiccate crystals in 95‘C drying oven for at least 24 hr prior to utilizing desiccate
    b. Grease lid and rim seal with vacuum grease
    c. This should be repeated after ~ 20 days of use
5. Prepare nitrogen evaporator
    a. Turn on and maintain temperature at 40°C

Extraction Procedures:

1. Weigh 2 g of pulverized/minced muscle sample
    a. Place in conical vial and seal
    b. Samples must remain chilled ~ 40°C

2. Add sample to glass homogenization tubes and add 30 ml of 2:1 Chloroform:Methanol/BHT and 1 ml of C19 internal standard

3. Homogenize for ~ 1 min on ice under hood

4. Prepare graduated cylinder for filtrate by adding 8 ml of 0.58% $NaCl_2$ to a clean and dry 50 ml graduated cylinder

5. Filter homogenate through Whatman # 1 into prepared graduated cylinder

6. Rinse homogenize tube with 10 ml of 2:1 C:M

7. Pour mixture into glass centrifuge tubes (carefully)

8. Cap tube with Teflon-lined cap and vortex for ~ 1 min

9. Centrifuge at 2000 x g for 15 min @ 6°C

10. Remove tubes from centrifuge and place in rack

11. Siphon off upper methanol-water phase and discard (carefully)

12. Complete above step ~ 3 times

13. Reduce remaining chloroform mixture to ~ 1 ml under nitrogen
    a. Place tubes in preheated nitrogen evaporator
    b. Turn nitrogen bottle on and adjust appropriate valves
    c. Slowly insert needle into tube to a point around 0.75 inches from fluid
    d. Slowly open individual needle valves
    e. Take care to minimize "splashing"

14. Transfer all of remaining reduced chloroform to a 10 ml volumetric flask and volume to 10 ml with chloroform under hood

15. Carefully mix and transfer to large amber vial

16. Pipet 1 ml of lipid extract, in duplicate, into pre-dried and pre-weighed (with respective sample ID transferred) glass test tubes

17. STORE remaining lipid extract + solvent in amber vial and place in -80'C freezer

18. Evaporate solvent in test tubes to dryness in nitrogen evaporator following similar steps as above

19. Dry test tubes + lipid extract at 95°C for 24 h

20. After 24 h carefully open drying oven taking care to minimize fume inhalation

21. Place tubes in pre-prepared desiccate

22. Weight test tubes containing lipid

23. Formula:
    a. (total lipid/g = (((tube with lipid – tube weight)/1 ml) * 10 ml)/ sample weight)

REFERENCE: Folch, J., M. Lees and G.H. Sloane-Stanley. 1957. A simple method for the isolation and purification of total lipids from animal tissues. J. Biol. Chem. 226:497-509.

SOLUTIONS:
1. 2:1 Chloroform:Methanol (1L): 667 ml Chloroform and 333 ml Methanol (for methanol use methanol + BHT mixture
2. Upper Phase Solvent: 30 ml Chloroform + 480 ml Methanol/BHT + 470 ml ddH_2O

APPENDIX F

METHYLATION for FAME PROFILE

Methylation for FAME Profile

Prior to Methylation:

1. Prepare/procure chemicals
    a. DCM (methylene chloride)
    b. ddH2O
    c. n-Pentane
    d. Sodium Methoxide (purchased accordingly)
    e. 14% BFl_3 in methanol (purchased accordingly)
    f. Anhydrous sodium sulfate
2. Desiccate preparation
    a. Place desiccate crystals in 95‘C drying oven for at least 24 hr prior to utilizing desiccate
    b. Grease lid and rim seal with vacuum grease
    c. This should be repeated after ~ 20 days of use
3. Clean dry glass ware necessary
    a. Test tubes (10 ml t-tubes)
    b. Tube with Teflon lined and Teflon wrapped threads (25 X 100 mm)
4. Teflon lines/wrapped GC vials
    a. ID transferred
5. Prepare heating block and nitrogen evaporator
    a. Turn on and maintain at temperature
        i. Heating block at 90°C
        ii. Evaporator at 40°C
6. Prepare 10 ml glass test tubes
    a. Transfer sample ID
    b. Insert ~ 0.5g of anhydrous sodium sulfate to each test tube and set in desiccate
7. Using lipid extracts, calculate from total lipid amount a volume containing approximately 3-4 mg lipid

Methylation procedures:

1. Pipette prescribed volume of lipid extract into screw-top test tubes

2. Add 100 µl of DCM and 1 ml of sodium methoxide solution

3. Take tubes to nitrogen stand – flush and cap
    a. Open appropriate valves
    b. Place tube beneath stand needle
    c. Flush with nitrogen and quickly cap

4. Heat tubes in pre-heated block at 90°C for 10 min under hood

5. Remove tubes and cool under hood for 2 min

6. To cool (to touch) add 1 ml of BFl_3 solution

7. Flush with nitrogen as specified above

8. Heat tubes in pre-heated block at 90°C for 10 min under hood

9. Remove tubes and cool to ROOM temperature under hood for ~ 5 min

10. To COOL tubes add 1 ml of ddH_2O and 2 ml of n-Pentane and re-cap

11. Vortex thoroughly (~1 min)

12. Centrifuge mixture in tube at 1500 X g for 5 min at 10°C
    a. After centrifugation two clear layers should appear

13. CAREFULLY remove tubes from centrifuge

14. Transfer upper layer to test tube containing a small amount (~ 0.5g) of anhydrous sodium sulfate

15. Allow tubes + contents to sit for ~ 2 min

16. Carefully transfer fluid – crystals (anhydrous sodium sulfate) into new test tube

17. Reduce n-Pentane + FAME under nitrogen to dryness

18. Reduce under nitrogen
    a. Place tubes in preheated nitrogen evaporator
    b. Turn nitrogen bottle on and adjust appropriate valves
    c. Slowly insert needle into tube to a point around 0.75 inches from fluid
    d. Slowly open individual needle valves - take care to minimize "splashing

19. To reduced FAME mixture add 1000µl of DCM

20. Transfer DCM + FAME into GC vial (prepared) and flush with nitrogen as previously described and cap

21. Store vials in -80°C freezer for further analysis

REFERNCE: Park, P. W., and R. E. Goins. 1994. In Situ preparation of FAME for analysis of fatty acid composition in foods J. Food Sci. 59:1262-1266.

APPENDIX G

THIOBARBITURIC REACTIVE SUBSTANCE (TBA) ASSAY

Thiobarbituric Reactive Substance (TBA) Assay

modified from:

Buege and Aust. 1978. Methods in Enzymol. 52.302, AP

Reagents:

1. TCA/TBA stock solution: 15% TCA (w/v) and 20mM TBA (MW 144.15) reagent in DW. **Dissolve 2.88g TBA in *warm* DDW first, add TCA (150g) and then add DW to the mark (1L).** One liter last 100 samples in duplicate.

2. BHA: Make 10% stock solution by dissolving in 90% ethanol. Make 500ml batches.

3. TEP standard: $1 * 10^{-3}$ M 1, 1, 3, 3-tetra-ethoxypropane in DW. This solution can be kept for about a week if stored in the refrigerator and diluted as needed. (MW 220.31, 95% purity, d = 0.918). Dilute 0.5 ml TEP with 499.5 ml DW, and dilute the resulting solution 1: 2.96 (TEP solution: DW) with DW.

Procedure:

1. Slice 10 g of fresh frozen meat and place in blender cup with 30ml of DW.

2. Homogenize with a blender for 2 min. (or homogenize for 10-15 sec using a polytron at speed 7-8.)

3. Take 2 ml of the homogenate, combine with 4 ml of the TCA/TBA reagent, 100µl BHA, vortex thoroughly.

4. Heat the solution for 15 min in a boiling water.

5. Cool for 10 min in cold water.

6. Vortex thoroughly.

7. Centrifuge at 2000G (3000RPM) for 10 min.

8. Read the absorbance of the supernatant at 531 nm against a blank that contains all the reagents minus sample.

Malonaldehyde standard curves ($CHO\text{-}CH^2\text{-}CHO$, MW 72.0)

1. Construct TBA standard curve using TEP.

2. Label tubes: six tubes- 0 and two tubes of each- 5, 10, 20, 30, 40 and 50.

3. Add the following amounts to each tube:

	TEP	DW	Set pipettor on:
0	0 µL	2000 µL	1000 (twice)
5	10µL	1990 µL	995 (twice)
10	20µL	1980 µL	990 (twice)
20	40µL	1960 µL	980 (twice)
30	60µL	1940 µL	970 (twice)
40	80µL	1920 µL	960 (twice)
50	100µL	1900 µL	950 (twice)

4. Add 4 ml TBA/TCA to each tube, vortex.

5. Heat the tubes in boiling water bath for 15 min.

6. Cool in cool water bath for 20 min.

7. Vortex.

8. Read the optical density of the standard against a blank at the same wavelength (531 nm).