EFFECTS OF CASTRATION ON CARCASS COMPOSITION, MEAT QUALITY, AND SENSORY PROPERTIES OF BEEF PRODUCED IN A TROPICAL CLIMATE.

by

JULIO RODRIGUEZ

A THESIS

Submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Department of Animal Science and Industry
College of Agriculture

KANSAS STATE UNIVERSITY
Manhattan, Kansas

2012

Approved by:

Major Professor

John A. Unruh

ABSTRACT

Forty-eight Brahman-cross male calves were fed to 26 mo of age and used to determine carcass cutability and meat quality characteristics of four muscles from intact bulls and steers castrated at 3, 7, or 12 mo of age grown under tropical pasture conditions. *Longissimus lumborum* (LL), *Psoas major* (PM), *Gluteus medius* (GM), and *Semitendinosus* (ST) steaks were aged for 2, 7, 14, or 28 d for Warner Bratzler shear force (WBSF) analysis. Live weight, carcass traits, and total subprimal yields were not affected by male sex condition. For PM, GM, and ST steaks, WBSF values were similar for steaks from intact bulls and steers castrated at all ages. For both PM and GM muscles, steaks aged for 28 d had the lowest (most tender) WBSF values and steaks aged for 2 d had the highest WBSF values. For the ST, WBSF values were highest for steaks aged 2 d. A treatment × aging interaction was detected for LL WBSF values. At 14 d of aging, LL steaks from steers castrated at 3 mo tended to have lower WBSF values than those from intact bulls. At 28 d of aging, steaks from steers had lower WBSF values than steaks from intact bulls and steaks from steers castrated at 3 mo tended to have lower WBSF values than steaks from steers castrated at 12 mo. For LL steaks from steers castrated at 3, 7 or12 mo, WBSF values linearly decreased with increased days of aging. Although all sensory panel data collected were not statistically different, LL steaks from steers castrated at 3 mo tended to have higher (more tender) scores for overall tenderness than steaks from intact bull. This study indicates that castration at 3 mo would be the recommended production practice as it provided the greatest improvement of LL tenderness over intact bulls with no differences in carcass traits or subprimal yields. The degree of improvement in tenderness due to aging is muscle dependent.

Key works: beef, bulls, steers, aging, tenderness

TABLE OF CONTENTS

LIST OF TABLES

ACKNOWLEDGEMENTS

I would like to thank Corporacion Ganadera (CORFOGA) and Consejo Nacional para Investigaciones Cientificas y Tecnologicas (CONICIT) for supporting my study program. In addition, thanks to the Instituto Tecnologico de Costa Rica (ITCR) where the trial was conducted, and Coopemontecillos R.L. packing plant facilities.

I would like to thank my advisor Dr. John Unruh for his guidance, patience, and support. Thanks to John and Judy Unruh, for your support during all the time we were in the U.S. You both made this a great experience will remain with us for the rest of our lives.

Dr. Reinhardt and Dr. Jaeger, thanks a lot! It was great that you both came to Costa Rica and support me with the project, but making apart the project, we had good times such that day in Manuel Antonio National Park! Dr. Jaeger thank you for your patience trying to teach me how to use ultrasound, I hope someday I will.

Thanks to all people involved in my project, the ITCR people (Farm, Meat Lab, and Administration), special thanks to Olger, Milton, Rodrigo, Arturo and Sailim, you all gave me your unconditional support. Thanks to Dr. Camacho for his great help in statistics. There is a very special person who came to Costa Rica from Nebraska and helped me out with my research at the hardest time and became part of our family, your support was invaluable and you are part of us, thanks to Tacy Langemaier!

Of course, thanks to my K-State friends. I had a great time sharing with you all. Finally, thanks to all my co-workers in CORFOGA, especially to Jorge Lopez, you are a big part of this buddy.

DEDICATION

I would like to dedicate this thesis to Taty, my wife, without her I never would have been able to finish my Master´s and many goals of my life. You always have been by my side for good and bad times. I am very lucky to have you. This is also for my mom (Maria Eugenia), my grandparents ("Nono" and "Nona"), to my sisters Eugenia, Marcela, my brother-in-law Jorge, and my nephews Marcelo and Alejandro.

CHAPTER I- INTRODUCTION

In Costa Rica, beef cattle production is based primarily on *Bos indicus* genotypes fed pasture/forage-based diets. *Bos indicus* cattle are well adapted to the temperature and nutritional stress prevalent in the tropics and subtropics were they evolved (Forbes *et al*., 1998). Beef from *Bos indicus* cattle has been generally characterized as less tender (Crouse *et al*., 1989; Elzo *et al*., 2012) resulting from increased muscle calpastatin activity and reduced postmortem proteolysis than beef from *Bos taurus* cattle (Johnson *et al*., 1990b; Wheeler *et al*., 1990a; Whipple *et al*., 1990). In addition, forage finishing cattle has negative consequences on carcass tenderness and organoleptic properties of the meat (Mitchell *et al*., 1991), and grass finished cattle have decreased ADG, longer finishing periods to reach a target endpoint, reduced dressing percentages, less acceptable fat and lean scores, and lower quality grades than cattle fed energy-dense concentrate diets (Bidner *et al*., 1981, 1986).

In the early fifties, castration was part of the typical annual cattle processing in Costa Rica which included identification, vaccination, and castration of male calves. This practice was eventually eliminated in the seventies driven by the growth of beef exports and the demand of packing plants for lean, large-framed cattle that produced a larger quantity of beef (Perez, 2009). It has been generally accepted that intact bulls provided adequate nutrition grow faster and more efficiently, and produce carcasses with less fat than castrated steers (Seideman *et al*., 1982; Mach *et al*., 2009). Today bull production is the primary production practice in Costa Rica because there has been a lack of economic incentive for producers to castrate male calves.

The tenderness of beef has been identified as a quality characteristic that is closely related to the overall acceptability of beef (Chambers and Bowers, 1993) and is often the cause of consumer dissatisfaction with beef quality. Consumers can segregate differences in beef tenderness and are willing to pay for more tender beef (Miller *et al*., 2001). In the past ten years the Costa Rican consumer has also shown an increased demand for improved tenderness and their willingness to pay higher prices for more tender subprimals and retail cuts (Retana, 2012).

Meat from steers and heifers is preferred by consumers over intact males because of its improved sensory traits, particularly tenderness (Seideman *et al*., 1989; Huerta-Leidenz and Rios, 1993). With renewed interest and the goal of improving beef quality, castration has been reintroduced to Costa Rica as production tool. For some niche markets, late castration (> 12 mo of age) has been incorporated by some producers to increase fatness of subprimals compared to bulls, yet take advantage of the believed superior growth rate and efficiency compared to early castrated steers (Murillo, 2012). However, early castration is recommended to reduce animal stress, improve animal welfare, and decrease male aggressiveness (Bretschneinder, 2005), and may potentially improve meat quality traits (Morón *et al*., 2005ab).

Aging is a postmortem technology that enhances beef palatability and is among the most popular options for improving tenderness (Dransfield, 1994). This practice is not widely used in Costa Rica and has been used by only a few beef retailers. Individual muscles respond differently in extent of tenderization improvement, to postmortem aging periods because of differences in connective tissue (Rhee *et al*., 2004), to the rate and extent of pH decline, in activity of calpains (Ilian *et al*., 2001), and thus in the extent of proteolityc degradation (Taylor *et al*., 1995; Rhee *et al*., 2004). Beef Tenderness Surveys (Morgan *et al*., 1991; Brooks *et*

al., 2000) have revealed substantial variation in the length of postmortem aging time to optimize tenderness of different beef cuts.

Beef cattle production in Costa Rica is facing many challenges, many directed toward the improvement of beef quality. Few research trials have been conducted using antemortem and postmortem technologies to improve beef quality and tenderness. Ardaya and Zapata (1999) found no difference in performance of *Longissimus* Warner Braztler shear force (WBSF) for bulls and late castration steers. Arce and Murillo (2004) found *Longissimus* steaks from steers had lower (more tender) WBSF means than those from bulls and aging improved tenderness for both sex classes. Therefore, the objectives of this study were to determine 1) the effects of castration and time of castration on the carcass composition and beef tenderness and 2) the effects of different lengths of aging on tenderness of four different muscles of beef produced in a tropical climate.

CHAPTER II – REVIEW OF LITERATURE

BULLS vs STEERS

Performance:

Several studies involving feeding bulls and steers in feedlots have shown bulls to have greater daily gains and improved feed efficiency than steers (Klosterman *et al*., 1954; Field, 1971; Arthaud *et al*., 1977; Seideman *et al*., 1982; Gerrard *et al*., 1987; Purchas and Grant, 1995). Field (1971) concluded after reviewing multiple studies that bulls gained 17% faster and were 13% more efficient in converting feed to live weight gains than steers. However, Seideman *et al*. (1982) in another review of literature stated that when cattle are reared on pasture, steers could have higher weight gains than bulls. Martin *et al*. (1978) conclude that bulls fed a low protein diets gained at essentially the same rate as steers. When bulls are fed a higher plane of nutrition with higher protein content, they perform superior to steers. The detrimental effects of castration on growth rate and feed efficiency are more strongly expressed on a higher plane of nutrition than on a lower plane (Cobic, 1968). Ardaya and Zapata (1999) in a study performed in Costa Rica did not find differences in average daily gain and final weight between steers and bulls. When fed a high plane of nutrition such as in a feedlot, bulls generally outperform steers in gain and feed efficiency. However, this enhanced performance may not occur under low planes of nutrition.

Hormonal differences:

The testicles produce androgens and estrogens that promote muscle growth by increasing nitrogen retention. When testes are removed, the production of the male´s natural anabolic steroids, testosterone and estrogen, are reduced (Unruh, 1986). Testosterone in particular is associated with a positive N balance, increased carcass

protein, and decreased carcass fat (Schanbacher, 1984). Unruh (1986) stated that the natural endogenous concentration of androgens and estrogens in intact males may allow for the near maximal expression of growth. Furthermore, these endogenous hormones serve as coordinators in the partitioning of nutrients supporting short-term demands (homeostasis) and long-term developmental processes during growth (homeorhesis). Barnes *et al*. (1983) concluded that bulls have higher serum testosterone and lower cortisol level than steers. Lunstra *et al*. (1978) evaluated serum testosterone concentrations of bulls from different breeds and found the average for all bulls increased linearly between 7 and 13 mo of age, and did not appear to be affected by the breed. *Bos indicus* cattle are typically slower to reach sexual maturity and are leaner at slaughter than British (*Bos taurus*) breeds of cattle (Martin *et al*., 1992; Pringle *et al*., 1997). Thomas *et al*. (2002) found that Angus and Brangus bulls had similar serum concentrations of testosterone and both had values greater than Brahman bulls. Testosterone is involved in muscle-collagen synthesis, accumulation and maturation which is responsible for some of the tenderness differences between intact males and castrates (Unruh, 1986).

The pituitary secretes growth hormone (GH), and is associated with increased growth rate and feed efficiency (Bauman *et al*., 1982). Frohman (1991) stated that GH is responsible for promoting differentiation of precursor cells under the influence of insulin-like growth factor I (IGF-I). Growth hormone is also anabolic in ruminants because daily injections have been shown to stimulate weight gain and increase N retention (Moseley *et al*., 1982). Thomas *et al*. (2002) evaluated serum concentrations of GH and found them to be greater in Brangus than Angus or Brahman bulls. In addition, the GH axis is sensitive to the level of adiposity. In particular, as ruminants age and gain adiposity, serum concentrations of GH decline.

Estrogens cause a release of GH releasing factors from the hypothalamus which cause an immediate release of GH, resulting in increased growth and nitrogen retention (Preston, 1975). Estrogens also may act indirectly on growth through regulation of plasma GH, insulin and thyroid hormone (Preston, 1975). Insulin stimulates protein synthesis and some insulin is required for GH actions (Beitz, 1985). The influence of estrogens administrated to steers is generally related to increased ribeye area and decreased fat deposition (Preston, 1975). Estrogens also cause epiphyseal plate fusion and accelerate skeletal maturation (Hafs *et al*., 1971). However, increases in environmental temperatures may decrease the response to estrogens (Ray *el at*., 1969).

Carcass composition:

In general bulls have a lower dressing percentage, more muscle, less fat cover and greater percentage of retail yield at a similar bone content compared with steers. Brannang (1966) and Hedrick (1968) concluded that dressing percentages were similar for bulls and steers. However, others (Watson, 1969; Jacobs *et al*., 1977a) determined that bulls had slightly lower dressing percentages than steers. According to Field (1971), it is reasonable to expect bulls to have lower dressing percentages than steers because they have less fat.

Due to increased testosterone, intact males have greater muscle hypertrophy resulting in 7% more muscle than steers (Bavera and Peñafort, 2005). Others (Prescott and Lamming, 1964:, Watson 1969; Kay and Houseman, 1974) reported that bull carcasses contained approximately 8% or more muscle than steer carcasses. As expected, several studies (Arthaud *et al*., 1969; Hunsley *et al*., 1971; Albaugh *et al*., 1975; Jacobs *et al*., 1977a; Purchas and Grant, 1995) found that bulls had larger ribeyes than steers.

Bulls generally have less fat cover and fewer pounds of carcass fat than steers (Watson, 1969). In agreement, several researchers (Hunsley *et al*., 1971; Jacobs *et al*., 1977a; Landon *et al*., 1978; Purchas and Grant, 1995) concluded that intact males have less fat thickness and lower percentages of fat trim than steers.

As a result of increased muscle and less fat, several researchers (Klosterman *et al*., 1954; Wierbicki *et al*., 1955; Arthaud *et al*., 1969; Landon *et al*., 1978, Purchas and Grant, 1995) concluded that bulls have greater retail yields than steers. Cohen *et al*. (1991) found bulls (60.5% retail yield) had higher cutability carcasses than steers (57.8% retail yield). In other study by Arthaud *et al*. (1977) comparing low energy diets, bulls had heavier hot carcass weights, less fat thickness, more separable lean at the 9-10-11th rib, less separable fat at the 9-10-11th rib, and more separable bone at the 9-10-11th rib (313 kg, 7 mm, 61.6%, 21.0%, and 17.3%), than steers (273 kg, 9 mm, 55.2%, 27.2%, 16.7%), respectively. Purchas and Grant (1995) found carcasses from bulls yielded 6.7 kg more salable product than steers. This is consistent with Jacobs *et al*. (1977a) who concluded that bulls yielded 10.6% more edible meat and 10.1% less fat trim than steers.

Most researchers (Jacobs *et al*., 1977a; Prescott and Lamming, 1964; Landon *et al*., 1978) have found no significant differences in bone yields when comparing bulls and steers. Field (1971) summarized several studies and concluded that separable carcass bone averaged 15.8% for bulls and 15.6% for steers. Even though differences in percentages of bone between bulls and steers may be small, bulls have been found to have higher muscle-bone ratios than steers (Berg and Butterfield, 1968; Wierbicki *et al*., 1955).

Seideman *et al*. (1982) concluded that bulls had advantages of greater carcass leaness and higher cutability carcasses than steers. However, they concluded that bull

carcasses may have some disadvantages such as minimal fat cover, more difficult hide removal, and heavier carcass weights than steers.

Meat quality:

Several studies (Field, 1971; Seideman *et al*., 1982; Dikeman *et al*., 1986) have shown differences in beef quality between bulls and steers. From the stand point of consumer acceptance, Seideman *et al*. (1982) indicated that tenderness, color, and texture are the most important disadvantages for producing beef from bulls.

Based on bone ossification, bull carcasses are more mature physiologically than steer carcasses at the same chronological age (Champagne *et al*., 1969; Glimp *et al*., 1971; Reagan *et al*., 1971). This may be explained by the actions of testosterone and estradiol-17β which are the most pronounced hormonal changes associated with puberty and sexual maturation in bulls (McCarty *et al*., 1979). The magnitude of serum estradiol-17β levels may be related to the growth rate of bulls and the maturation (ossification) of bone (Gray *et al*., 1986).

Consumers often conclude that tenderness is the most important beef quality trait (Shackelford *et al*., 1995b; Polidori *et al*., 1996; Shackelford *et al*., 1997ab). Consumers can detect differences in beef tenderness and are willing to pay more for more tender beef (Miller *et al*., 2001). Other sensations, mainly juiciness and connective tissue amount (residue to chew) are closely linked to tenderness (Jerez-Timaure *et al*., 1994; Huerta *et al*., 1997).

Bulls have often been shown to have tougher meat than steers (Klosterman *et al*., 1954; Field, 1971; Hunsley *et al*., 1971; Arthaud *et al*., 1977; Seideman *et al*., 1982; Dikeman *et al*., 1986; Morgan *et al*., 1993; Purchas *et al*., 2002). In a literature review conducted by Field (1971), he concluded that meat from bulls was slightly less tender than meat from steers. However, Champagne et al. (1969), Albaugh *et al*.

(1975), and Landon *et al*. (1978) observed no differences in Warner Bratzler shear force values due to sex condition. Field *et al*. (1966) stated that there were no significant differences in tenderness of meat from bulls and steers at 300 to 399 d of age, but steers 400 to 499 d of age had slightly higher tenderness ratings than bulls that were similar in age and marbling. Hedrick *et al*. (1969) reported that bulls less than 16 months of age had Warner Bratzler shear force (WBSF) values that were comparable in tenderness to steers and heifers. In a trial done by Unruh *et al*. (1987), bulls (3.9 kg) had greater *Longissimus* WBSF values (were tougher) than steers (2.7 kg). In agreement Morgan *et al*. (1993) attained *Longissimus* WBSF values of 4.9 kg and 4.2 kg for bulls and steers, respectively. For cattle raised on pasture in a tropical climate, both Ardaya and Zapata (1999) and Arce and Murillo (2004) evaluated *Longissimu*s tenderness of castrated and intact Brahman males and concluded that bulls had higher WBSF values compared to steers.

Tenderness differences between steers and bulls appear to be influenced by age and the accumulative influence of testosterone over time. Younger bulls and steers appear to have minimal differences in tenderness, and tenderness differences between bulls and steers increase with age. These hormonally mediated variations in tenderness appear to be related to the nature or state of contractile (myofibrillar) proteins and the content and properties of connective tissue (Unruh, 1986).

Cross *et al*. (1984) attributed the increase in toughness of meat from bulls to increased crosslinking of connective tissue resulting from increased testosterone levels in the intact animal. Teira (2004) found muscles from intact males to have higher levels of intramuscular collagen and more intermolecular cross-links at the same chronological age, than castrated animals. Boccard *et al*. (1979) investigated the influence of sex on the amount of total soluble collagen in various beef muscles. They

reported that the collagen content in muscles was higher in bulls than steers, regardless the age, and that collagen solubility decreased markedly between 12 and 16 months in bulls. Increased toughness of meat from bulls may at least be partially attributed to connective tissue amount and maturity (crosslinking).

Burson *et al*. (1986) proposed that different types of collagen may also play a role in tenderness differences between bulls and steers. Bailey *et al*. (1979) concluded that tender muscles may have a lower percentage of type III collagen than tougher muscles. However, Light *et al*. (1985) evaluated six different muscles and reported that percentage of type III collagen in either the endomysium or perimysium was not related to tenderness. Burson *et al*. (1986) further concluded that the proportion of type I and type III collagen does not relate well to *Longissimus* tenderness differences between bulls and steers. However, collagen characteristics, such the extent and type of crosslinking and the fiber size (Light *et al*., 1985) of each collagen type, may play a role in tenderness differences between muscles from bulls and steers.

Bulls may also have meat with more myofibrillar toughness that may be more resistant to aging than meat from steers. Morgan *et al*., (1993) explained that bulls have higher calpastatin activity (endogenous calpain inhibitor). A high correlation has been detected for 24 h calpastatin activity, myofibrillar proteolysis, and meat tenderness in steers and heifers (Whipple *et al*., 1990). Several experiments have indicated that calpastatin is the primary regulator of the μ-calpain in postmortem muscle (Morgan *et al*., 1993). Furthermore, the postmortem activity of calpastatin is highly related to the rate of postmortem proteolysis and tenderness in meat from *Bos indicus* breeds of cattle (Whipple *et al*., 1990; Shackelford *et al*., 1991). In addition, zinc is a potent inhibitor of calpain proteinases (Koomaraie, 1990). Seideman *et al*.

(1989) reported that the *Longissimus* from bulls was tougher and contained higher concentrations of zinc than the *Longissimus* from steers (45.1 vs 34.8 ppm respectively). Thus, in addition to the elevated calpastatin activity, higher endogenous zinc concentration in bull *Longissimu*s muscles could also contribute to the decreased activation of μ-calpain and the resulting decrease in meat tenderness (Morgan *et al*., 1993).

Differences in the amount of fat covering (subcutaneous fat) between bull and steer carcasses may contribute to meat tenderness differences. Bowling *et al*. (1978) indicated that fat thicknesses greater than 7 mm provide maximum protection against the effect of cold shortening of muscles fibers. Lochner *et al*. (1980) indicated that the greater subcutaneous fat cover of steers could be expected to have a beneficial effect on tenderness. Differences in subcutaneous fat cover between bulls and steers, could result in differences in cold shortening which could be expected to contribute to potential differences in tenderness.

Meat purchasing decisions are influenced by color more than any other quality factor because consumers use discoloration as indicator of freshness and wholesomeness (Mancini and Hunt, 2005). Seideman *et al*. (1982) indicated that from the stand point of consumer acceptance tenderness, color and texture are the most important disadvantages for meat from bulls. Meanwhile, flavor and juiciness would have less impact on meat quality. Color measures and its relationship to pH may also be important as an indicator of meat tenderness. Several researches have shown that meat tenderness is correlated with an optimum muscle pH (Purchas, 1990; Watanabe *et al*., 1996) and desirable muscle color (Jeremiah *et al*., 1991; Wulf *et al*., 1997).

Subjective evaluations for color of lean indicate minimal differences between bulls and steers (Field, 1971). This conclusion is supported by others (Weniger and Steinhauf, 1968; Watson, 1969) who found the myoglobin level in bulls and steers were similar. However, Varela *et al*. (2003) indicated that the final pH of meat from bulls was higher than that from steers. In addition, Arthaud *et al*. (1969) found carcasses from steers had a finer textured lean and more desirable, brighter color than carcasses from bulls. This could be partially attributed to the temperament and stress susceptibility of bulls compared to steers. Glycogen depletion in type IIB muscle fibers predisposes cattle and hogs to Dry, Firm and Dark (DFD) meat (Shaefer *et al*., 2001). Hedrick et al. (1969) and Field (1971) suggested that bulls are more likely candidates for dark cutters than steers. Therefore, they need to be handled more carefully to minimize stress and glycogen depletion.

The time period prior to slaughter can have a major impact on meat quality as well as live and carcass weight losses (Shaefer *et al*., 2001). The activation of both hypothalamic-pictuitary-adrenal (HPA) axis and non-HPA axis events evoke a number of biochemical changes that can result in muscle dehydration, ion depletion, energy depletion, and protein catabolism (Shaefer *et al*., 2001). The antemortem physiological changes such a dehydration and tissue catabolism determine the extent of degradation of meat yield and quality (Shaefer *et al*., 2001).

In a literature review conducted by Field (1971), he concluded that marbling scores are one to two degrees higher in steers than bulls. Since marbling has a high correlation with juiciness and flavor (Killinger *et al*., 2004), meat from bulls could be expected to be less juicy and flavorful that meat from steers. However, several studies (Hendrick *et al*., 1969; Watson, 1969; Jacobs *et al*., 1977b) have found flavor and juiciness scores of cooked steaks were not significantly affected by sex condition.

Beef from bull carcasses was acceptable in quality with no undesirable flavors or aromas detected (Klosterman *et al*., 1954). Hunsley *et al*. (1971) also found no differences between steers and bulls in *Longissimus* flavor and juiciness. Unruh et al. (1986) found meat from steers to have advantages in juiciness, amount of connective tissue, myofibrillar tenderness, and overall tenderness compared to meat from bulls, but found no differences in flavor. Similar findings were reported Dikeman *et al*. (1986) who found no flavor difference, but tenderness and juiciness were superior for the steers. In a trial conducted in Costa Rica utilizing *Bos indicus* cattle, Ardaya and Zapata (1999) found no differences in *Longissimus* juiciness and flavor. Even though there are differences in marbling in meat from bulls and steers, it appears that the impact on juiciness is variable with minimal differences in flavor.

The major contributor of the juiciness sensation is the water retained during cooking. Jacobs *et al*. (1977b) concluded that cooking loss at 24 h was greater for steaks from bulls than those from steers. This was partially attributed to the increased fat content (marbling) in meat from steers and the melting of fat by heat protecting against moisture lost. Purchas (1990) reported higher cooking losses from steaks from bulls than those from steers; however, Reagan *et al*. (1971) reported no differences in cooking loss between steaks from bulls and steers. Varela *et al*. (2003) did not find drip loss differences in meat from steers or bulls; but Dikeman (1985) concluded that purge in the vacuum package may be slightly higher for meat from bulls than from steers. Most measures of moisture retention, while variable, appear to favor meat from steers compared to bulls.

In general, meat quality from castrated steers is superior to intact bulls. Bulls are often characterized as having tougher and darker lean than steers. The extent of this advantage in tenderness, color, and juiciness is dependent on multiple factors

such as animal age and handling practices before slaughter. Among these variables are the levels of endogenous hormones and enzymatic activity that can have a negative influence on fat deposition, postmortem proteolysis, and collagen properties.

Time of castration:

Castration is performed to reduce animal aggressiveness and improve meat quality. As a result, steers can often have a greater commercial value than bulls (Morón *et al*., 2005ab). According to (Huerta-Leidenz and Ríos, 1993) castration categories by age and weight are as follows:

a) Early castration: less than 4 mo of age or less than 100 kg of live weight.
b) Slightly late castration: between 4 to 7 mo of age or 100 - 250 kg of live weight.
c) Moderately late castration: between 8 to 11 months or 251 - 350 kg of live weight.
d) Very late castration: between 12 - 15 months or 351 - 450 kg of live weight.
e) Extremely late castration: after 15 months or 450 kg of live weight.

Immediately after castration, calves begin to lose weight and daily gain drops for a period of time. The severity of this period of stress is related to the age of castration. King *et al*. (1991) concluded that early castration calves were physiological less stressed than those castrated at weaning. Bretschneinder (2005) further found that early castration resulted in reduced weight loss associated with stress during the recovery period.

Boccard and Bordes (1986) concluded that late castration can improve final weight, but decreases tenderness compared to early castrated calves. Late castration delays the accumulation of adipose tissue compared to early castrated calves resulting in carcasses with less fat (Muller *et al*., 1991). They concluded that late castration

provides an opportunity to increase production performance and improve carcass composition.

Champagne *et al*. (1969) in a feedlot trial compared bulls and steers castrated at birth, two, seven and nine mo of age. They concluded that bulls gained more rapidly and efficiently than the castration groups. No significant differences in *Longissimus* area were found among castrated groups but the trend toward a larger *Longissimus* area was present with increasing age at castration. Bulls had less fat thickness and greater edible portion than all steer groups except those castrated at 9 mo of age. The estimated edible portion was 74.3% for bulls, 69.1% for calves castrated at birth, 66.2% for calves castrated at 2 mo, 69.7% for calves castrated at 7 mo, and 70.1% for calves castrated at 9 mo. In addition, bull carcasses exhibited less marbling than all steer carcass groups, but no difference in tenderness, flavor, juiciness and WBSF were observed. Landon *et al*. (1978), in another time of castration study, found bull carcasses had greater retail cut yields and less fat trim than carcasses than those from steers. The steers castrated at 7 mo had greater edible meat yields and less fat trim than early castrated steers.

Klosterman *et al*. (1954) compared early and late castration methods and concluded that there were no differences of gain, dressing percentage or carcass quality. They found that bull calves were heavier at weaning but their gains were sufficiently retarded immediately following late castration and their weights was very similar to the early castrated steers when the two groups started on feed.

According to Destefanis *et al*. (2003), the results comparing meat quality of steers compared with bulls are inconsistent. Several authors (Gregory *et al*., 1983; Riley *et al*., 1983; Dikeman *et al*., 1986) have found steers to have lower shear force values and higher sensory scores particularly for tenderness, but others (Field, 1971;

Calkins *et al*., 1986; Morgan *et al*., 1993) have found little or no effect. Destefanis *et al*. (2003) found no differences in WBSF or sensory traits for groups castrated at different ages and intact males. They observed cooking losses of steaks from the late castrated group were greater than those from the intact or early castrated groups. In addition, they concluded that castration affected the chemical composition of beef by decreasing water and increasing fat content. Finally, they found lower collagen content in early compared with late castrated animals, but this difference was not significant.

Animal welfare, reduced cattle aggressiveness, and enhanced beef quality support the practice of early castration compared to late castration. In tropical or subtropical climates where humidity and temperature are high and create the ideal environment for diseases and parasites, late castration could provide additional production challenges and inconvenience. In addition, *Bos indicus* breeds are more aggressive than *Bos taurus*, thus early castration would be useful for cattle handling. Finally, consumers are increasing their demand for tender beef and practices such as early castration would limit testosterone production and could benefit meat quality.

***BOS INDICUS* CATTLE**

The economic value of *Bos indicus* breeds of cattle, primarily Brahman, in crossbreeding programs in semitropical and tropical climates has been well established (Carroll *et al*., 1955; Cole *et al*., 1963; Crockett *et al*., 1979). *Bos indicus* cattle are used in crossbreeding programs to improve cattle productivity by increasing disease and insect resistance, climatic tolerance, heterosis, and additive genetic variation (Wheeler *et al*., 1990ab).

Live Performance:

Crouse *et al*. (1989) concluded that final live weights were lighter for *Bos indicus* crosses than *Bos taurus* breed crosses. In addition, they stated that increasing the percentage of *Bos indicus* inheritance greater than 25% decreased carcass weights. In contrast, Koch *et al*. (1982) observed that F1 Brahman x Hereford-Angus crosses had heavier live weights than F1 Hereford-Angus crosses. Koger *et al*. (1975) explained that the increasing weight advantage of Brahman x Hereford-Angus crosses may have been due to the estimated two-fold heterosis in *Bos indicus* x *Bos taurus* crosses compared to the *Bos taurus* x *Bos taurus* crosses.

Carcass Composition:

The utilization of *Bos indicus* breeds such as Brahman cattle have great advantages mainly in the tropic and subtropical regions; however, there are some widely known undesirable palatability attributes which reduce the value of Brahman cattle. Koch *et al*. (1982) and Pringle *et al*. (1997) found greater dressing percentages for *Bos taurus* than *Bos indicus* cattle. In contrast, Ramsey et al. (1965) found greater dressing percentages for Brahman cattle and attributed this advantage to lower weights of gastrointestinal tract and contents than in other breeds. Koch *et al*. (1982) concluded that Brahman crosses had higher retail product percentages (71.05%) compared to Tarentaise (70.2%) and Hereford- Angus (66.9%) crosses. Koch *et al*. (1982) also reported bone percentages were similar for Brahman crosses and other *Bos taurus* breeds. In a trial conducted by Crouse et al. (1989), *Bos taurus* males had greater fat thickness, and kidney, pelvic and heart fat than *Bos indicus* males. However, Highfill et al. (2011) did not find differences in fat thickness and kidney and pelvic fat percentages between *Bos taurus* and *Bos indicus* breeds. Koch *et al*. (1982) concluded *Bos indicus* ranked lower in kidney and pelvic fat percentages than

Tarentaise and Pinzgauer crosses. Pringle *et al*. (1997) concluded that fat thickness was greater for *Bos taurus* than for *Bos indicus*, and percentage of KPH was not different. Elzo *et al*. (2012) found less fat thickness and smaller REA for Brahman, but similar KPH compared to Angus. Sherbeck *et al*. (1995) compared 100% Hereford and ½ Hereford × ½ Brahman and did not found differences in fat thickness and % KPH, but REA was greater for the Hereford × Brahman cross. Crouse *et al*. (1989) found that Hereford × Angus cross cattle had *Longissimus* muscle areas similar to Brahman or Sahiwal crosses. In contrast, Marshall (1994) found *Longissimus* muscle areas for *Bos indicus* cattle (Brahman, Sahiwal, and Nelore) were 74.2, 74.4, and 77.8 cm^2 respectively, meanwhile, *Longissimus* muscle areas for *Bos taurus* cattle (Angus, Shorthorn, and Simmental) were 76.1, 76.2, and 82.0 cm^2, respectively.

Resistance to high temperature and humidity in tropical and subtropical regions has been associated with differentiation of fat accumulation and distribution. In all cattle, deposition of fat near the kidney precedes deposition at intermuscular, subcutaneous and intramuscular sites (Owens *et al*., 1993). However, Dairy breeds and *Bos indicus* cattle deposit more fat internally than subcutaneously, compared to temperate beef breeds (Kempster, 1981). Cartwright (1980) also found more fat accumulation in the hump and dewlap in cattle raised in tropical regions.

Bos taurus cattle generally have greater marbling (intramuscular fat) than *Bos indicus* cattle (Crouse *et al*., 1989; Marshall, 1994). It has been documented that *Bos indicus* breeds are known for their limited ability to deposit intramuscular fat and the general rule is that as the proportion of *Bos indicus* increases, marbling decreases (Koch *et al*., 1982; Crouse *et al*., 1989). Pringle *et al*. (1997) concluded that both fat thickness and marbling were greater for *Bos taurus* than *Bos indicus*. However, Highfill *et al*. (2011) found no differences in intramuscular fat in *Longissimus*

lumbarum, *Psoas major*, *Gluteus medius*, and *Semitendinosus* muscles between *Bos indicus* and *Bos taurus* cattle. Koch *et al*. (1982) indicated *Bos indicus* (Brahman and Sahiwal) had lower marbling scores compared to *Bos taurus* cattle. Marshall *et al*. (1994) concluded Brahman and Sahiwal, were similar in marbling to several of the continental European *Bos taurus* breeds but had lower sensory tenderness scores than any of the *Bos taurus* breeds. In general, retail product and bone content are similar when comparing *Bos indicus* cattle and *Bos taurus* cattle. The major difference between *Bos indicus* and *Bos taurus* cattle is carcass composition. *Bos indicus* have less subcutaneous fat thickness and intramuscular fat and also smaller REA.

Meat Quality:

Tenderness is the major meat quality concern related to the production of *Bos indicus* cattle. Possible causes of increased toughness compared to *Bos taurus* cattle include degree of marbling, amount of heat resistant connective tissue, and differences in enzymatic degradation of myofibrillar proteins (Marshall, 1994). Most studies (Koch *et al*., 1982; Crouse *et al*., 1987; Whipple *et al*., 1990; Marshall, 1994; Pringle *et al*., 1997) comparing the tenderness of meat from *Bos indicus* and *Bos taurus* cattle have observed that meat obtained from *Bos indicus* breed crosses was less tender than meat obtained from *Bos taurus* cattle. In a study (O´Connor *et al*., 1997) comparing steaks from 3/8 *Bos indicus* steers with steaks form *Bos taurus* steers, they found that *Bos taurus* steaks received higher sensory panel ratings for tenderness than *Bos indicus* steaks. The differences in tenderness among *Bos taurus* breed crosses of cattle is less than the differences in tenderness between *Bos indicus* breed crosses and *Bos taurus* breed crosses (Koch *et al*., 1976, 1979, 1982). In general meat from cattle possessing *Bos indicus* breeding is less tender than meat obtained from cattle of only *Bos taurus* breeding.

Warner-Bratzler shear force values for *Longissimus lumbarum, Gluteus medius,* and *Psoas major* steaks from *Bos indicus* cattle were higher (tougher) than those from *Bos taurus* cattle (Highfill *et al*., 2011). Shackelford et al. (1995b) reported that *Longissimus lumbarum, Gluteus medius,* and *Psoas major* tenderness decreased as the percentage of *Bos indicus* inheritance increased. Elzo *et al*. (2012) reported higher WBSF values for Brahman cattle compared to Angus cattle. Crouse et al. (1989) summarized several literature reports and generally found steaks from Brahman and Brahman crosses were less tender as measured by shear force than steaks from British breeds, but these differences have not always been significant. Sherbeck *et al*. (1995) reported greater shear force values as percentage of Brahman breeding increases. Marshall (1994) concluded that as the proportion of *Bos indicus* increases, shear force increases and marbling and sensory tenderness values decrease. This increase in shear force and decrease in sensory tenderness values with increasing levels of *Bos indicus* breeding tended to be more pronounced for Sahiwal cattle than for Brahman cattle.

Proteolytic enzyme activity in beef cattle has been determined to be an important factor in tenderness. The calpain system which consists of two calcium requiring enzymes, µ-calpain and m-calpain, and an inhibitor, calpastatin, is believed to be the primary proteolitic enzyme system involved in postmortem tenderization of aged beef (Koohmaraie, 1988, 1992). Increased calpastatin activity measured at 24 h postmortem has been implicated as a major contributor of beef tenderness differences between *Bos indicus* and *Bos taurus* cattle (Whipple *et al*., 1990). Both Red Angus and Simmental cattle had less 24 h calpastatin activity than Brahman cattle (O´Connor *et al*., 1997). Elzo *et al*. (2012) found that calpastatin activity increased linearly and µ-calpain activity decreased as proportion of Brahman breeding increased. Higher

levels of calpastatin have been associated with higher percentages of Brahman in cattle and limited postmortem tenderization resulting from blockage of the natural tenderization process of μ-calpain (Pringle *et al*., 1997). Several researchers (Johnson *et al*., 1990a; Wheeler *et al*., 1990a; Whipple *et al*., 1990; Shackelford *et al*., 1991) have reported increased activity of calcium-dependent protease inhibitor (calpastatin) for *Bos indicus* compared with *Bos taurus*. Johnson *et al*. (1990a) reported reduced cathepsin B + L total activity for Bos indicus compared with Angus, whereas Wheeler *et al*. (1990b), Whipple *et al*. (1990), and Shackelford *et al*. (1991) reported no differences for cathepsin B or B + L between *Bos indicus* and *Bos taurus* activity. Cundiff (1993) suggested that selection for low calpastatin activity may be especially useful in improving beef tenderness of *Bos indicus* breeds and composites because of their inherently high calpastatin activities and corresponding tendency to produce tougher beef.

Heritability of tenderness is approximately 0.4, making it a highly heritable trait that can be selected for to improve tenderness (Dikeman *et al*., 2005). However, the heritability estimate for shear force decreases with increasing proportion of Brahman breeding in cattle (Elzo *et al*., 1998). In contrast, Crews and Franke (1998) reported higher estimates of heritability for shear force from ½ or greater Brahman steers (0.24 to 0.36) than estimates for steers with ¼ or less Brahman inheritance (0.20). In agreement, Robinson *et al*. (2001) reported a heritability estimate of 0.11 for shear force in Hereford, Angus, Shorthorn, and Murray Grey cattle, whereas for tropically adapted cattle of Brahman, Belmont Red, and Santa Gertrudis breeding the estimate was 0.38. Riley *et al*. (2003) stated that the estimated of heritability for traits related to tenderness in Brahman cattle including Warner Bratzler shear force, postmortem calpastatin activity, sensory panel tenderness score, juiciness score, and

amount of connective tissue were low and improvement due to selection of these traits would be slow.

Crouse *et al*. (1989) concluded that meat from *Bos taurus* cattle is more finely textured and less dark in color than meat from *Bos indicus*. Otherwise meat was observed to be similar for juiciness, intensity of beef flavor, and off flavor. Elzo *et al*. (2012) compared steaks from Angus and Brahman cattle and did not find differences in flavor and off-flavor; however, evaluation of tenderness, connective tissue, and juiciness were favorable for Angus cattle. Johnson *et al*. (1990b) did not find differences in breeds groups (Angus and Brahman) for flavor or off-flavors, but steaks from ¾ Angus × ¼ Brahman were juicer than steaks from ½ Brahman and ¾ Brahman . Sherbeck *et al*. (1995) found juiciness and tenderness of steaks from 100% Hereford were superior to ½ Hereford × ½ Brahman steaks, but not in flavor. Pringle *et al*. (1997) concluded that juiciness and flavor intensity scores decreased linearly as percentage of Brahman breeding increased, and this is partially explained by the same tendency in marbling. Koch *et al*. (1982) found juiciness of steaks from Brahman and Sahiwal was lower than steaks from *Bos taurus* breeds; however, flavor intensity scores were similar among breed groups.

Tropical adaptation and nutritional intake and usage differences may have resulted in muscle cell structure and maturation changes that have contributed to tenderness differences between *Bos indicus* and *Bos taurus* breeds (Oddy *et al*., 2001). These and other forms of environmental stressors can have a dramatic influence on carcass and palatability traits (Burrow *et al*., 2001). Crouse *et al*. (1989) concluded that these tenderness problems seem to be independent of the environment in which animals were produced or composition of the meat. Regardless tenderness differences are most likely related to the fragmentation of the myofibril component of

the muscle and, to a lesser extent, to the connective tissue portion of the lean. O´Connor *et al*. (1997) suggested viable strategies for improving tenderness of beef produced by heat-tolerant composite breeds. They proposed using postmortem aging periods adequate in length to improve tenderness for all cuts from *Bos indicus* cattle. A second strategy would be to select for improved beef tenderness (via progeny testing) in *Bos indicus* breeds and crossing with *Bos taurus* breeds. And finally, substitute tropically adapted *Bos taurus* germplasm for *Bos indicus* breeding in the development of heat-tolerant composite breeds.

AGING

Postmortem Aging:

Aging is a postmortem technology that enhances beef palatability and is among the most popular options for improving tenderness (Dransfield, 1994). Beef can be "wet aged" (held for periods of time in vacuum packages) or "dry aged" (held for periods of time with no protection or package) to allow time for degradation of myofibrils via loss of integrity of sarcomeres at the Z-lines (Smith *et al*., 2008). Olson and Parrish (1977) and Koohmaraie, (1994) concluded that postmortem proteolysis of myofibrillar proteins leads to fragmentation of the muscle fiber and is the main cause of improving the tenderness of meat. Postmortem aging reduces the major determinant of tenderness by diminishing the myofibrillar influence on tenderness, and therefore, increasing the influence of stromal proteins as the latter are less affected by aging than myofibrillar proteins (Riley *et al*., 2005). The calpain system which consists of two calcium requiring enzymes, µ-calpain and m-calpain, and an inhibitor, calpastatin, is believed to be the primary proteolitic enzyme system

involved in postmortem tenderization of aged beef (Koohmaraie, 1988, 1992). Dransfield (1994) concluded that μ-calpain is activated at pH 6.3 approximately 6 h after slaughter and m-calpain is activated by calcium ions at approximately 16 h after slaughter with both forms of calpains becoming less active with increased storage. Crouse *et al*. (1991) stated that calpain activity decreases over time and suggested that postmortem proteolysis is completed at 6 d. Stolowski *et al*. (2006) evaluated calpastatin activity in ¾ Angus × ¼ Brahman cattle and found the *Triceps brachii* and *Vastus lateralis* had the highest calpastatin activity while the *Gluteus medius* and *Longissimus* had the lowest activity with the *Semitendinosus* intermediate in activity. Postmortem aging is an important management practice that can consistently improve the tenderness of beef (Tatum *et al*., 1999).

Muscle differences:

The National Beef Tenderness Survey indicated that 17 d is the average time needed to reach adequate tenderness (Morgan *et al*., 1991). However, individual muscles respond differently, in extent of tenderization improvement, to postmortem aging periods because of differences in rate and extent of pH decline and activity of calpains (Ilian *et al*., 2001) and thus in the extent of proteolityc degradation (Taylor *et al*., 1995; Rhee *et al*., 2004). Numerous studies (Smith *et al*., 1978; Eilers *et al*., 1996; Bratcher *et al*., 2005; Gruber *et al*., 2006) have been conducted to identify the optimum postmortem aging times for specific primal cuts or muscles. The influence of aging on four selected muscles is demonstrated in Table 1.

Aging times for optimum muscle tenderness vary by muscle and USDA Quality Grades. Bratcher *et al*. (2005) evaluated the *Infraspinatus, Triceps brachii-lateral head, Ttriceps brachii-long head, Serratus ventralis, Complexus, Splenius, Rhomboideus, Vastus lateralis,* and *Rectus femoris* muscles and concluded that

muscles from the Upper Two-Thirds of USDA Choice did not need aging periods beyond 7 d while beef from USDA Select should be aged at least 14 d. To achieve the optimum aging response of 17 muscles studied, Gruber *et al*. (2006) recommended 20 or more days if from USDA Select carcasses, but 10 of these 17 muscles required 18 or fewer days if they were from Upper Two-Thirds USDA Choice carcasses. Stolowski *et al*. (2006) grouped muscles according to different aging/tenderness categories and concluded that the *Gluteus medius* and *Longissimus* muscles were tender with a gradual continued response to aging for up to 42 d, the *Semitendinosus* was slightly tough with a gradual aging response up to 28 d, and the *Biceps femoris* was tough regardless of aging time. Stolowski *et al*. (2006) concluded that the total amount of collagen was related to the aging potential of a muscle and was higher for *Biceps femoris* and *Vastus lateralis* muscles than *Longissimus* and *Gluteus medius* muscles. Muscles with higher total collagen amounts also had the highest WBSF values. Collagen solubility was also highest for the *Longissimus* followed by the *Gluteus medius* and *Semitendinosus*. Tenderness improvement responses due to aging vary for different muscles and may be related to differences in collagen properties, proteolytic capabilities, and lipid deposition within the muscle.

***Bos indicus* Breeds:**

Strip loin steaks from *Bos taurus* steers exhibit a much faster rate of postmortem tenderization from 1 to 4 d than those from *Bos indicus* steers (O´Connor *et al*., 1997). Consequently, shear force values were substantially lower for steaks from *Bos taurus* cattle at 4 days and remained lower at 7, 14, 21 and 35 d of aging. From 7 to 35 d, the rate of tenderization due to aging was slightly faster for steaks from 3/8 *Bos indicus* steers than those from *Bos taurus* steers. The slower rate of tenderization during the first 7 d postmortem for beef produced by 3/8 *Bos indicus*

steers was likely associated with its higher calpastatin activity. They concluded that due to the different postmortem tenderization rates, steaks from *Bos taurus* and *Bos indicus* cattle would require different lengths of aging to ensure acceptable tenderness. Stolowski *et al*. (2006) stated that postmortem aging can improve WBSF values up to 14 d. However, postmortem aging beyond 14 d may be required to improve WBSF of steaks from cattle with large *Bos indicus* influence. Stolowski *et al*. (2006) concluded that breed type was associated with calpastatin activity and rate of postmortem aging resulting in inherent tenderness differences of their muscles.

Moisture Loss:

Aging may potentially have an effect on moisture losses such as vacuum purge, thawing losses, and cooking losses. Wheeler *et al*. (1999b) found higher thawing losses for steaks aged 3 d than those aged for 14 d. This can be partially explained as increased aging times increase package purge and moisture losses. However, George-Evins *et al*. (2004) found steaks aged for 7 d had higher percentages of thawing loss than steaks aged 21 d, but steaks aged 14 and 21 d had greater a proportion of cooking loss than those aged for 7 d. In contrast, Wheeler *et al.* (1990a) reported higher cooking losses for steaks aged 7 d when compared to those aged 14, 21 or 28 d. However, Morgan *et al*. (1993) found no cooking loss differences for steaks aged 1, 7, and 14 d. Arce and Murillo (2004) concluded that cooking losses for *Longissimus* steaks were higher in steaks aged for 28 d than those aged for 2, 7, 14, and 21 d. Although not conclusive and variable, total moisture losses generally increases as the aging time increases.

MUSCLE PROPERTIES

Muscle properties such as fat content, water holding capacity, fragmentation of myofibrils, calpastatin activity, μ-calpain activity, sarcomere length, and connective tissue amount can be influenced by multiple factors such as farm management practices, genetics, environment, postmortem processing, and cooking temperatures. Therefore, muscles need to be identified, and merchandising according to their value differences. Identifying inherent muscle characteristics would be useful when applying techniques such as aging to enhance beef quality and value. Muscle properties for the four muscles investigated in this study are described in Table 2. Following is a discussion of muscle properties and their relationships.

Tenderness:

Tenderness of cooked beef muscle is determined by amounts of connective tissue left insolubilized (gristle), amounts of intramuscular moisture and fat, and the structural integrity of sarcomeres, myofibrils and muscle fibers at the time of consumption (Smith *et al*., 2008).

The tenderness of cooked beef can be measured by a sensory panel or mechanically by WBSF. For a sensory panel, tenderness can be described as myofirillar tenderness, connective tissue amount and overall tenderness (Savell *et al*., 1982). Otremba *et al*. (1999) described myofibrillar tenderness as the perception of how tough or tender the myofibrillar component is. This perception is determined by the softness to the tongue to the cheek, softness to tooth pressure, and the ease with which muscle fibers break (Blumer, 1963). The amount of connective tissue is defined as the tissue (gristle) remaining in the palate upon completion of mastication,

prior to swallowing. Overall tenderness is the composite perception of how tough or tender a meat sample is in totality.

Warner–Bratzler shear force (WBSF) has been proven as an effective predictor of tenderness (Arthaud *et al*., 1969). Warner-Braztler shear force assesses the tenderness of meat by measuring the amount of force in kilograms to shear 1.24-cm core samples (AMSA, 1995). There is a high correlation (r=0.78) between WBSF and sensory panel tenderness (Gruber et al., 2006). Shakelford *et al*., (1995) reported high correlation values (r=0.70) when assessed sensory tenderness and WBSF. Otremba *et al*. (1999) determined a correlation (r=0.54 and r=0.56) between sensory and WBSF in *Longissimus* and S*emitendinosus* muscles cooked to an internal temperature of 71 ºC. Huffman et al., (1996) concluded that a Warner-Bratzler shear force of 4.1 kg could be used as a threshold to indicate that 98% of restaurant and home consumers would find a *Longissimus* steak acceptable in tenderness. Warner-Bratzler shear force is an accepted and highly effective measure to predict beef tenderness and consumer acceptance.

Steaks from different muscles have different properties and therefore different tenderness values (Tables 1 and 2). Shackelford, *et al*. (1995) compared the tenderness of 10 major beef muscles using WBSF. They reported significant differences in tenderness among muscles and found: *Psoas major* = *Infraspinatus* > *Triceps brachii* = *Longissimus* > *Semitendinosus* = *Gluteus medius* = *Supraspinatus* > *Biceps femoris* = *Semimembranosus* = *Quadriceps femoris*. In a similar study (Rhee *et al*., 2004) comparing WBSF values from 11 beef muscles. Significant differences were found with the *Psoas major* having the lowest values followed by the *Infraspinatus*, while the *Adductor* and *Supraspinatus* had the greatest values. Highfill *et al*. (2011) compared *Longissimus, Gluteus medius, Semitendinosus* and *Psoas*

major muscles from *Bos indicus* and *Bos taurus* and found steaks from *Bos taurus* were more tender than those from *Bos indicus*. However, steaks from *Bos taurus* cattle had advantages in intramuscular lipid content and likely contributed to an associative tenderness advantage. Furthermore, when comparing *Bos indicus* steaks, the tenderness order was: *Psoas major* > *Longissimus* > *Gluteus medius* > *Semitendinosus*. In addition, some muscles (*Longissimus* and *Gluteus medius*) appeared to have more variability than others (*Psoas major* and *Semitendinosus*).

Juiciness and Moisture Losses:

The ability of fresh meat to retain moisture is arguably one of the most important quality characteristics of raw products (Huff-Lonergan and Lonergan, 2005). The majority of water in muscle is held either within the myofibers between the myofibrils and between the myofibrils and the sarcolemma, or between the myofibers and muscle bundles. Water can be classified as bound water which is firmly attached to proteins, immobilized water which is most affected by the rigor process and the conversion of muscle to meat, and finally, free water that flows from the tissue unimpeded. Furthermore, the manipulation of the net charge of myofibrillar proteins, the structure of the muscle cell, and the amount of extracellular space within the muscle itself are factors that can influence the retention of entrapped water (Huff-Lonergan and Lonergan, 2005).

Juiciness is the amount of liquid expressed from the sample from the initial chews. It is related to moisture content and the influence of lipids as they stimulate salivation and the sensory perception of juiciness (Blumer, 1963). Fat stimulates the flow of saliva with the net result being an increase in juiciness. The juiciness attributable to beef fat comes primarily from fatty acids since only about of 10% beef fat is water (Blumer, 1963).

Highfill *et al*. (2011) reported *Longissimus, Psoas major* and *Gluteus medius* steaks aged for 10 d postmortem had cooking losses of 23.6, 30.0, and 29.9%, respectively. Wheeler *et al*. (1999b) cooked strip loin steaks to final endpoint temperatures of 60, 70, or 80 ºC and found cooking losses of 13.5, 18.2, and 23.6%, respectively. In a study conducted by Feoli (2002) in Costa Rica using *Bos indicus* breeds, strip loin, tenderloin, and top sirloin steaks aged 5 d displayed thawing losses of 7.4%, 4.2%, and 4.1% respectively and cooking losses of 25.7%, 22.2%, and 27.2% respectively. Highfill *et al*. (2011) determined cooking losses for *Longissimus, Gluteus medius, and Psoas major* steaks and found 23.6%, 29.9% and 30.0% , respectively.

According to Jones *et al*. (2004), the muscle rank for increased water holding capacity (Table 2) is: *Gluteus medius* > *Longissimus* > *Semitendinosus* > *Psoas major*. The muscle rank for total moisture is: *Semimembranosus* > *Psoas major* > *Gluteus medius* > *Longissimus*. In addition, Rhee *et al*. (2004) concluded that the cooking loss ranking for these muscles is: *Semitendinosus* > *Psoas major* = *Gluteus medius* > *Longissimus* (Table 2). For juiciness the order is: *Psoas major* > *Gluteus medius* > *Longissimus* > *Semitendinosus,* but Sullivan and Calkins (2011) found the order for juiciness to be: *Longissimus* > *Psoas major* > *Gluteus medius* > *Semitendinosus.*

Moisture properties for muscles are variable and dependent on many contributing factors and interactions.

Beef Flavor:

Flavor is a combination of several chemicals interactions involving proteins, lipids and carbohydrates (Spanier *et al*., 1997) and is a very complex attribute of meat palatability (Calkins and Hodgen, 2007). Beef flavor intensity is defined as the intensity with which the beef sample is recognized as distinctly beef rather than meat

from other species. Flavor consists of taste-active compounds, flavor enhancers and aroma components with over 880 compounds presently identified in cooked beef (Stelzleni and Johnson, 2008). Off-flavor development in beef is affected by several factors which include nutrition, animal species, sex of the animal, age of the animal, breed, aging of meat, muscle type, cooking method and type of storage (Spanier *et al*., 1997). Off-flavors develop with increased aging (Calkins and Hodgen, 2007) because meat nitrogen containing compounds can be formed by natural degradation. According to Rhee *et al*. (2004) beef flavor intensity (Table 2) for different muscles are ranked: *Longissimus* > *Gluteus medius* = *Semitendinosus* > *Psoas major*. However, they found that off-flavor from most to least were ranked: *Psoas major* > *Gluteus medius* = *Semitendinosus* > *Longissimus*. Sullivan and Calkins (2011) obtained the same rankings for beef flavor intensity and Lorenzen *et al*. (2003) concluded that beef flavor intensity was slightly greater for *Gluteus medius* than *Longissimus* steaks. Overall that *Longissimus* and *Gluteus medius* rank high and the *Psoas major* ranks lower in beef flavor. The *Psoas major* appears to be more susceptible to off-flavors.

Table 1. Warner-Bratzler shear force values of Select grade *Longissimus, Psoas major, Gluteus medius*, and *Semitendinosus* steaks aged for 2, 6, 14, and 28 d1.

	Days of Aging			
Muscle	2 d	6 d	14 d	28 d
Longissimus	6.7	5.9	5.0	4.3
Psoas major	4.6	4.2	3.7	3.3
Gluteus medius	6.2	5.9	5.4	4.7
Semitendinosus	6.4	5.7	5.2	4.8

[1]Warner-Bratzler shear force estimated from aging curves from Industry Guidelines for Aging Beef, NCBA 2006.

Table 2. Overall means for physical and sensory properties of selected muscles.

Trait	Muscle			
	Gluteus medius	*Longissimus*	*Psoas major*	*Semitendinosus*
pH[1]	5.7	5.6	5.7	5.7
WHC	45.7	44.2	43.7	44.0
L*[1]	32.6	40.6	34.4	38.3
a*[1]	28.3	31.1	34.1	28.0
b*[1]	21.7	24.0	20.9	21.8
Fat[1], %	4.8	4.6	5.7	2.9
Moisture[1], %	74.4	74.2	74.5	75.9
Ash[1], mg/g	1.6	1.5	1.6	1.4
Protein[1], mg/g	19.3	19.7	18.3	19.7
Collagen[2], mg/g	4.3	4.5	2.7	8.7
WBSF2, kg	4.4	4.0	3.0	4.3
Sarcomere lenght[2],µm	1.8	1.8	2.9	2.1
Cooking loss[2], %	23.6	20.7	23.6	27.4
Connective tissue[2]	6.2	6.9	7.7	5.6
Flavor intensity[2]	4.1	4.4	3.9	4.1
Juiciness[2]	5.1	5.1	5.2	4.8
Off flavor[2]	2.4	2.7	2.2	2.4
Overall tenderness[2]	4.7	5.7	7.4	4.1

[1]Jones et al. (2004).

[2]Rhee et al., (2004).

Sensory traits were evaluated on a scale of 1 to 8 for connective tissue amount (1 = abundant, 8 = none), flavor intensity (1 = extremely bland, 8 = extremely intense), juiciness (1 = extremely dry, 8 = extremely juicy), off flavor (1 = extremely intense, 8 = none), and overall tenderness (1 = extremely tough, 8 = extremely tender).

LITERATURE CITED

AMSA. 1995. Research Guidelines for Cookery, Sensory Evaluation and Instrumental Tenderness Measurements of Fresh Meat. American Meat Sci. Association in cooperation with National Livestock and Meat Board, Chicago Illinois.

Albaugh, A., F. D. Carrol, K. W. Ellis, and R. Albaugh. 1975. Comparison of carcasses and meat from steers, short scrotum bulls and intact bulls. J. Anim. Sci. 41:1627-1631.

Arce, E., and Murillo, O. 2004. "Efecto de la maduración sobre la suavidad de la carne de animales cebuínos en pastoreo". Thesis. Escuela de Agronomía. Instituto Tecnológico de Costa Rica. Alajuela (ITCR), Costa Rica.

Ardaya, J., and Zapata, P. 1999. "Efecto de la castración en la ganancia de pesoel rendimineto y calidad de canal de bovinos machos semiestabulados". Thesis. Escuela de Agricultura de la Región Tropical Húmeda (EARTH). Limón, Costa Rica.

Arthaud, V. H., C. H. Adams, D. R Jacobs, and R. M. Koch. 1969. Comparison of carcass traits of bulls and steers. J. Anim. Sci. 28:742-745.

Arthaud, V. H., R. W. Mandigo, R. M. Koch, and A. W. Kotula. 1977. Carcass composition, quality and palatability attributes of bulls and steers fed different energy levels and killed at four ages. J. Anim. Sci. 44:53-64.

Bailey, A. J., D. J. Restall, T. J. Sims, and V. C. Duance. 1979. Meat tenderness: Immunofluorescent localization of the isomorphic forms of collagen in bovine muscles of varying texture. J. Sci. Food Agr. 30:203-210.

Barnes, M. A., G. W. Kazmer, G. P. Birrenkott, and L. W. Grimes. 1983. Induced gonadotropin release in adrenocorticotropin-treated bulls-steers. J. Anim. Sci. 56:155-161.

Bauman, D. E., J. H. Eisemann, and W. B. Currie. 1982. Hormonal effects on partitioning for tissue growth: Role of growth hormone and prolactin. Fed. Proc. 41:2538-2544.

Bavera, G. A., and C. H. Peñafort. 2005. Evaluación exterior de los signos de fertilidad y subfertilidad de un rodeo. Cursos de Producción Bovina de Carne, FAV UNRC. Pp 1-15.

Beitz, D. C. 1985. Physiological and metabolic systems important to animal growth: An overview. J. Anim. Sci. 61(Suppl.2):1-20.

Berg, R. T., and R. M. Butterfield. 1968. Growth patterns of bovine muscle fat and bone. J. Anim. Sci. 27:611-619.

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

Bidner, T. D., A. R. Schupp, A. B. Mohamad, N. C. Rumore, R. E. Montgomery, C. P. Bagley, and K. W. Mc Millin. 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.

Blumer, T. N. 1963. Relationship of marbling to the palatability of beef. J. Anim. Sci. 22:771-778.

Boccard, R., and P. Bordes. 1986. Caracteristiques qualitatives et technologiques des viandes bovines: influence des facteurs de production. In D. Micol (Ed.), Production de viande bovine Paris: INRA. Pp 61-84.

Boccard, R., R. T. Naude, D. E. Cronje, M. C. Smith, H. J. Venter, and E. J. Rossouw.1979. The influence of age, sex and, breed of cattle on their muscle characteristics. Meat Sci. 3:261-279.

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.

Brannang, E. 1966. The effect of castration and age of castration of the growth rate, feed conversion and casrcass traits of Swedish red and white cattle. Lantbrukshogskolansannaler 32. Pp 329-415.

Bratcher, C. L., D. D. Johnson, R. C. Littell, and B. L. Gwartnery. 2005. The effects of quality grade, aging and location within muscle on Warner-Bratzler shear force in beef muscles of locomotion. Meat Sci. 70:279-284.

Bretschneinder, G. 2005. Effects of age and method of castration on performance and stress response of beef male cattle. Liv. Prod. Sci. 97:89-100.

Brooks, J. C., J. B. Belew, D. B. Griffin, B. L. Gwartney, D. S. Hale, W. R. Henning, D. D. Johnson, J. B. Morgan, F. C. Parrish, Jr., J. O. Reagan, and J. W. Savell. 2000. National Beef Tenderness Survey - 1998. J. Anim. Sci. 78:1852–1860.

Burrow, H. M., S. S. Moore, D. J. Johnston, W. Barendse, and B. M. Bindon. 2001. Quantitative and molecular genetic influences on properties of beef: A review. Aust. J. Exp. Agric. 41:893-920.

Burson, D. E., M. C. Hunt, J. A. Unruh , and M. E. Dikeman. 1986. Proportion of types I and III collagen from bulls and steers. J. Anim. Sci. 63:453-456.

Calkins, C. R., D. C. Clanton, T. J Berg and J. E. Kinder. 1986. Growth, carcass and palatability traits of intact males and steers implanted with zeranol or estradiol early and throughout life. J. Anim. Sci. 62:625-631.

Calkins, C. R. and J. M. Hodgen. 2007. A fresh look at meat flavor. Meat Sci. 77:63-80.

Carroll, F. D., W. C. Rollins, and N. R. Ittner. 1955. Brahman-Hereford crossbreeds and Herefords gains, carcass yields and carcass differences. J. Anim. Sci. 14:218-223.

Cartwright, T.C. 1980. Prognosis of Zebu cattle: research and application. J. Anim. Sci. 50:1221-1226.

Chambers, E., and J. R. Bowers. 1993. Consumer perception of sensory qualities in muscle foods. Food Tech. 47:116-120.

Champagne, J. R., J. W. Carpenter, J. F. Hentges, Jr., A. Z. Palmer, and M. Morger. 1969. Feedlot performance and carcass characteristics of young bulls and steers castrated at four ages. J. Anim. Sci. 29:887-890.

Cobic, T. 1968. Castration experiments with Yugoslav Simmental cattle. I. The effect of castration on growth and live-weight gains. Anim. Prod. 10:103-107.

Cohen, R. D. H., B. D. King, E. D. Jansen, and H. H. Nicholson. 1991. The effect of castration age, method and implant regime on growth and carcass traits of male beef cattle. Can. J. Anim. Sci. 71:301-309.

Cole, J. W., C. B. Ramsey, C. S. Hobbs, and R. S. Temple. 1963. Effects of type and breed of British, Zebu and dairy cattle on production, palatability and composition. I. Rate of gain, feed efficiency and factors affecting market value. J. Anim. Sci. 22:702-707.

Crews, D. H., Jr., and D. E. Franke. 1998. Heterogeneity of variances for carcass traits by percentage Brahman inheritance. J. Anim. Sci. 76:1803-1809.

Crockett, J. R., F. S. Baker, Jr., J. W. Carpenter, and M. Koger. 1979. Preweaning, feedlot and carcass characteristics of calves sired by Continental, Brahman and Brahman-derivative sires in subtropical Florida. J. Anim. Sci. 49:900-907.

Cross, H.R., B. D. Schanbacher, and J. D. Crouse. 1984. Sex, age and breed related changes in bovine testosterone and intramuscular collagen. Meat Sci. 10:187-195.

Crouse J. D., L. V. Cundiff., R. M. Koch., M. Koohmaraire, and S.C. Seideman. 1989. Comparisons of *Bos indicus* and *Bos taurus* inheritance for carcass beef characteristics and meat palatability. J. Anim. Sci. 67:2661-2668.

Crouse J. D., M. Koohmaraire, and S. C. Seideman. 1991. The relationship of muscle fiber size to tenderness of beef. Meat Sci. 30:295-302.

Crouse J. D., S. C. Seideman, and L. V. Cundiff. 1987. The effect of carcass electrical stimulation on meat obtained from *Bos indicus* and *Bos taurus* cattle. J. Food Qual. 10:407-416.

Cundiff, L. V. 1993. How breed variations affect carcass quality and cutability. Presented at the National Cattlemen's Association Annual Convention, Phoenix, AZ. Pp 1-33.

Destefanis, D., A. Brugiapaglia., M. T. Barge, and C. Lazzaroni. 2003. Effect of castration on meat quality in Piemontese cattle. Meat Sci. 64:215-218.

Dikeman, M. E., E. J. Pollak, Z. Zhang, D. W. Moser, C. A. Gill, and E. A. Dressler. 2005. Phenotypic ranges and relationships among carcass and meat palatability traits for fourteen cattle breeds, and heritablities and expected progeny differences for Warner–Bratzler shear force in three beef cattle breeds. J. Anim. Sci. 83:2461-2467.

Dikeman, M. E., G. B. Reddy , V. H. Arthaud, H. J. Tuma, R. M. Koch, R. W. Mandigo, and J. B. Axe. 1986. *Longissimus* muscle quality, palatability and connective tissue histological characteristics of bulls and steers fed different energy levels and slaughtered at four ages. J. Anim. Sci. 63:92-101.

Dikeman, M. E., H. C. Russell, and J. D. Crouse. 1985. Recommendations for the production of young bulls for meat. Agricultural Experiment Station. Kansas State University, Manhattan. Bulletin 648. Pp1-12.

Dransfield, E. 1994. Optimization of tenderization, aging, and tenderness. Meat Sci. 36:105-121.

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.

Elzo, M. A., D. D. Johnson, J. G. Wasdin, and J. D. Driver. 2012. Carcass and meat palatability breed differences and heterosis effects in an Angus-Brahman multibreed population .Meat Sci. 90:87-92.

Elzo, M. A., R. L. West, D. D. Johnson, and D. L. Wakeman. 1998. Genetic variation and prediction of additive and non-additive genetic effects for six carcass traits in an Angus-Brahman multibreed herd. J. Anim. Sci. 76:1810-1823.

Feoli, C. 2002. "Efecto de la edad y el sexo del ganado cebuino de dos zonas del norte de Costa Rica sobre el rendimiento y las características de la calidad de la carne". Thesis. Facultad de Agronomía, Escuela de Zootecnia. Universidad de Costa Rica (UCR). San José, Costa Rica.

Field, R.A. 1971. Effect of castration on meat quality and quantity. J. Anim. Sci. 1971. 32: 849-858.

Field, R. A., G. E. Nelms, and C. O. Schoonover. 1966. Effect of age, marbling and sex on palatability of beef. J. Anim. Sci. 25:360-366.

Forbes, T. D. A., F. M. Rouquette, Jr., and J. W. Holloway. 1998. Comparisons among Tuli, Brahman and Angus sired heifers: Intake, digesta kinetics, and grazing behavior. J. Anim. Sci. 76:220-227.

Frohman, L. A. 1991. Endocrine and endocrine regulation of cell function and growth. J. Anim. Sci. 69:74-81.

George-Evins, C. D., J. A Unruh, A. T. Waylan, and J. L. Marsden . 2004. Influence of quality classification, aging period, blade tenderization, and endpoint cooking temperature on cooking characteristics and tenderness of beef gluteus medius steaks. J. Anim. Sci. 82:1863-1867.

Gerrard, D. E., S. J. Jones, E. D. Aberle, R. P. Lemenager, M. A. Diekman, and M. D. Judge. 1987. Collagen stability, testosterone secretion and tenderness in growing bulls and steers. J. Anim. Sci. 65:1236-1242.

Glimp, H. A., M. E. Dikeman, H. J. Tuma., K. E. Gregory, and L. V. Cundiff. 1971. Effect of sex condition on growth and carcass traits of male Hereford and Angus cattle. J. Anim. Sci. 33:1242-1247.

Gray, D. G., J. A. Unruh, M. E. Dikeman, and J. S. Stevenson. 1986. Implanting young bulls with zeranol from birth to four slaughter ages: III. Growth performance and endocrine aspects. J. Anim. Sci. 63:747-756.

Gregory, K. E., S. C. Seideman, and J. J. Ford. 1983. Effects of late castration, zeranol and breed group on composition and palatability characteristics of longissimus muscle of bovine males. J. Anim. Sci. 56:781-786.

Gruber, S. L.; J. D. Tatum, J. A. Scanga, P. L. Chapman, G. C. Smith , and K. E. Belk. 2006. Effects of postmortem aging and USDA quality grade on Warner-Braztler shear force values of seventeen individual muscles. J. Anim. Sci. 84:3387-3396.

Hafs, H. D., R. W. Purchas, and A. M. Pearson. 1971. A review: Relationships of some hormones to growth and carcass quality of ruminants. J. Anim. Sci. 33:64-71.

Hedrick, H.B. 1968. Bovine growth and composition. Univ. Mo. Agr. Exp. Sta. Bull. 928. Pp37-96.

Hedrick, H. B., G. B. Thompson, and G. F. Krause. 1969. Comparison of feedlot performance and carcass characteristics of half-sib bulls, steers and heifers. J. Anim. Sci. 29:687-694.

Highfill, C. M., O. Esquivel-Font, M. E. Dikeman,, and D. H. Kropf. 2011. Tenderness profiles of ten muscles from F1 *Bos indicus* x *Bos taurus* and *Bos taurus* cattle cooked as steaks and roasts. Meat Sci. 90:881-886.

Huerta-Leidenz, N., O. Atencio-Valladares., A. Rodas-Gonzalez., N. Jerez-Timaure, and B. Bracho. 1997. Características de canales de novillos y novillas acebuados producidos a pastoreo y su relación con atributos de la calidad comestible de la carne. Arch. Latinoame. Prod. Anim. 5(Supl.1):565-567.

Huerta-Leidenz, N., and G. Ríos. 1993. La castración del bovino a diferentes estadios de su crecimiento. II. Las características de la canal. Una revisión. Rev. Fac. Agron. 10:163-187.

Huff-Lonergan, E., and S. M. Lonergan. 2005. Mechanisms of water-holding capacity of meat: The role of postmortem biochemical and structural changes. Meat Sci. 71:194-204.

Huffman, K. L., M. F. Miller, L. C. Hoover, C. K. Wu, H. C. Brittin, and C.B. Ramsey. 1996. Effect of beef tenderness on consumer satisfaction with steaks consumed in the home and restaurant. J. Anim. Sci. 74:91-97.

Hunsley, R. E., R. L. Verter, E. A. Kline, and W. Burroughs. 1971. Effects of age and sex on quality, tenderness and collagen content of bovine *Longissimus* muscle. J. Anim. Sci. 33:933-938.

Ilian, M. A., J. D. Morton, M. P. Kent, C. E. LeCouteur, J. Hickford, R. Cowley, and R. Bickerstaffe. 2001. Intermuscular variation in tenderness: Association with ubiquitous and muscle-specific calpains. J. Anim. Sci. 79:122-132.

Jacobs, J. A., C. E. Hurst, J. C. Miller, A.D. Howes, and Gregory T.L. 1977a. Bulls versus Steers. I. Carcass composition, wholesale yields and retail values. J. Anim. Sci. 45:695-698.

Jacobs, J. A., J. C. Miller, E. A. Sauter, A. Howes, A. A. Araji., T. L. Gregory, and Hurst, C.E. 1977b. Bulls versus steers. II. Palatability and retail acceptance. J. Anim. Sci. 45:699-702.

Jeremiah, L. E., A. K. W. Tong, and L. L. Gibson. 1991. The usefulness of muscle color and pH for segregating beef carcasses in to tenderness groups. Meat Sci. 30:97-114.

Jerez-Timaure, N., N. Huerta-Leidenz., E. Rincon, and M. Arispe. 1994. Estudio preliminar sobre las caracteristicas que afectan las propiedades organolépticas de solomos de res en Venezuela. Rev. Fac. Agron. 11:283-295.

Johnson, M. H., C. R. Calkins, R. D. Huffman, D. D. Johnson, and D. D. Hargrove. 1990a. Differences in cathepsin B + L and calcium dependent protease activities among breed type and their relationship to beef tenderness. J. Anim. Sci. 68:2371-2379.

Johnson, D. D., R. D. Huffman, S. E. Williams, and D. D. Hargrove. 1990b. Effects of percentage of Brahman and Angus breeding, age, season of feeding and slaughter endpoint on meat palatability and muscle characteristics. J. Anim. Sci. 68:1980-1986.

Jones, S. J., A. Guru, V. Singh, B. Carpenter, C. R. Calkins, and D. Johnson. 2004. Bovine myology and muscle profiling. http://bovine.unl.edu. Accessed March 8, 2012.

Kay, M., and R. Houseman. 1974. The influence of sex in meat production. In: D.J.A. Cole and R.A. Lawrie (Ed.) Proc. of the 21st Easter School in Agr. Sci. pp 85-108. Butterworth, London.

Kempster, A. J. 1981. Fat partition and distribution in the carcasses of cattle, sheep and pigs: a review. Meat Sci. 5:83-98.

King, B. D., R. D. H. Cohen, C. L. Guenther, and E. D. Jansen. 1991. The effect of age and method of castration on plasma cortisol in beef calves. Can. J. Anim. Sci. 71:257-263.

Killinger, K. M., C. R. Calkins, W. J. Umberger, D. M. Feuz, and K. M. Eskridge. 2004.Consumer sensory acceptance and value for beef steaks of similar tenderness, but differing marbling level. J. Anim. Sci. 82:3294-3301.

Klosterman, E. W., L. E. Kunkle, P. Gerlaugh, and V. R. Cahill. 1954. The effect of age of castration upon rate and economy of gain and carcass quality of beef calves. J. Anim. Sci. 13:817-825.

Koch, R. M., M. E. Dikeman, D. M. Allen, M. May, J. D. Crouse, and D. R. Campion. 1976. Characterization of biological types of cattle III. Carcass composition, quality and palatability. J. Anim. Sci. 43:48-62.

Koch, R. M., M. E. Dikeman, and, J. D. Crouse. 1982. Characterization of biological types of cattle (Cycle III). III. Carcass composition, quality and palatability. J. Anim. Sci. 54:35-45.

Koch, R. M., M. E. Dikeman, R. J. Lipsey, D. M. Allen, and J. D. Crouse. 1979. Characterization of biological types of cattle – Cycle: II:III. Carcass composition, quality and palatability. J. Anim. Sci. 49:448-460.

Koger, M., F. M. Peacock, W. G. Kirk, and J. R. Crockett. 1975. Heterosis effects on weaning performance of Brahman-Shorthorn calves. J. Anim. Sci. 40:826-833.

Koohmaraie, M. 1988. The role of endogenous proteases in meat tenderness. Proc. Recip. Meat Conf. 41:89-100.

Koohmaraie, M. 1992. Role of the neutral proteinases in postmortem muscle protein degradation and meat tenderness. Proc. Recip. Meat Conf. 45:63-74.

Koohmaraie, M. 1994. Muscle proteinases and meat ageing. Meat Sci. 36:93-104.

Landon, M. E., H. B. Hedrick, and G. B. Thompson. 1978. Live animal performance and carcass characteristics of beef bullocks and steers. J. Anim. Sci. 47:151-155.

Light, N., A. E. Champion, C. Voyle, and A. J. Bayley. 1985. The role of epimysial, perimisyal and endomysial collagen in determining texture in six bovine muscles. Meat Sci. 13:137-149.

Lochner, J. V., R. G. Kaufman, and B. B. Marsh.1980. Early postmortem cooling rate and beef tenderness. Meat Sci. 4:227-241.

Lorenzen, C. L., R. K. Miller, J. F. Taylor, T. R. Neely, J. D. Tatum, J. W. Wise, M. J. Buyck, J.O. Reagan, and J. W. Savell. 2003. Beef consumer satisfaction: Trained sensory panel ratings and Warner Bratzler shear force values. J. Anim. Sci. 81:143-149.

Lunstra, D. D., J. J. Ford, and S. E. Echternkamp. 1978. Puberty in beef bulls: Hormone concentrations, growth, testicular development, sperm production and sexual aggressiveness in bulls of different breeds. J. Anim. Sci. 46:1054-1062.

Mach, N., C. Realini., M. F. Furnols., A. Velarde, and M. Devant. 2009. Effects of pre-pubertal Burdizzo castration on performance, carcass characteristics and meat quality from young Holstein bulls fed high-concentrate diets. Meat Sci. 81:329-334.

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

Marshall, D. M. 1994. Breed differences and genetic parameters for body composition traits in beef cattle. J. Anim. Sci. 72:2745-2755.

Martin, L. C., J. S. Brinks, R. M. Bourdon, and L. V. Cundiff. 1992. Genetic effects on beef heifer puberty and subsequent reproduction. J. Anim. Sci. 70:4006-4017.

Martin, T. G., T. W. Perry, W. M. Beeson, and M. T. Mohler. 1978. Protein levels for bulls: Comparison of three continuous dietary levels on growth and carcass traits. J. Anim. Sci. 47:29-33.

McCarty, M. S., H. D. Hafs, and E. M. Convey. 1979. Serum hormone patterns associated with growth and sexual development in bulls. J. Anim. Sci. 49:1012-1020.

Miller, M. F., M. A. Carr, C. B. Ramsey, K. L. Crockett, and L. C. Hoover. 2001. Consumer thresholds for establishing the value of beef tenderness. J. Anim. Sci. 79:3062-3068.

Mitchell, G. E., A. W. Reed, and S. A. Rogers. 1991. Influence of feeding regimen on the sensory qualities and fatty acid content of beef steaks. J. Food Sci. 56:1102-103.

Morgan, J. B., J. W. Savell., D. S. Hale., R. K. Miller., D. B. Griffin., H. R. Cross, and S. D. Shackelford. 1991. National Beef Tenderness Survey. J. Anim. Sci. 69:3274-3280.

Morgan, J. B., T. L Wheeler, M. Koohmaraie, J. W. Savell, and J. D. Crouse. 1993. Meat tenderness and the calpain proteolytic system in *Longissimus* muscle of young bulls and steers. J. Anim. Sci. 71:1471-1476.

Morón, O., S. Pietrosemoli, and J. Mazza. 2005a. Efecto del tipo de castración sobre las cualidades sensoriales de bovinos en confinamiento II. XIX Reunión de la Asociación Latinoamericana de Producción Animal. BIOTAM. Nueva Serie. Pp 521.

Morón, O., S. Pietrosemoli, and J. Mazza. 2005b. Efecto del tipo de castración sobre la ganancia de peso y el rendimiento en canal de bovinos en confinamiento. XIX Reunión de la Asociación Latinoamericana de Producción Animal. BIOTAM. Nueva Serie. Pp 548.

Mosely, W. M., L. F. Krabill and R. F. Olsen. 1982. Effect of bovine growth hormone administrated in various patterns on nitrogen metabolism in the Holstein steer. J. Anim. Sci. 44:1062-1070.

Muller A., D. Micol., J. R. Peccatte, and D. Dozias. 1991. Choix de l'âge à la castration en production de viande bovine semi-intensive. INRA Prod. Anim., 4:287-295.

Murillo, O. Personal communication. March 5, 2012.

O'Connor, S. F., J. D. Tatum, D. M. Wulf, R. D. Green, and G. C. Smith,. 1997. Genetic effects on beef tenderness in *Bos indicus* composite and *Bos taurus* cattle. J. Anim. Sci. 75:1822-1830.

Oddy, V. H., G. S. Harper, P. L. Greenwood, and M. B. McDonagh. 2001. Nutritional and developmental effects on the intrinsic properties of muscles as they relate to the eating quality of beef. Aust. J. Exp. Agric. 41:921-942.

Olson, D. G., and F. C. Parrish. 1977. Relationship of myofibril fragmentation index to measures of beefsteak tenderness. J. Food Sci. 42:506-509.

Otremba, M. M., M. E. Dikeman, G. A. Milliken, S. L. Stroda, J. A. Unruh, and E. Chambers. 1999. Interrelationships among evaluations of beef *Longissimus* and *Semitendinosus* muscle tenderness by Warner Braztler shear force, a descriptive texture profile sensory panel, and descriptive attribute sensory panel. J. Anim. Sci. 77:865-873.

Owens, F. N., P. Dubeski, and C. F. Hanson. 1993. Factors that alter the growth and development of ruminants. J. Anim. Sci. 71:3138-3150.

Perez, E. Personal communication. March 11, 2009.

Polidori, P., R. Kauffman, and F. Valfre. 1996. The effects of electrical stimulation on meat quality. Italian J. Food Sci. 8:183-199.

Prescott, J. D., and G.E. Lamming, 1964. The effects of castration on meat production in cattle, sheep and pigs. J. Agric. Sci. 63:341-357.

Preston, R. L. 1975. Biological responses to estrogen additives in meat producing cattle and lambs. J. Anim. Sci. 44:1414-1430.

Pringle, T. D., S. E. Williams, B. S. Lamb, D. D. Johnson, and R. L. West. 1997. Carcass characteristics, the calpain proteinase system, and age tenderness of Angus and Brahman crossbreed steers. J. Anim. Sci. 75:2955–2961.

Purchas, R. W.1990. An assessment of the role of pH differences in determining the relative tenderness of meat from bulls and steers. Meat Sci. 27:129-140.

Purchas, R. W., D. L. Burnham and, and S. T. Morris. 2002. Effects of growth potential and growth path on tenderness of beef *Longissimus* muscle from bulls and steers. J. Anim. Sci. 80:3211-3221.

Purchas, R. W and D. A. Grant. 1995. Liveweight gain and carcass characteristics of bulls and steers farmed on hill country. J. Agri. Res. 38: 131-142.

Ramsey, C. B., J. W. Cole, R. N. Terrell, and R. S. Temple. 1965. Effects of type and breed British, Zebu and dairy cattle on production, palatability and composition. IV. Yield of gastrointestinal tract and other non -carcass components. J. Anim. Sci. 24:120-126.

Ray, D. E., W. H. Hale, and J. A. Marchello. 1969. Influence of season, sex and hormonal growth stimulants on feedlot performance of beef cattle. J. Anim. Sci. 29:490-495.

Reagan, J. O., Z. L. Carpenter., G. C. Smith, and G. T. King. 1971. Comparison of palatability traits of beef produced by young bulls and steers. J. Anim. Sci. 32:641-646.

Retana, F. Personal communication. March 11, 2012.

Rhee, M. S., T. L. Wheeler., S. D. Shackelford, and M. Koohmaraie. 2004. Variation in palatability and biochemical traits within and among eleven beef muscles. J. Anim. Sci. 82:534-550.

Riley, D. G., C. C. Chase, Jr., A. C. Hammond, R. L. West, D. D. Johnson, T. A. Olson, and S. W. Coleman. 2003. Estimated genetic parameters for palatability traits of steaks from Brahman cattle. J. Anim. Sci. 81:54-60.

Riley, D. G., D. D. Johnson, C. C. Chase, Jr., R. L. West , S. W. Coleman, T. A. Olson, and A. C. Hammond. 2005. Factors influencing tenderness in steaks from Brahman cattle. Meat Sci. 70:347-3356.

Riley, R. R., J. W. Savell, C. E. Murphey, G. C. Smith, D. M. Stiffler, and H. R. Cross. 1983. Palatability of beef from steers and young bull carcasses as influenced by electrical stimulation, subcutaneous fat thickness and marbling. J. Anim. Sci. 56:592–597.

Robinson, D. L., D. M. Ferguson, V. H. Oddy, D. Perry, and J. M. Thompson. 2001. Genetic and environmental influences on beef tenderness. Aust. J. Exp. Agric. 41:997-1004.

Savell, J. W., F. K. McKeith, C. E. Murphey, G. C. Smith, and Z. L. Carpenter. 1982. Singular and combined effects of electrical stimulation, postmortem ageing, and blade tenderization on the palatability attributes of beef from young bulls. Meat Sci. 6:97-109.

Schanbacher, B. D. 1984. Manipulation of endogenous and exogenous hormones for red meat production. J. Anim. Sci. 59:1621-1630.

Seideman, A. C., H. R. Cross, and J. D. Crouse. 1989. Carcass characteristics, sensory properties and mineral content of meat from bulls and steers. J. Food. Qual. 11:497-507.

Seideman, A. C., H. R. Cross, R. R. Oltjen, and B. D. Schanbacher. 1982. Utilization of the intact male for red meat production: a review. J. Anim. Sci. 55:826-840.

Shackelford, S. D., M. Koohmaraie, M. F. Miller, J. D. Crouse, and J. O. Reagan. 1991. An evaluation of tenderness of the *Longissimus* muscle of Angus by Hereford versus Brahman crossed heifers. J. Anim. Sci. 69:171-177.

Shackelford S. D., M. Koohmaraie, and T. L. Wheeler. 1994. The efficacy of adding a minimum adjusted fat thickness requirement to the USDA beef quality grading standards for select grade beef. J. Anim. Sci. 72:1502-1507.

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

Shackelford, S. D., T. L. Wheeler, and M. Koohmaraie. 1995b. Relationship between shear force and trained sensory panel tenderness ratings of 10 major muscles from *Bos indicus* and *Bos taurus* cattle. J. Anim. Sci. 73:3333-3340.

Shackelford, S. D., T. L. Wheeler, and M. Koohmaraie. 1997a. Tenderness classification of beef: I: Evaluation of beef *Longissmus* shear force at 1 or 2 days postmortem as a predictor of aged beef tenderness. J. Anim. Sci. 75:2417-2422.

Shackelford, S. D., T. L. Wheeler, and M. Koohmaraie. 1997b. Repeatability of tenderness measurements on beef round muscles. J. Anim. Sci. 75:2411-2416.

Shaefer, A. L., P. L. Dubeski, J. L. Aalhus, and A. K. W. Tong. Role of nutrition in reducing antemortem strees and meat quality aberrations. 2001. J. Anim. Sci. 79 (E. Suppl.): E91-E101.

Sherbeck, J. A., J. D. Tatum, T. G. Field, J. B. Morgan, and G. C. Smith. 1995. Feedlot performance, carcass traits, and palatability traits of Hereford and Hereford x Brahman steers. J. Anim. Sci. 73:3613-3620.

Smith, G. C., G. R. Culp, and Z. L. Carpenter. 1978. Postmortem aging of beef carcasses. J. Food Sci. 43:823-826.

Smith, G. C., J. D Tatum., K. E. Belk, and J. A. Scanga. 2008. Post-harvest practices for enhancing beef tenderness. Colorado State University. National Cattlemen's Beef Association. Pp .1-19.

Spanier, A. M., M. Flores, K. W. McMillin, and T. D. Bidner. 1997. The effect of post-mortem aging on meat flavor quality in Brangus beef: Correlation of treatments, sensory, instrumental and chemical descriptors. Food Chemistry. 59:531-538.

Stelzleni, A. M., and D. D. Johnson. 2008. Effect of days on concentrate feed on sensory off-flavor score, off-flavor descriptor and fatty acid profiles for selected muscles from cull beef cows. Meat Sci. 79:382-393.

Stolowski, G. D., B. E. Baird, R. K. Miller, J. W. Savell, A. R. Sams, J. F. Taylor, J. O. Sanders, and S. B. Smith. 2006. Factors influencing the variation in tenderness of seven major muscles form three Angus and Brahman breed crosses. J. Meat Sci. 73:475-483.

Sullivan, G. A., and C. R. Calkins. 2011. Ranking beef muscles for Warner Bratzler shear force and trained sensory panel ratings from published literature. J. Food Qual. 34:195-203.

Tatum, J. D., K. E. Belk., M. H. George, and G. C. Smith. 1999. Identification of quality management practices to reduce the incidence of retail beef tenderness problems: Development and evaluation of a prototype quality system to produce tender beef. J. Anim. Sci. 77:2112-2118.

Taylor, R. G., G. H. Geesink., V. F. Thompson., M. Koohmaraie, and D. E. Goll. 1995. Is Z-disk degradation responsible for post-mortem tenderization. J. Anim. Sci. 73:1351-1367.

Teira, G. 2004. Actualidad y perspectivas de un componente principal de la calidad de carnes bovinas: la terneza. Ciencia, Docencia y Tecnología, mayo, año/vol. XV, número 28:215-244.

Thomas, M. G., R. M. Enns, D. M. Hallford, D. H. Keisler, B. S. Obeidat, C. D. Morrison, J. A. Hernandez, W. D. Bryant, R. Flores, R. Lopez, and L. Narro. 2002. Relationships of metabolic hormones and serum glucose to growth and reproductive development in performance-tested Angus, Brangus, and Brahman bulls. J. Anim. Sci. 80:757-767.

Unruh, J. A. 1986. Effects of endogenous and exogenous growth-promoting compounds on cracass composition, meat quality and meat nutritional value. J. Anim. Sci. 62:1441-1448.

Unruh, J. A., C. D. Pelton, D. G. Gray, M. E. Dikeman, D. M. Allen, and L. R. Corah. 1987. Effects of Zeranol-implantation periods on palatability of Longissimus steaks from Young bulls and steers. J. Anim. Sci. 65:165-172.

Varela, A., B. Oliete, T. Moreno, C. Portela, J. A. Caballo, L. Sánchez , and L. Monserrat. 2003. Calidad de la carne de machos enteros y castrados de raza Rubia Gallega sacrificados con 24 meses. Arch. Zootec. 52:347-358.

Watanabe, A., C. C. Daly, and C. E. Devine.1996. The effects of the ultimate pH of meat on tenderness changes during ageing. Meat Sci. 42:67-78.

Watson, M.J. 1969. The effects of castration on the growth and meat quality of grazing cattle. Australian J. Exp. Agr. and Anim. Hus. 9:164-171.

Weniger, J. H., and D. Steinhauf. 1968. Meat quality in respect to carcass evaluation in cattle. World Review of Anim. Prod. 4:87-93.

Wheeler, T. M., J. W. Savell, H. R. Cross, D. M. Lunt, and S. B. Smith. 1990a. Effect of postmortem treatment on the tenderness of meat from Hereford, Brahman-cross beef cattle. J. Anim. Sci. 68:3677-3686.

Wheeler, T. L., J. W. Savell, H. R. Cross, D. K. Lunt, and S. B. Smith. 1990b. Mechanisms associated with the variation in tenderness of meat from Brahman and Hereford cattle. J. Anim. Sci. 68:4206-4220.

Wheeler, T. L., S. D. Shackelford, and M. Koohmaraie. 1999a. Tenderness classification of beef: IV. Effect of USDA quality grade on the palatability of "tender" beef *Longissimus* when cooked well done. J. Anim. Sci. 77:882-888.

Wheeler, T. L., S. D. Shackelford , and M. Koohmaraie. 1999b. Tenderness classification of beef: III. Effect of interaction between endpoint temperature and tenderness on Warner Bratzler shear force on beef *Longissimus*. J. Anim. Sci. 77:400-407.

Whipple, G. M., M. Koohmaraie, M. E. Dikeman., J. D. Crouse., M. C. Hunt, and R. D. Klemm. 1990. Evaluation of attributes that affect longissimus muscle tenderness in *Bos taurus* and *Bos indicus* cattle. J. Anim. Sci. 68:2716-2728.

Wierbicki, E., V. R. Carhill, L. E. Kunkle, E. W. Klosterman, and F. E. Deatherage. 1955. Effect of castration on biochemistry and quality of beef. J. Agr. Food Chem. 3:244-249.

Wulf, D. M., S. F. O´Connor, J.D. Tatum, and G. C. Smith. 1997. Using objective measures of muscle color to predict beef *Longissimu*s tenderness. J. Anim. Sci. 75:684-692.

Chapter III - Effects of castration on carcass composition, meat quality, and sensory properties of beef produced in a tropical climate.

ABSTRACT

Forty-eight (3/4 Brahman × 1/4 Charolais) male calves were used to determine carcass cutability and quality characteristics of steaks from four muscles aged for 2, 7, 14, or 28 d from intact bulls and steers castrated at 3, 7, or 12 mo of age grown under tropical pasture conditions. The experiment was conducted as a randomized complete block design with animal as the experimental unit and harvest group as a blocking factor with aging period as a repeated measure for Warner-Bratzler shear force (WBSF). Male calves were randomly assigned at birth to castration treatments, weaned at 7 mo, and raised together their entire life on pasture in Costa Rica. At 26 mo of age, three cattle from each treatment were harvested in 1 of 4 groups at a commercial harvest facility. Strip loin (*Longissimus lumborum*, LL), tenderloin (*Psoas major*, PM), top sirloin butt (*Gluteus medius*, GM), and eye of round (*Semitendinosu*s, ST) steaks were aged for 2, 7, 14, or 28 d for WBSF. A sensory panel was conducted for all four muscles aged for 14 d from intact bulls and steers castrated at 3 mo of age. Live BW, carcass traits, and total subprimal yields were not affected ($P \geq 0.10$) by male sex condition. For PM, GM, and ST steaks, WBSF values were similar ($P \geq 0.41$) for steaks from intact bulls and steers castrated at all ages. For both PM and GM, steaks aged for 28 d had the lowest ($P < 0.05$; most tender) WBSF values and steaks aged for 2 d had the highest ($P < 0.05$, toughest) WBSF values. For the ST, WBSF values were highest ($P < 0.05$) for steaks aged 2 d. A treatment × aging interaction ($P < 0.05$) was detected for LL WBSF values. At 14 d of aging, LL WBSF values from steers castrated a 3 mo tended ($P = 0.07$) to be lower than those

LL steaks from intact bulls. At 28 d of aging, steaks from steers had lower ($P < 0.05$) WBSF values than steaks from intact bulls and steaks from steers castrated at 3 mo tended ($P = 0.07$) to have lower WBSF values than steaks from steers castrated at 12 mo. For LL steaks from steers castrated at 3 mo, steaks aged for 28 d had lower ($P < 0.05$) WBSF values than steaks aged 2, 7, or 14 d and steaks aged 14 d had lower ($P < 0.05$) WBSF values than those aged 2 d. For LL steaks from steers castrated at 7 mo, steaks aged 28 d had lower ($P < 0.05$) WBSF values than steaks aged 2, 7, or 14 d. For LL steaks from steers castrated at 12 mo and intact bulls, steaks aged 28 d had lower ($P < 0.05$) WBSF values than steaks aged for 2 or 14 d. Although all sensory panel data collected were not statistically different ($P > 0.05$), LL steaks from steers castrated at 3 mo tended ($P = 0.17$) to have higher (more tender) overall tenderness scores than steaks from intact bulls. The GM followed a similar trend with steaks from steers castrated at 3 mo having higher scores for myofibrillar ($P = 0.14$) than steaks from intact bulls. This study indicates that castration at 3 mo would be the recommended production practice as it provided the greatest improvement LL tenderness over intact bulls with no differences in carcass traits or subprimal yields. The degree of improvement in tenderness due to aging appears to be muscle dependant.

Key words: beef, bulls, steers, aging, tenderness

MATERIALS AND METHODS

Animals:

Procedures involving male cattle were reviewed and approved by the Kansas State University Institutional Animal Care and Use Committee (Protocol # 3001) and the administration of the Instituto Tecnologico de Costa Rica (ITCR)-San Carlos. Forty-eight male cattle (3/4 Brahman × 1/4 Charolais) were randomly selected to represent four treatments of intact bulls and steers castrated at 3, 7, or 12 mo of age. Cattle were pasture fed at the ITCR-San Carlos Cattle Unit. One calf from the 7-mo castration treatment died of unknown causes.

At approximately 26 mo of age, cattle were randomly assigned within treatments to one of four harvest groups of twelve cattle consisting of three cattle per treatment. Harvest was conducted weekly during a 4 wk period. For each harvest group, individual live weight was recorded on the farm 5 d before transportation to a commercial harvest facility. Cattle were transported 70 km by truck early at night to minimize stress and avoid exposure to high daily temperatures.

Animal History:

Cattle were born and raised in Costa Rica at the Instituto Tecnologico de Costa Rica (ITCR)-San Carlos cattle farm. The area is located 85 m above the sea level, a flat topography, annual rainfall of 3400 mm, average daily temperature of 26 °C and relative humidity of 85%. At birth, male calves from the crossbred herd were assigned randomly to treatments of intact male, castration at 3 mo, castration at 7 mo, or castration at 12 mo for a farm production trial. Castration was surgically performed by an experienced technician. At the time of castration, the 12-mo castration treatment had an average live weight of 195.2 ± 28.4 kg.

Calves were weaned at 7 mo of age and placed on pasture at the ITCR-San Carlos Cattle Unit. All animals were fed as a group in a single pasture paddock and rotated to another paddock every 21 days. Pasture grasses consisted of Ratana (*Ischaemum indicum*), Toledo (*Brachiaria brizantha*) and Tanner (*Brachiaria radicans*). A mineral supplement (Multivex, Dos Pinos, Alajuela, Costa Rica) was available ad libitum and 1kg/hd /per day of Citrocom energy supplement (Dos Pinos, Alajuela, Costa Rica) with 86.5% dry matter, 2,850 kcal/kg digestible energy, and 5.5% crude protein was fed.

Harvest Data:

Cattle were individually weighed and harvested early in the morning at a commercial harvest facility. Immediately following harvest, beef carcass classification data were collected by a trained Corporacion Ganadera Technician (CORFOGA, 2002; Appendix Table 1) consisting of hot carcass weight (225.9 kg ± 19.9), dentition (0.43 ± 0.83 where 0 = no permanent incisors and 1 = first pair of permanent incisors), muscle score (2.96 ± 0.28 where 2 = average and 3 = below average muscling), fat cover (1.0 ± 0 where 1 = $\leq$ 0.5 cm fat thickness over the loin) and fat color (1.3 ± 0.45 where 1 = white and 2 = light yellow). The average male carcass harvested in Costa Rica in 2011 had heavier carcasses (average weight = 269.4 kg), were older (dentition = 4.0), were slightly heavier muscled (muscle score = 2.8) and had more yellow fat (fat color score = 1.4) (CORFOGA, 2011). In addition, hide and kidney fat weights were recorded. Carcasses were chilled at -3 to 2 $^{\circ}$C.

Carcass Data:

At 3- and 24-h postmortem, *Longissimus* pH and temperature were measured from the medial side of the carcass at a location between the 3rd and 5th lumbar vertebrae. Three pH measurements (Hanna Instruments HI 99163N Meat pH Meter;

HANNA Instruments, Woonsocket., RI) with a stainless steel probe inserted 2.54 cm into the *Longissimus lumborum* were averaged for data analysis.

At 24-h postmortem, carcass length, round circumference, hump height, 12th rib fat thickness, and ribeye area were measured. Carcass length was measured from the posterior tip of the *Ischium* (aicth bone) to the anterior point of the sternum. Round circumference was measured at the maximum circumference of the round. The left side of each carcass was ribbed between the 12th and 13th rib to measure fat thickness and ribeye area.

Subprimal Fabrication:

The tail was removed before the left side was weighed, quartered between the 12th and 13th rib, and fabricated in a commercial fabrication facility at approximately 28 h postmortem into boneless subprimals. Closely-trimmed whole-muscle subprimals from the forequarter consisted of the ribeye (*Longissimus thoracis*), ribeye cap (*Spinalis dorsi*), back rib fingers (*Intercostal muscles*), outside skirt (*Diaphragm*), chuck tender (supraspinatus), top blade (*Infraspinatus*), underblade (*Serratus ventralis*), clod (*Triceps brachii*), top chuck (*Splenis, Complexus*, etc.), hump (*Rhomboidius),* brisket flat (*Deep pectoral*), and foreshank. The closely-trimmed whole-muscle subprimals from the hindquarter consisted of the strip loin (*Longissimus lumborum* and *Gluteus medius* anterior the pelvic bone), tenderloin (*Psoas major* and *minor*), center-cut top sirloin butt (*Gluteus medius*), top sirloin cap (anterior *Biceps femoris*), tri-tip (*Tensor faciae latae*), flank (*Rectus abdominis*), inside skirt (*Transverse abdominis*), knuckle (*Vastus intermedius, Vastus lateralis, Vastus medialis*, and *Rectus femoris*), top (inside) round (*Adductor, Semimembranosus, Sartorious, Gracilis* and *Pectinius*), bottom (outside) round (*Biceps femoris*), eye of round (*Semitendinosus*), and hindshank. All subprimals, bone

and fat trim, and remaining lean trim were weighed for each left side. The strip loin, center-cut top sirloin butt, eye of round and tenderloin from both sides of each animal were collected and vacuum-packaged for shipping.

Steak Fabrication:

Following fabrication, the strip loin, center-cut top sirloin butt, eye of round and tenderloin subprimals from both sides of the carcass were transported in a refrigerated truck to the ITCR Meat Sensory Laboratory. Subprimals were stored in a cooler with an average temperature of 1.2 ^{0}C until they were fabricated into 2.54-cm thick steaks. Twelve steaks (six from each subprimal) from the *Longissimus lumborum* (**LL)**, *Semitendinosus* (**ST)**, and *Psoas major* (**PM)** were cut perpendicular to the long axis and from the center portion of each subprimal. Two steaks from each subprimal were randomly assigned to aging periods of 2, 7, 14, or 28 d for Warner-Bratzler shear force (**WBSF**) determination, or an aging period of 14 d for sensory panel determination. For the *Gluteus medius* (**GM)**, six steaks (three from each subprimal) were cut perpendicular to the long axis and from the center portion of each subprimal. A single steak was assigned to each of the WBSF aging periods and for sensory panel.

After cutting each subprimal from the last 3 harvest groups, steaks were allowed to bloom for 15 min before color was evaluated by a trained visual panelist. Color was evaluated on an eight-point scale to the nearest 0.5 where 1 = pale, 2 = very light red, 3 = light red, 4 = red, 5 = slightly dark red, 6 = moderately dark red, 7= dark red and 8 = very dark red.

All steaks were individually vacuum-packaged in a Multivac A200/15 (Multivac, Kansas City., MO) and returned to the cooler until their assigned aging

period was reached. The WBSF analysis for LL and ST steaks were performed on fresh, never frozen, steaks. However due to cooking limitations, PM and GM steaks were frozen at the end of their aging periods in a freezer with an average temperature of –13.5 °C and remained frozen until analysis. At 14 d postmortem, sensory panel steaks were removed from the cooler and frozen.

Warner-Bratzler Shear Force:

At 2, 7, 14, and 28 d postmortem, two LL and two ST steaks per treatment were removed from the cooler for analysis. Frozen GM and PM steaks that had been previously aged in a cooler for 2, 7, 14, and 28 d were thawed for 24 h at 4 °C in a McCall refrigerator (Kolpak Industries Inc., Parsons, TN) before analysis. For the last two harvest groups, steaks were weighed in the bag with juices and weighed again out of the bag prior to cooking. Percentage of purge loss was averaged for the two steaks representing each treatment from the LL, ST and PM. For the GM, a single steak representing each treatment was used. Steaks were cooked according to an established protocol consistent with AMSA (1995) guidelines in a Vulcan dual-air-flow convection oven (Vulcan-Hart Co., Lousville, KY) pre-heated at 163 °C. Temperature was monitored by 30-gauge, type T thermocouples inserted into the geometric center of the steak and attached to a Barnant temperature recorder (692-0000 Benchtop, Barrington, IL). When each steak reached an internal temperature of 50 °C, it was turned over and cooked to a final temperature of 71 °C. Steaks were cooled at least 30 min, reweighed, and percentage of cooking loss was calculated. Percentage of total moisture loss was calculated as the sum of the package purge and cooking loss weights divided by the weight of the initial raw steak. Steaks were stored overnight at 4 °C in a McCall refrigerator (Kolpak Industries Inc., Parsons, TN), before eight 1.27-cm-diameter cores were taken parallel to the muscle fiber

orientation. Cores were sheared perpendicular to the muscle fiber orientation as recommended by AMSA (1995) using a Dillon Quantrol testing machine (Dillon/Quality Plus Inc, Kansas City, MO) with a Warner-Bratzler shear force V-shaped blade attachment (G-H Manufacturing CO., Manhattan, KS).

Sensory Panel Evaluation:

Two 14-d aged steaks from the LL, ST, and PM subprimals, and one 14-d aged steak from the GM subprimals from intact bulls and steers castrated at 3 mo were used for sensory panel evaluation. These treatments were selected to represent treatments that would support discussion of potential differences that may exist in WBSF analysis. The sensory panel protocol was reviewed and approved by the Kansas State University Institutional Review Board of Human Subjects (Protocol # 5796) and the administration of the Instituto Tecnologico de Costa Rica (ITCR)-San Carlos. Panelists were trained according to AMSA (1995) guidelines. Steaks were thawed and cooked as described for WBSF to an internal temperature of 71 °C. Each steak was cut into 1.27cm × 1.27cm × thickness of the cooked steak cubes perpendicular to the cut surface. Sensory panel evaluations were conducted in a room partitioned into booths with a mixture of adjustable red and green light. For each session, duplicate samples from a subprimal representing steaks from a harvest group of three bulls and three steers castrated at 3 mo were served warm and evaluated by a seven-member panel. The order of presentation was randomized for each panelist within each session. Samples were assessed for six sensory attributes using an eight-point numerical scale evaluated to the nearest 0.5. Sensory traits (Appendix Table 4) evaluated were myofibrillar tenderness (1 = extremely tough to 8 = extremely tender), juiciness (1 = extremely dry to 8 = extremely juicy), beef flavor intensity (1 = extremely bland to 8 = extremely intense), connective tissue amount (1 = abundant to

8 = none), overall tenderness (1 = extremely tough to 8 = extremely tender), and off flavor intensity (1 = abundant to 8 = none).

Statistical Design:

A randomized complete block design with animal as the experimental unit and harvest group as the block was used for all data. A one-way analysis of variance (ANOVA) was performed using the PROC MIXED procedure of SAS (SAS Inst. Inc., Cary, NC). For Warner-Bratzler shear force and moisture losses during cooking, days of aging was used as a repeated measure. This model statement included castration treatment, days of aging and the treatment × day interaction. Means were separated ($P < 0.05$) using the Tukey-Kramer procedure when the respective F-test was significant ($P < 0.05$). In addition selected contrasts of steers vs bulls and early steers (castrated at 3 and 7 mo) vs bulls as well as linear and quadratic contrasts (Appendix Tables 6-9) were performed when respective F-test were significant ($P < 0.05$).

RESULTS

Harvest and Carcass Traits:

Live, hot carcass and hide weights were not affected ($P \geq 0.55$) by male sex condition resulting in similar ($P \geq 0.14$) percentages of live shrink (farm to harvest), dress (dressing percentage), and hide (Table 3). However, steers castrated at all ages (3, 7, and 12 mo) had ($P < 0.05$) heavier and a higher proportion of kidney and pelvic fat than intact bulls. Carcass measures of carcass length, round circumference, fat thickness, ribeye area, hump height, pH and temperature were not affected ($P \geq 0.10$) by male sex condition (Table 4).

Subprimal Weights and Proportions:

Subprimal weights and percentages for intact bulls and steers castrated at different ages are presented in Tables 5 and 6, respectively. Intact bulls had ($P < 0.05$) heavier and a higher proportion of bone and fat trim loss than steers castrated at 3 mo. In a contrast comparison of steers vs bulls, bulls had ($P < 0.05$) heavier and a higher proportion of bone and fat trim loss than steers. No differences in subprimal weights ($P \geq 0.15$) were observed among intact bulls and steers castrated at different ages. When expressed as a proportion of chilled side weight, all steer groups had higher ($P < 0.05$) proportion of top (inside) round than intact bulls; and steers castrated at 3 and 7 mo had higher ($P < 0.05$) proportion of center cut top sirloin butt than intact bulls. When the steer vs bull contrast was performed, steers had ($P < 0.05$) a higher proportion of center-cut top sirloin butt and top round.

Color, Moisture Loss, and Warner-Bratzler Shear Force :

Lean color, proportion of package purge, proportion of cooking loss, and proportion of total moisture loss for LL, PM, GM, and ST steaks were not affected ($P \geq 0.06$) by male sex condition (Table 7). In addition, WBSF values were similar ($P \geq$

0.41) for PM, GM, and ST steaks from intact bulls and steers castrated at different ages. Although not statistically significant ($P = 0.45$), means for GM steaks appeared to be somewhat lower (more tender) for steaks from early castrate groups than intact bulls.

A treatment × aging interaction ($P < 0.05$) was detected for LL WBSF values (Table 9). For 2, 7, and 14 d of aging, no differences ($P > 0.05$) were observed for WBSF values among LL steaks from intact bulls and steers castrated at different ages. However, at 14 d of aging LL steaks from steers castrated a 3 mo tended ($P = 0.07$) to be lower (more tender) than LL steaks from intact bulls. At 28 d of aging, steaks from steers castrated at 3 and 7 mo had lower ($P < 0.05$; more tender) WBSF values than steaks from intact bulls; and steaks from steers castrated at 3 mo tended ($P = 0.07$) to have lower WBSF values than steaks from steers castrated at 12 mo. In the contrast comparison of steers vs bulls, steaks aged 28 d from steers had ($P < 0.05$) lower (more tender) WBSF values than steaks aged 28 d from bulls.

For LL steaks from steers castrated at 3 mo, steaks aged for 28 d had lower ($P < 0.05$; more tender) WBSF values than steaks aged 2, 7, and 14 d; and steaks aged 14 d had lower ($P < 0.05$) WBSF values than those aged 2 d. For LL steaks from steers castrated at 7 mo, steaks aged 28 d had lower ($P < 0.05$) WBSF values than steaks aged 2, 7, and 14 d. For LL steaks from steers castrated at 12 mo and intact bulls, steaks aged 28 d had lower ($P < 0.05$) WBSF values than steaks aged for 2 or14 d. For steers, WBSF linearly ($P < 0.05$) decreased with increased days of aging.

Aging linearly decreased ($P < 0.05$) WBSF values for PM, GM, and ST steaks (Table 8). In addition this decrease was quadratic for PM and GM steaks. For both PM and GM steaks, steaks aged for 28 d had the lowest ($P < 0.05$; most tender) WBSF values and steaks aged for 2 d had the highest ($P < 0.05$, toughest) WBSF

values. For ST steaks, WBSF values were highest ($P < 0.05$, toughest) for steaks aged 2 d.

The influence of aging on proportion of package purge and proportion of cooking loss of LL, PM, GM, and ST steaks is reported in Table 8. In general, proportion of package purge linearly ($P < 0.05$) increased with days of aging for steaks from all subprimals; however, proportion of cooking and total moisture losses were more variable. For LL steaks, proportion of package purge increased ($P < 0.05$) for each increase in days of aging; and steaks aged for 14 d had a greater ($P < 0.05$) proportion of cooking loss than steaks aged for 7 and 28 d. In addition, LL steaks aged for 14 d had a greater ($P < 0.05$) proportion of total moisture loss than steaks aged for 2 and 7 d.

For PM steaks, a quadratic ($P < 0.05$) relationship was observed with the proportion of package purge greatest ($P < 0.05$) at 28 d of aging and least ($P < 0.05$) at 2 d of aging. The proportion of cooking loss linearly ($P < 0.05$) decreased with aging and was lowest ($P < 0.05$) at 28 d of aging resulting in no differences ($P = 0.69$) in total moisture loss all aging periods.

For GM steaks, proportion of package purge was linearly ($P < 0.05$) increased with aging and greatest ($P < 0.05$) at 28 d of aging and least ($P < 0.05$) at 2 d of aging. The proportion of cooking loss linearly ($P < 0.05$) decreased with aging and was greatest ($P < 0.05$) at 2 and 7 d of aging and least ($P < 0.05$) at 28 d of aging. As a result, total moisture loss for GM steaks was similar ($P = 0.50$) among all aging periods.

For ST steaks, the proportion of purge linearly ($P < 0.05$) increased with aging and was greatest ($P < 0.05$) at 14 and 28 d of aging and least ($P < 0.05$) at 2 d of

aging. A quadratic ($P < 0.05$) relationship was observed for cooking loss of ST steaks with the lowest ($P < 0.05$) proportion of cooking loss at 2 days of aging and steaks aged for 28 d had a lower ($P < 0.05$) proportion of cooking loss than steaks aged for 14 d. As a result, the proportion of total moisture loss increased linearly ($P < 0.05$) with aging and steaks aged 14 d had more ($P < 0.05$) total losses than steaks aged for 2 and 7 d; and steaks aged for 28 d had more ($P < 0.05$) losses than steaks aged for 2 d.

Sensory Panel:

Sensory panel data for LL, PM, GM, and ST steaks aged for 14 d from intact bulls and steers castrated at 3 mo of age are reported in Tables 10, 11, 12, and 13, respectively. Although all sensory panel data collected were not statistically different ($P > 0.05$), LL steaks from steers castrated at 3 mo had higher (more tender) scores for myofibrillar ($P = 0.20$) and overall tenderness ($P = 0.17$) compared to steaks from intact bulls. The GM steaks followed a similar trend with steaks from steers castrated at 3 mo of age having higher (more tender) scores for myofibrillar ($P = 0.14$) and overall tenderness ($P = 0.24$) compared to steaks from intact bulls.

DISCUSSION

In the present study, few differences were observed for harvest, carcass, and subprimal yield traits. The exception was that intact bulls had less kidney and pelvic fat than steers. Most studies (Arthaud *et al*., 1969; Jacobs *et al*., 1977; Purchas and Grant, 1995; Purchas *et al*, 2002) indicate that bulls fed adequate nutrition are heavier and have higher cutability carcasses than steers. Bulls are expected to have greater ADG, weigh more, and produce higher cutability carcasses since androgens promote

muscular development by an increase of nitrogen retention (Galbraith *et al*., 1978). Most studies involving bulls and steers are conducted under favorable nutritional and environmental growing conditions resulting in bulls growing 10-20% faster than steers (Field 1971; Sideman *et al*., 1982). However, when nutritional conditions are more marginal, bulls and steers grow at the same rate (Martin *et al*., 1978), possibly because of the higher maintenance requirements for bulls (Webster *et al* 1977; Griffiths 1980). The ARC feed requirement indicate a 15% higher maintenance requirement for a bull than for a steer of the same weight (ARC, 1980). In addition, the efficiency of utilization of low quality roughages by ruminants is influenced by the thermal environment which determines the requirements for substrate oxidation for maintenance of body temperature and alters the balance of nutrients available for anabolic functions (Leng, 1990). Heat stress affects the maintenance energy because greater metabolic action is needed to increase heat dissipation (Morrison, 1983). As a partial result, no differences were observed in this study for final weight and carcass cutability for bulls and steers fed on pasture under tropical climate conditions.

The four subprimal cuts in the present study appear to have different inherent properties and are influenced differently by castration and days of aging. Steers were more tender (lower WBSF) than bulls at 28 d of aging. The influence of castration on tenderness was more pronounced with earlier castration. Steers castrated at 3 mo tended ($P = 0.07$) to have lower WBSF at 14 d of aging; and although not statistically significant, this difference was supported by sensory panel data of steaks aged 14 d.

Many researchers have reported that meat from bulls is less tender and less palatable than meat from steers (Field, 1971; Seideman *et al*., 1982; Dikeman *et al*., 1986). Serum testosterone has been shown to linearly increase in bulls from 7 to 13 mo of age (Lunstra *et al*., 1978). The increased testosterone for a bull is believed to

stimulate collagen synthesis (Cross *et al*., 1984) resulting in greater amounts of intramuscular collagen than for castrated steers (Gerrad *et al*., 1987). In addition, Judge and Aberle (1982) determined that intact males have collagen with a higher thermal shrinkage temperature than steers which increases from 12 to 18 mo of age. Gerrard *et al*. (1987) also found that the thermal stability of collagen from bulls increases more rapidly than collagen from steers indicating that testosterone may play a role in the maturation of collagen by decreasing the collagen degradation rate.

The Myofibril Fragmentation Index (MFI) indicates the amount of myofibrillar proteolysis that has occurred (Morgan *et al*., 1993) and *Longissimus* muscle (**LM**) tenderness is highly and positively correlated with MFI (Parrish *et al*., 1979). Morgan *et al*. (1993) determined that LM steaks from bulls had higher shear force and lower MFI values than LM steaks from steers. Morgan *et al*. (1993) found calpastatin activity (endogenous calpain activity inhibitor) was 81% greater in the LM from bulls than steers. The greater calpastatin activity in bull LM likely decreases the amount of myofibrillar protein proteolysis by u-calpain through 7d postmortem resulting in less tender meat (Morgan *et al*., 1993). Koohmaraie (1988) stated that the calpain proteolityc system plays a major role in postmortem tenderization.

Previous research (Shackelford *et al*., 1995; Rhee *et al*., 2004) concluded that the LM muscle is one of the the most variable muscles in WBSF. Martin et al. (1971) reported a 14 % reduction in *Longisssimus* shear force from 3 to 6 d and an 11% reduction between 6 and 13 d. Gruber *et al*. (2006) showed continued improvement in WBSF for Select LM muscle aged up to 28 d. In the present study LL steaks from steers castrated a 3 mo had a 40% improvement in WBSF from 2 to 28 d, but LL steaks from bulls only displayed an 18% improvement in WBSF from 2 to 28 d. Koohmaraie *et al*. (1988) found the PM was more tender than the LM at 1 d

postmortem; however, after 14 d of postmortem storage, they were similar. This greater capacity to increase tenderness during aging was partially attributed to greater initial Calcium dependent inhibitor activity and later increased calcium dependent protease activities in LM compared to the PM muscle. This difference in calpastatin/calpain can partially explain the 40% and 37% improvement in WBSF from 2 to 28 d postmortem for LD steaks from steers castrated at 3 and 7 mo, respectively, and only a 18% improvement across all treatments in WBSF for PM steaks.

As expected, steaks from the PM were inherently more tender than steaks from the other subprimals. At 2 d postmortem, PM WBSF values averaged 4.4 kg in the present study. In agreement, Rhee *et al*. (2004) reported WBSF values at 2 d postmortem of 4.5 kg. Tenderness of PM steaks measured by WBSF was similar for all castration treatments; however, increased days of aging improved tenderness. The greatest improvement in WBSF occurred between 2 and 7 d postmortem with a smaller improvement to 28 d postmortem. Gruber *et al*., (2006) also showed an improvement in WBSF for up to 28 d for Select PM steaks. The tenderloin is known as a very tender muscle as it has the least collagen content and longest sarcomeres compared to other muscles studied by Rhee *et al*. (2004). However, Rhee *et al*. (2004) also found less desmin degradation for the PM which relates to less improvement in tenderness due to aging. In addition, Koohmaraie *et al*. (1990) reported that muscles with higher proportions of red fibers such as the Psoas major have higher concentrations of Zn^{++}, which inhibits calpain activity and desmin degradation. As a partial result, castration treatment in this study did not affect PM tenderness and aging improved tenderness, but not to the extent observed for the LL and GM.

Although not statistically significant, tenderness of GM steaks appeared to be somewhat impacted by castration treatment. Early castrated steers had lower means for WBSF and improved sensory panel tenderness scores compared to intact bulls. Therefore the tendency for lower WBSF values for early castration groups and improved sensory panel tenderness for steers castrated at 3 mo compared to bulls is consistent with the reduced levels of serum testosterone and calpastatin activity. For GM steaks, increased days of aging improved tenderness. These steaks aged 28 d had 31% lower WBSF values than steaks aged 2 d. Rhee *et al*. (2004) determined that the GM is intermediate in collagen concentration and variable in tenderness partially attributing this variability to connective tissue. George-Evins et al. (2004) found aging the GM steaks for 21 d improved tenderness and Gruber *et al*. (2006) determined that the GM muscle continued to improve in tenderness through 28 d.

The GM is generally characterized as muscle that is variable in tenderness (Morgan *et al*., 1991) and is often blade tenderized to improve consistency (George-Evins *et al*., 2004). Rhee *et al*. (2004) characterized the GM as having similar properties to the LL except for slightly greater collagen content as well as more connective tissue and lower overall tenderness as evaluated by a sensory panel. In contrast, WBSF values of GM steaks in the present study were generally more favorable than those from LL steaks. A partial explanation could be related to the chill rate of the two different muscle locations. The carcasses in this study had minimal fat cover and could have been susceptible to cold shortening. Considering the mass of the GM and surrounding round muscles, we would expect a slower chilling rate for the GM than the LL. According to King *et al*. (2003) there is an interaction between muscle and chilling temperature for sarcomere length. Then, postmortem proteolysis and sarcomere length are both implicated in myofibrillar

tenderness of meat (Wheeler and Koohmaraie. 1994). Locker (1982) suggested that cold shortened meat does not improve tenderness to the same degree because of increased overlapping of the thick and thin filaments and possibly limited access of calpain enzymes to degradable proteins.

Tenderness of ST steaks was not impacted by castration treatment and responded to 7 d of aging with minimal improvement due to increased days of aging thereafter. At 2 d postmortem ST WBSF values averaged 6.6 kg in the present study. In agreement, Rhee *et al*., (2004) reported WBSF values at 2 d postmortem of 6.4 kg. Gruber *et al*., (2006) showed no improvement in Warner Bratzler shear force for Select ST muscle beyond 21 d. According to Rhee *et al*. (2004) the ST was the most variable in sarcomere length and higher in collagen content (8.7 mg/g) compared with other muscles including the GM (4.3 mg/g), PM (2.7 mg/g), and LM (4.5 mg/g). Cross *et al*. (1973) found less soluble collagen in ST compared to LM muscles and concluded that the proportion of soluble collagen was significantly related to the contribution of connective tissue to toughness. Nishimura *et al*. (1996) stated that the arrangement of collagen fibrils and fibers in the intramuscular connective tissue becomes more regular during development of bovine ST muscle. These changes in collagen and collagen fibrils could be related to decreased ST heat solubility of collagen during increased chronological age of cattle and toughening of meat during growth (Nishimura et al., 1999). Both the greater amount and decreased solubility of connective tissue found in the ST muscle has been proposed to predominate the evaluation of tenderness and mask the potential improvement in myofibrillar tenderness due to proteolysis.

In general package purge increased with days of aging for all muscles studied. Studies conducted by Hodges *et al*. (1974), Bentley *et al*. (1989) and Fandino *et al*. (

1989) concluded that purge loss increased with storage. In addition, Hodges *et al*. (1974) reported that cuts from low grading (leaner) carcasses had greater purge than those for high grading (fatter carcasses). The aging process may cause a change in the protein structure and functionality resulting in a modification in the ability of meat to retain moisture (Huff-Lonergan and Lonergan, 2005). For PM and GM steaks cooking losses decreased with days of aging compensating for increased purge losses and resulted in similar total moisture losses across aging periods. However cooking losses were more variable across aging periods for LL and ST steaks resulting in inconsistent results for total moisture losses.

CONCLUSIONS

In conclusion, castration should be performed as early as possible since all weights (live, carcass and subprimal) and cutability were similar to bulls, and there is the potential benefit of enhanced tenderness for some muscles such as the LL and GM. In addition, early castration promotes animal welfare and ease of handling, especially for *Bos indicus* cattle. Further management practices to consider that could potentially improve performance and beef quality (especially tenderness) of cattle raised in tropical climates could include use higher energy diets, harvest at younger ages, genetic selection within *Bos indicus* breeds and crossbreeding with *Bos taurus* breeds.

Aging improved beef tenderness of LL, PM, GM and ST steaks, however these muscles reacted differently to aging. These differences can be attributed to differences in proteolysis of myofibrillar proteins and connective tissue properties. Castration and aging for 28 d provided the greatest benefit in improving the

tenderness of LL steaks. This tendency was also observed for GM steaks with means favoring early castration and aging improving tenderness. Aging of tenderloin steaks for 7 d provided the greatest improvement in tenderness with aging to 28 d providing only a slight improvement in of an already tender PM. Aging the ST for 7 d provided improvement in tenderness with no benefit of extended aging.

TABLES

Table 3. Harvest traits of intact bulls and steers castrated at different ages.

	Age of Castration			Intact	
Trait	3 mo	7 mo	12 mo	Bulls	SE
Age, d	787	782	789	791	7.1
Farm wt, kg	427.5	439.1	424.3	437	11.78
Harvest plant wt, kg	391.6	407	391.7	403.3	12.84
Live shrink, %	6.6	5.7	5.9	6.0	1.1
Carcass wt, kg	214.2	223.6	213.4	217.3	7.9
Dressing percentage, %	55.1	55.2	54.8	54.3	0.4
Kidney and pelvic fat, kg[1]	2.4[a]	2.8[a]	2.5[a]	1.6[b]	0.3
Kidney and pelvic fat, %[1]	1.2[a]	1.3[a]	1.2[a]	0.8[b]	0.1
Hide wt, kg	33.9	31.5	33.8	32.7	1.3
Hide, %[2]	8.6	7.8	8.6	8.1	0.35

[1]Contrast: steer vs bull ($P < 0.05$).

[2]Expressed as a percentage of harvest plant wt.

[a-b] Within a row, means without a common superscript letter differ ($P < 0.05$).

Table 4. Carcass traits of intact bulls and steers castrated at different ages.

	Age of Castration			Intact	
Trait	3 mo	7 mo	12 mo	Bulls	SE
Carcass length, cm	157.4	162.8	157.3	157.9	1.8
Round circumference, cm	104	104.1	105.1	104.3	1.1
Fat thickness, cm	0.23	0.23	0.23	0.23	0.024
Ribeye area, cm^2	61.0	62.3	60.2	62.4	1.8
Hump height, cm	9.7	9.1	9.2	10.5	0.7
3 h pH[1]	6.3	6.3	6.3	6.4	0.1
3 h temperature, ^0C[1]	10.6	11.5	13.8	10.8	2.4
24 h pH[1]	5.6	5.7	5.6	5.7	0.0
24 h temperature, ^0C[1]	4.4	4.6	4.4	3.7	0.41

[1]*Longissimus lumborum* pH and temperature were measured between the 3rd and 5th lumbar vertebrae.

Table 5. Closely-trimmed subprimal and lean trim weights per carcass side of intact bulls and steers castrated at different ages.

	Age of Castration			Intact	
Trait	3 mo	7 mo	12 mo	Bulls	SE
Chilled side wt, kg	107.7	112.5	107.4	110.3	3.8
Bone and fat trim, kg[1]	23.7[a]	24.2[ab]	24.6[ab]	26.5[b]	0.58
Forequarter subprimals, kg	33.6	35.0	32.6	34.4	1.37
Ribeye, kg	2.3	2.5	2.2	2.3	0.13
Ribeye cap, kg	1.3	1.3	1.3	1.4	0.08
Back rib fingers, kg	5.4	6.0	5.2	5.2	0.32
Outside skirt, kg	0.7	0.7	0.7	0.7	0.07
Chuck tender, kg	1.4	1.3	1.3	1.3	0.06
Top blade, kg	1.9	2.0	1.9	1.9	0.11
Under blade, kg	1.6	1.6	1.6	1.9	0.23
Clod, kg	2.4	2.5	2.4	2.6	0.19
Chuck, kg	4.8	4.9	4.7	5.3	0.23
Hump, kg	0.9	1.2	0.6	1.1	0.27
Brisket, kg	3.4	3.4	3.1	3.4	0.14
Foreshank, kg	6.0	6.2	6.3	6.0	0.24
Hindquarter subprimals, kg	32.0	33.0	32.0	31.4	1.02
Strip loin, kg	2.4	2.7	2.5	2.5	0.11
Tenderloin, kg	1.7	1.8	1.6	1.6	0.06
Center cut top sirloin butt, kg	3.1	3.2	3.0	3.0	0.15
Top sirloin cap, kg	1.4	1.4	1.3	1.4	0.05
Tri tip, kg	1.1	1.1	1.1	1.0	0.08
Flank, kg	0.6	0.7	0.6	0.6	0.06
Inside skirt, kg	1.0	1.0	1.5	0.9	0.29
Knuckle (Tip), kg	4.8	4.7	4.8	4.8	0.21
Top (inside) round, kg	7.4	7.6	7.4	7.1	0.24
Bottom (outside) round, kg	4.1	4.3	4.0	4.1	0.14
Eye of round, kg	2.1	2.1	2.0	2.0	0.07
Hindshank, BNLS, kg	1.7	1.9	1.8	1.8	0.1
Total subprimals, kg	65.0	67.6	64.2	65.3	2.3
Lean trim, kg	18.1	19.5	17.8	18.2	1.09
Total salable meat, kg[2]	82.4	86.3	81.2	82.7	3.49

[1]Contrast: steer vs bull ($P < 0.05$).

[2]Total salable meat = total subprimals + lean trim.

[a-b] Within a row, means without a common superscript letter differ ($P < 0.05$).

Table 6. Closely-trimmed subprimals and lean trim as a percentage of chilled side weight of intact bulls and steers castrated at different ages.

	Age of Castration			Intact	
Trait	3 mo	7 mo	12 mo	Bulls	SE
Bone and fat trim, %[1]	22.2[a]	21.9[a]	23.2[ab]	24.2[b]	0.68
Forequarter subprimals, %	30.1	30.1	29.3	30.2	0.71
Ribeye, %	2.1	2.2	1.9	2.0	0.1
Ribeye cap, %	1.3	1.2	1.3	1.3	0.04
Back rib fingers, %	4.9	5.2	4.7	4.7	0.31
Outside skirt, %	0.8	0.8	0.7	0.7	0.04
Chuck tender, %	1.3	1.2	1.2	1.2	0.04
Top blade, %	1.8	1.8	1.8	1.7	0.07
Under blade, %	1.5	1.4	1.5	1.8	0.17
Clod, %	2.3	2.3	2.3	2.3	0.12
Chuck, %	4.5	4.5	4.5	4.9	0.23
Hump, %	0.8	1.0	0.6	1.0	0.19
Brisket, %	3.2	3.2	2.9	3.2	0.15
Foreshank, %	5.5	5.4	5.7	5.3	0.20
Hindquarter subprimals, %	28.8	28.5	28.9	27.6	0.38
Strip loin, %	2.4	2.5	2.4	2.4	0.11
Tenderloin, %	1.5	1.5	1.4	1.5	0.03
Center cut top sirloin butt, kg[1]	2.9[a]	2.9[a]	2.8[ab]	2.7[b]	0.05
Top sirloin cap, %	1.3	1.2	1.1	1.2	0.04
Tri tip, %	1.0	1.0	1.0	1.0	0.06
Flank, %	0.6	0.6	0.6	0.6	0.04
Inside skirt, %	0.9	0.8	1.2	0.8	0.21
Knuckle (Tip), %	4.4	4.1	4.4	4.3	0.11
Top (inside) round, %[1]	6.7[a]	6.6[a]	6.7[a]	6.2[b]	0.12
Bottom (outside) round, %	3.8	3.8	3.9	3.7	0.11
Eye of round, %	1.9	1.9	1.8	1.8	0.06
Hindshank, BNLS, %	1.6	1.7	1.7	1.6	0.05
Total subprimals, %	58.9	58.8	58.2	57.9	0.61
Lean trim, %	17.3	17.6	16.9	16.9	0.69
Total salable meat, %[2]	76.8	76.9	75.8	75.3	0.73

[1]Contrast: steer vs bull ($P < 0.05$).

[2]Total salable meat = total subprimals + lean trim.

[a-b] Within a row, means without a common superscript letter differ ($P < 0.05$).

Table 7. Color, package purge, cooking moisture loss and Warner-Braztler shear force (WBSF) of four muscles from intact bulls and steers castrated at different ages.

	Age of Castration			Intact	
Trait	3 mo	7 mo	12 mo	Bulls	SE
Longissimus lumborum					
Color[1]	5.3	5.6	4.9	5.1	0.42
Package purge, %	4.0	3.7	4.8	3.6	0.61
Cooking loss, %	26.6	27.7	27.2	28.3	0.72
Total moisture loss, %[2]	29.6	29.9	30.6	30.4	1.19
Psoas major					
Color[1]	4.8	4.5	4.2	4.0	0.3
Package purge, %	4.6	4.1	5.1	4.4	0.77
Cooking loss, %	31.9	32.7	31.8	32.9	0.73
Total moisture loss, %[2]	36.1	33.7	35.5	35.8	0.96
WBSF, kg	4.0	3.9	3.7	3.9	0.41
Gluteus medius					
Color[1]	4.9	4.4	4.5	4.4	0.26
Package purge, %	4.1	3.9	4.6	4.0	0.61
Cooking loss, %	33.9	34.1	34.0	34.8	1.17
Total moisture loss, %[2]	37.6	34.7	37.1	36.9	1.17
WBSF, kg	6.4	6.6	7.0	7.3	0.45
Semitendinosus					
Color[1]	3.9	3.8	3.3	2.9	0.3
Package purge,%	4.2	3.1	3.2	2.9	0.78
Cooking loss, %	31.8	33.2	32.9	32.9	0.8
Total moisture loss, %[2]	37.0	35.8	35.4	37.4	3.13
WBSF, kg	6.1	6.3	6.1	6.1	0.67

[1]Color was evaluated on a scale of 1 to 8 (1 = pale, 8 = very dark red).

[2]Percentage of moisture loss was a combination of the package purge and cooking loss divided by the initial raw weight.

Table 8. Package purge, cooking moisture loss and Warner-Braztler shear force (WBSF) of steaks aged for 2, 7, 14 and 28 d.

	Aging time				
Trait	2 d	7 d	14 d	28 d	SE
Longissimus lumborum					
Package purge,%[1]	1.6[a]	3.1[b]	4.4[c]	6.6[d]	0.54
Cooking loss, %	27.5[ab]	26.7[a]	29.1[b]	26.7[a]	0.75
Total moisture loss, %	28.6[a]	30.0[a]	32.1[b]	30.2[ab]	1.07
Psoas major					
Package purge,%[12]	2.1[a]	3.5[b]	4.2[b]	8.5[c]	0.73
Cooking loss, %[1]	33.4[a]	32.4[a]	32.9[a]	30.6[b]	0.71
Total moisture loss, %	35.6	35.7	35.5	34.3	0.92
WBSF, kg [12]	4.4[a]	3.8[b]	3.8[b]	3.6[c]	0.11
Gluteus medius					
Package purge,%[1]	2.3[a]	3.5[b]	4.4[b]	6.4[c]	0.41
Cooking loss, %[1]	35.5[a]	35.4[a]	33.8[b]	31.9[c]	1.00
Total moisture loss, %	37.6	36.4	36.4	35.9	0.89
WBSF, kg[12]	8.3[a]	6.8[b]	6.4[b]	5.7[c]	0.46
Semitendinosus					
Package purge,%[1]	0.9[a]	2.4[b]	4.4[c]	5.7[c]	0.59
Cooking loss, %[12]	30.4[a]	33.5[bc]	34.4[c]	32.5[b]	0.69
Total moisture loss, %[1]	33.5[a]	35.4[ab]	38.9[c]	37.7[bc]	1.77
WBSF, kg [1]	6.6[a]	6.1[b]	6.2[b]	6.0[b]	0.10

[1]Linear ($P < 0.05$).

[2]Quadratic ($P < 0.05$).

[a-c]Within a row, means without a common superscript letter differ ($P < 0.05$).

Table 9. Male sex condition × aging interaction means for Warner-Bratzler shear force values of *Longissimus lumborum* steaks (SE=1.03).

	Age of Castration			
Aging Period	3 mo[1]	7 mo[1]	12 mo[1]	Bulls
2 d, kg	10.1[x]	10.8[x]	9.5[x]	10.5[x]
7 d, kg	9.3[xy]	9.7[x]	9.2[xy]	10.1[xy]
14 d, kg	8.7[y]	10.0[x]	9.4[x]	10.5[x]
28 d, kg[2]	6.4[az]	6.8[ay]	8.2[aby]	9.0[by]

[1]Linear ($P < 0.05$) decrease in Warner Bratzler shear force values with increased days of aging.

[2]Contrast: steers vs bulls ($P < 0.05$).

[a-b]Within a row, means without a common superscript letter differ ($P < 0.05$).

[x-z]Within a column, means without a common superscript letter differ ($P < 0.05$).

Table 10. Sensory panel characteristics of *Longissimus lumborum* steaks aged for 14 d from intact bulls and steers castrated at 3 mo.

Trait[1]	Steer	Bull	SE
Myofibrillar tenderness	4.7	4.1	0.33
Connective tissue amount	5.8	5.6	0.16
Overall tenderness	4.7	4.0	0.31
Juiciness	4.8	4.5	0.17
Beef Flavor	3.6	3.5	0.20
Off flavor intensity	6.5	6.4	0.15

[1]Sensory traits were evaluated on a scale of 1 to 8 for myofibrillar tenderness (1 = extremely tough, 8 = extremely tender), connective tissue amount (1 = abundant, 8 = none), overall tenderness (1 = extremely tender, 8 = extremely tough), juiciness (1 = extremely dry, 8 = extremely juicy), beef flavor (1 = extremely bland, 8 = extremely intense) and off flavor intensity (1 = extremely intense, 8 = none).

Table 11. Sensory panel characteristics of *Psoas major* steaks aged for 14 d from intact bulls and steers castrated at 3 mo.

Trait[1]	Steer	Bull	SE
Myofibrillar tenderness	6.7	6.6	0.21
Connective tissue amount	6.4	6.3	0.15
Overall tenderness	6.7	6.7	0.19
Juiciness	5.5	5.5	0.12
Beef Flavor	4.9	4.8	0.21
Off flavor intensity	6.4	6.4	2.42

[1]Sensory traits were evaluated on a scale of 1 to 8 for myofibrillar tenderness (1 = extremely tough, 8 = extremely tender), connective tissue amount (1 = abundant, 8 = none), overall tenderness (1 = extremely tender, 8 = extremely tough), juiciness (1 = extremely dry, 8 = extremely juicy), beef flavor (1 = extremely bland, 8 = extremely intense) and off flavor intensity (1 = extremely intense, 8 = none).

Table 12. Sensory panel characteristics of *Gluteus medius* steaks aged for 14 d from intact bulls and steers castrated at 3 mo.

Trait[1]	Steer	Bull	SE
Myofibrillar tenderness	4.9	4.4	0.20
Connective tissue amount	5.7	5.5	0.13
Overall tenderness	4.8	4.5	0.18
Juiciness	4.3	4.3	0.23
Beef Flavor	4.2	4.0	0.09
Off flavor intensity	6.2	6.1	0.11

[1]Sensory traits were evaluated on a scale of 1 to 8 for myofibrillar tenderness (1 = extremely tough, 8 = extremely tender), connective tissue amount (1 = abundant, 8 = none), overall tenderness (1 = extremely tender, 8 = extremely tough), juiciness (1 = extremely dry, 8 = extremely juicy), beef flavor (1 = extremely bland, 8 = extremely intense) and off flavor intensity (1 = extremely intense, 8 = none).

Table 13. Sensory panel characteristics of *Semitendinosus* steaks aged for 14 d from intact bulls and steers castrated at 3 mo.

Trait[1]	Steer	Bull	SE
Myofibrillar tenderness	4.8	5.1	0.15
Connective tissue amount	5.6	5.5	0.24
Overall tenderness	4.9	5.0	0.17
Juiciness	3.9	3.8	0.23
Beef Flavor	3.9	3.8	0.11
Off flavor intensity	6.0	6.1	0.14

[1]Sensory traits were evaluated on a scale of 1 to 8 for myofibrillar tenderness (1 = extremely tough, 8 = extremely tender), connective tissue amount (1 = abundant, 8 = none), overall tenderness (1 = extremely tender, 8 = extremely tough), juiciness (1 = extremely dry, 8 = extremely juicy), beef flavor (1 = extremely bland, 8 = extremely intense) and off flavor intensity (1 = extremely intense, 8 = none).

LITERATURE CITED

ARC. 1980. The nutrient requirements of ruminant livestock. Slough, United Kingdom, Commonwealth Agricultural Bureau.

Arthaud, V. H., C. H. Adams, D. R Jacobs, and R. M. Koch. 1969. Comparison of carcass traits of bulls and steers. J. Anim. Sci. 28:742-745.

Bentley, D. S., J. O. Reagan, and M. P. Miller. 1989. Effects of gas atmosphere, storage temperature and storage the on the shelf life and sensory attributes of vacuum packaged ground beef patties. J. Food Sci. 54:284-286.

Cross, H. R.., Z. L. Carpenter, and C. G. Smith. 1973. Effects of intramuscular collagen and elastin on bovine muscle tenderness. J. Food Sci. 38:998-1003.

Cross, H. R., B. D. Schanbacher, and J. D. Crouse. 1984. Sex, age and breed related ch angesin bovine testosterone and intramuscular collagen. Meat Sci. 10:187-195.

Dikeman, M. E., G. B. Reddy , V. H. Arthaud, H. J. Tuma, R. M. Koch, R. W. Mandigo, and J. B. Axe. 1986. Longissimus muscle quality, palatability and connective tissue histological characteristics of bulls and steers fed different energy levels and slaughtered at four ages. J. Anim. Sci. 63:92-101.

Fandino, G., G. C. Skelley and, D. L. Handlin 1989. Acceptability, shrinkage and microbial growth of vacuum packaged pork comparing intact packages, leaking packages and roast sprayed with sodium hypochlorite. J. Food Protection. 52:35-40.

Field, R.A. 1971. Effect of castration on meat quality and quantity. J. Anim. Sci. 1971. 32:849-858.

Galbraith, H., D. G. Dempster, and T. B. Miller, 1978. A note of the effect of castration on the growth performance and concentrations of some blood metabolites and hormones in British Friesian male cattle. Anim. Prod. 26:339-342.

George-Evins, C. D., J. A Unruh, A. T. Waylan, and J. L. Marsden . 2004. Influence of quality classification, aging period, blade tenderization, and endpoint cooking temperature on cooking characteristics and tenderness of beef *Gluteus medius* steaks. J. Anim. Sci. 82:1863-1867.

Gerrard, D. E., S. J. Jones, E. D. Aberle, R. P. Lemenager, M. A. Diekman, and M. D. Judge. 1987. Collagen stability, testosterone secretion and tenderness in growing bulls and steers. J. Anim. Sci. 65:1236-1242.

Griffits, T. W. 1980. The relative efficiency of food utilization of British Friesian entire male and castrate male cattle at two levels of feeding. Anim. Prod. 30: 53-59.

Gruber, S. L., J. D. Tatum, J. A. Scanga, P. L. Chapman, G. C. Smith, and K. E. Belk. 2006. Effects of postmortem aging and USDA quality grade on Warner – Braztler shear force values of seventeen individual muscles. J. Anim. Sci. 84:3387-3396.

Huff-Lonergan, E., and S. M. Lonergan. 2005. Mechanisms of water-holding capacity of meat: The role of postmortem biochemical and structural changes. Meat Sci. 71:194-204.

Hodges, J. H., V. R. Cahill, and H. W. Ockerman. 1974. Effect of vacuum-packaging on weight loss, microbial growth and palatability of fresh beef wholesale cuts. J. Food Sci. 39:143-146.

Jacobs, J. A., C. E. Hurst, J. C. Miller, A. D. Howes, and Gregory T. L. 1977. Bulls versus Steers.I. Carcass composition, Wholesale Yields and Retail Values. J. Anim. Sci. 45:695-698.

King, D. A., M. E. Dikeman, T. L. Wheeler, C. L. Kastner, and M. Koohmaraie. 2003. Chilling and cooking rate effects on some myofibrillar determinants of tenderness of beef. J. Anim. Sci. 81:1473-1481.

Koohmaraie, M. 1988. The role of endogenous proteases in meat tenderness. Proc. Recip. Meat Conf. 41:89-100.

Koohmaraie, M. 1990. Inhibition of postmortem tenderization in ovine carcasses through infusion of zinc. J. Anim. Sci. 68:1476-1483.

Leng, R. A. Factors affecting the utilization of poor quality forages by ruminants particularly under tropical conditions.1990. Nutrition Research Reviews.3:277-303.

Light, N., A. E. Champion, C, Voyle, and A. J. Bayley. 1985. The role of epimysial, perimisyal and endomysial collagen in determining texture in six bovine muscles. Meat Sci. 13:137-149.

Locker, R. H. 1960. Degree of muscular contraction as a factor in tenderness of beef. J. Food Sci. 25:304-307.

Lunstra, D. D., J. J. Ford, and S. E. Echternkamp. 1978. Puberty in beef bulls: Hormone concentrations, growth, testicular development, sperm production and sexual aggressiveness in bulls of different breeds. J. Anim. Sci. 46:1054-1062.

Martin, A. H., H. T. Fredeen, and G. M. Weiss.1971. Tenderness of beef *Longissimus dorsi* muscle from steers, heifers and bulls as influenced by source, post mortem aging and carcass characteristics. J. Food Sci. 36:619-623.

Martin, T. G., T. W. Perry, W. M. Beeson, and M. T. Mohler. 1978. Protein levels for bulls: Comparison of three continuous dietary levels on growth and carcass traits. J. Anim. Sci. 47:29-33.

Morgan, J. B., J. W. Savell, D. S. Hale, R. K. Miller, D. B. Griffin, H. R. Cross and S.D. Shackelford. 1991. National Beef Tenderness Survey. J. Anim. Sci. 69:3274-3280.

Morgan, J. B., T. L. Wheeler, M. Koohmaraie, J. W. Savell, and J. D. Crouse. 1993. Meat tenderness and the calpain proteolytic system in *longissimus* muscle of young bulls and steers. J. Anim. Sci. 71:1471-1476.

Morrison, S. R. 1983. Ruminant heat stress: Effect on production and means of alleviation. J. Anim. Sci. 57:1594-1600.

Nishimura, T., A. Hattori, and K. Takahashi. 1999. Structural changes in intramuscular connective tissue during the fattening of Japanese black cattle: effect of marbling on beef tenderization. J. Anim. Sci. 77:93-104.

Parrish, F. C., Jr., C. J. Vandell, and R. D. Culler. 1979. Effect of maturity and marbling on the myofibril fragmentation index of bovine *Longissimus* muscle. J. Food Sci. 44:1668-1671.

Purchas, R. W., D. L. Burnham and, and S. T. Morris. 2002. Effects of growth potential and growth path on tenderness of beef *Longissimus* muscle from bulls and steers. J. Anim. Sci. 80:3211-3221.

Purchas, R. W., and D. A. Grant. 1995. Liveweight gain and carcass characteristics of bulls and steers farmed on hill country. J. Agri. Res. 38:131-142.

Rhee, M. S., T. L. Wheeler, S. D. Shackelford, and M. Koohmaraie. 2004. Variation in palatability and biochemical traits within and among eleven beef muscles. J. Anim. Sci. 82:534-550.

Shackelford, S. D., T. L. Wheeler, and M. Koohmaraie. 1995. Relationship between shear force and trained sensory panel tenderness ratings of 10 major muscles from *Bos indicus* and *Bos taurus* cattle. J. Anim. Sci. 73:3333-3340.

Seideman, A. C., H. R. Cross, R. R. Oltjen, and B. D. Schanbacher. 1982. Utilization of the intact male for red meat production: a review. J. Anim. Sci. 55:826-840.

Webster, A. J. F., J. S. Smith, and G. S. Mollison. 1977. Prediction of the energy requierements for growtw in beef cattle. 3. Body weight and heat production in Hereford x Friesian bulls and steers. Anim. Prod. 24:237-244.

Wheeler, T. L., and M. Koohmaraie. 1994. Prerigor and postrigor changes in tenderness of ovine *Longissimus* muscle. J. Anim. Sci. 72:1232–1238.

APPENDIX TABLES

Appendix Table 1. Beef carcass classification descriptors used by CORFOGA1 to classify carcasses.

ITEM	VALUE	DESCRIPTION
DENTITION	0	No permanent incisors.
	2	First and second permanent incisors.
	4	Third and fourth permanent incisors.
	6	Five and six permanent incisors.
	8	Seven and eight permanent incisors.
MUSCLE	1	Slightly convex round profile, wide round and clod.
	2	Linear profile, ribs are slightly visible.
	3	Concave round, round and clod narrow and ribs are visible.
	4	Ultra-concave profiles, ribs easily visible, narrow carcasses.
FAT COVER	1	≤ 0.5 cm fat thickness over the loin.
	2	0.5≤ 2 cm fat thickness over the loin.
	3	>2 cm fat thicness over the loin.
FAT COLOR	1	White to slightly pink
	2	Light yellow
	3	Extremely yellow

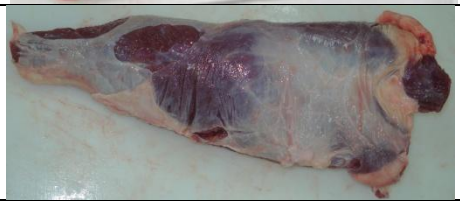
[1]CORFOGA, 2002.

Appendix Table 2. Subprimals list with Spanish (Costa Rican) name and muscles.

SUBPRIMAL CUT	SPANISH NAME	MUSCLES
Tenderloin	Lomito	*Psoas major* and *Psoas minor*
Strip loin	Lomo ancho	*Longissimus lumbarum*
Ribeye	Cola de lomo	*Longissimus thoracis*
Knuckle (Tip)	Bolita	*Vastus lateralis, Vastus medialis, Vastus intermedius*, and *Rectus femoris*
Top sirloin butt, center-cut	Vuelta de lomo	*Gluteus medius*
Top (Inside) round	Posta de cuarto	*Adductor, Gracilus, Pectineus Sratorious,*and *Semimenbranosus*
Bottom (Outside) round	Solomo	*Biceps femoris*
Sirloin cap	Punta de solomo	*Biceps femoris*
Tri tip	Cacho de vuelta de lomo	*Tensor fasciae latae*
Eye of round	Mano de piedra	*Semitendinosus*
Ribeye cap	Lomo de aguja	*Spinalis dorsii*
Clod	Posta de paleta	*Triceps brachii*
Top blade	Lomo de paleta	*Infraespinatus*
Chuck tender	Cacho de paleta	*Supraspinatus*
Under blade	Quititeña	*Serratus ventralis*
Flank	Cecina	*Rectus abdominus*
Back rib, rib fingers	Costilla	*Intercostal*
Brisket, flat	Pecho	*Deep pectoral*
Hump	Giba	*Rhomboideus*
Outside skirt	Arrachera	*Diaphragm*
Inside skirt	Lomo de entraña	*Traversus abdominis*
Shank	Ossobuco	

Appendix Table 3. Boneless subprimal cuts, pictures and descriptions.

CUT	PICTURE	DESCRIPTION
Tenderloin		Consists of the psoas major and minor muscles. The principal membranosus tissue over the main body of the tenderloin remains intact.
Strip loin		Consists of the Longissimus lumborum, gluteus medius on the sirloin end and a rib mark on the rib end.
Ribeye		Consists of the Longissimus muscle only from the 12th rib to the anterior end of the Longissimus.
Knuckle (Tip)		Consists of the full knuckle comprised of the Vastus *lateralis, Vastus medialis, Vastus intermedius and Rectus femoris.*
Top sirloin butt, center-cut		Consists of the *Gluteus medius* anterior the pelvic bone and excludes the anterior *Gluteus medius* in the Strip loin.
Inside (Top) round		Consists of the *Semimembranosus, Sartorious, Adductor, Gracilis and Pectinius*.

Outside (Bottom) round		Consists of the entire *Biceps femoris* excluding the *Biceps femoris* of the sirloin cap.
Sirloin cap		Consists of the *Biceps femoris* muscle above the *Gluteus medius* of the sirloin.
Tri tip		Consists of the *Tensor fasciae latae* muscle from the bottom sirloin butt.
Eye of round		Consists of the *semitendinosus* muscle removed at the natural seams.
Ribeye cap		Consists of the *spinalis dorsi* muscle from the ribeye roll.
Clod		Consists of the muscle system of the thick end of the clod (*Triceps brachii).*
Top blade		Consists of the *infraespinatus* muscle lying ventral the medial ridge of the scapula.
Chuck tender (Mock tender)		Consists of the *supraespinatus* muscle that lies dorsal to the medial ridge of the scapula.

Under blade		Consists of *serratis ventralis* muscle adjacent to the scapula
Flank		Consists of the *rectus abdominis* muscle from the flank region of the carcass.
Back rib, rib fingers		Consists of the *intercostal* muscles of thoracic vertebrae.
Brisket, flat		Consists of the *deep pectoral* muscle from the brisket.
Hump		Consists of the *rhomboideus* muscle.
Outside skirt		Consists of the *diaphragm* from the plate.
Hind shank		Consists of shank muscles surrounding tibia bone.

Appendix Table 4. Sensory attributes and descriptors used for sensory panel evaluation.

Score	Myofibrillar Tenderness	Juiciness	Beef Flavor Intensity	Connective Tissue Amount	Overall Tenderness	Off Flavor Intensity
1	Extremely tough	Extremely dry	Extremely bland	Abundant	Extremely tough	Abundant
2	Very tough	Very tough	Very bland	Moderately abundant	Very tough	Moderately abundant
3	Moderately tough	Moderately dry	Moderately bland	Slightly abundant	Moderately tough	Slightly abundant
4	Slightly tough	Slightly dry	Slightly bland	Moderate	Slightly tough	Moderate
5	Slightly tender	Slightly juicy	Slightly intense	Slight	Slightly tender	Slight
6	Moderately tender	Moderately juicy	Moderately intense	Traces	Moderately tender	Traces
7	Very tender	Very juicy	Very intense	Practically none	Very tender	Practically none
8	Extremely tender	Extremely juicy	Extremely intense	None	Extremely tender	None

Appendix Table 5. Interaction means for vacuum package purge, cooking loss, total moisture loss, and Warner-Bratzler shear force (WBSF) of *Longissimus lumborum* (LL), *Psoas major* (PM), *Gluteus medius* (GM) and *Semitendinosus* (ST) aged for 2, 7, 14, and 28 d from bulls and steers castrated at different ages.

	Age of castration												Intact				
	3 mo				7 mo				12 mo				Bull				
Days of Aging	2 d	7d	14 d	28 d	2 d	7 d	14 d	28 d	2 d	7d	14 d	28 d	2 d	7 d	14 d	28 d	SE
Subprimal Steak and Trait																	
LL																	
Package purge, %	1.2	3.3	4.0	7.4	1.2	2.8	4.9	6.0	2.8	3.6	5.0	7.8	1.1	2.7	3.8	6.7	0.87
Cooking loss, %	27.7	26.1	27.6	24.9	27.8	26.9	29.4	27.0	27.1	26.3	29.0	26.4	27.5	27.0	30.4	28.4	1.29
Total moisture loss, %	28.8	29.6	30.8	29.4	28.6	30.2	31.2	29.4	28.4	28.7	33.8	31.3	28.7	29.5	32.7	30.5	1.88
WBSF, kg	10.1	9.3	8.7	6.4	10.8	9.7	10.0	6.8	9.5	9.2	9.4	8.2	10.5	10.1	10.5	9.0	1.03
PM																	
Package purge, %	2.2	2.9	4.0	9.1	2.0	3.3	3.7	7.2	2.4	4.1	4.2	9.7	1.6	3.5	4.6	7.9	0.94
Cooking loss, %	33.0	32.3	32.3	29.8	35.0	31.5	32.9	31.3	32.2	33.6	32.7	28.9	33.3	32.4	33.6	32.3	1.25
Total moisture loss, %	39.2	35.5	35.1	34.5	33.7	34.0	34.1	33.1	35.3	36.3	35.8	34.8	34.2	36.9	37.1	35.0	1.86
WBSF, kg	4.4	4.0	4.0	3.6	4.5	3.8	3.8	3.6	4.1	3.8	3.5	3.5	4.4	3.7	4.0	3.6	0.19
GM																	
Package purge, %	2.4	3.1	4.6	6.3	1.8	3.6	3.3	6.9	2.7	4.2	4.9	6.7	2.3	3.2	4.9	5.6	0.82
Cooking loss, %	35.1	34.3	34.0	31.8	36.3	34.7	33.6	31.8	35.2	36.1	32.9	31.6	35.6	36.6	34.7	32.3	1.51
Total moisture loss, %	37.5	37.6	38.5	36.6	36.5	34.0	33.3	35.1	39.7	37.1	36.1	35.4	36.5	37.1	37.4	36.6	1.79
WBSF, kg	7.9	6.7	5.8	5.5	8.3	6.8	6.1	5.4	8.4	6.9	6.5	6.1	8.8	7.1	7.3	6.1	0.62
ST																	
Package purge, %	0.9	2.9	6.4	6.6	0.8	2.2	4.0	5.5	1.1	1.8	4.0	5.8	0.7	2.7	3.1	4.9	1.19
Cooking loss, %	29.2	32.5	32.5	32.9	30.5	34.2	35.4	32.9	31.1	33.0	35.1	32.3	30.7	34.4	34.5	32.0	1.23
Total moisture loss, %	33.0	36.7	41.6	36.6	33.1	34.5	37.8	37.8	32.6	34.3	37.5	37.3	35.4	36.1	38.7	39.3	3.57
WBSF, kg	6.4	6.1	6.1	5.9	6.5	6.2	6.6	5.9	6.8	5.9	6.3	6.3	6.6	6.2	5.9	5.8	0.21

Appendix Table 6. P-values for linear, quadratic and selected contrasts for bulls and steers castrated at 3, 7, and 12 mo of age[a].

Trait	Linear	Quadratic	Steers vs Bulls	Early Steers vs Bulls[b]
KPH, kg	0.0138	0.0134	0.0027	0.0050
KPH, %	0.0115	0.0149	0.0021	0.0050
Bone and fat, kg	0.0067	0.2384	0.0058	0.0024
Bone and fat, %	0.0088	0.1773	0.0101	0.0050
Centre cut top sirloin, %	0.0114	0.4353	0.0199	0.0107
Top inside round, %	0.0455	0.1044	0.0052	0.0279

[a]P-values for linear and quadratic contrasts: 3 mo, 7 mo, 12 mo and bulls.
[b]Early steers = steers castrated at 3 and 7 mo.

Appendix Table 7. P-values for linear and quadratic contrasts for traits aged for 2, 7, 14 and 28 d.

Trait	Linear	Quadratic
Longissimus lumborum		
Package purge, %	<0.0001	0.1117
Cooking loss, %	0.9796	0.2355
Total moisture loss, %	0.0563	0.0940
Psoas major		
Package purge, %	<0.0001	<0.0001
Cooking loss, %	0.0024	0.2415
WBSF, kg	<0.0001	0.0494
Gluteus medius		
Package purge, %	<0.0001	0.2500
Cooking loss, %	<0.0001	0.0931
WBSF, kg	<0.0001	0.0092
Semitendinosus		
Package purge, %	<0.0001	0.8248
Cooking loss, %	0.0025	<0.0001
Total moisture loss, %	0.0003	0.1222
WBSF, kg	<0.0001	0.1455

Appendix Table 8. P-values for linear, quadratic and selected contrasts for LL steaks from bulls and steers castrated at 3, 7, and 12 mo of age[a].

Days of aging	Linear	Quadratic	Steers vs Bulls	Early Steers vs Bulls[b]
2d	0.9688	0.7645	0.5288	0.9312
7d	0.4103	0.5781	0.2285	0.3556
14d	0.0397	0.8709	0.0632	0.0619
28d	0.0002	0.6977	0.0022	0.0005

[a]P-values for linear and quadratic contrasts: 3 mo, 7 mo, 12 mo and bulls.
[b]Early steers = steers castrated at 3 and 7 mo.

Appendix Table 9. P-values for linear and quadratic contrasts of LL steaks aged for 2, 7, 14 and 28 d.

Castration	Linear	Quadratic
3 mo	<0.0001	0.2026
7 mo	<0.0001	0.0561
12 mo	0.0491	0.2101
Bull	0.0771	0.2589