THE EFFECT OF VACUUM AGING, DISPLAY AND LEVEL OF NUTRITION ON BEEF QUALITY

by

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CHAPTER I

GENERAL INTRODUCTION

Tenderness is the most important palatability characteristic considered by consumers when selecting beef cuts. Consumers heavily emphasize price when selecting beef and resist significant price increases. Hence, systems that will reduce or aid the control of production and marketing costs are important considerations for the livestock and meat industry. Feeding cattle on lower planes of nutrition or for shorter periods of time on full feed can reduce animal production costs through lower nutritional investment expenditures. The effect of varying nutritional regimes on beef quality has not been completely defined, thus more research is needed to measure the total impact of alternative feeding practices on beef quality.

New systems for processing and handling beef are constantly being explored. Cost, efficacy and energy efficiency are the major criteria dictating selection of new systems. Distribution of vacuum packaged subprimals used in the industry is expected to become more widespread (Meat Processing, March 1975 and National Provisioner, March 1975). However, limited work has been published evaluating the feasibility of vacuum aging of meat cuts from cattle fed on various nutritional regimes.

Meat tenderness has been studied extensively by many researchers and the only major conclusion that can be drawn from these studies is that tenderness is a function of many interrelated variables. Most beef tenderness research is based on work involving the longissimus muscle. The relatively high value of this

muscle justifies this intensive research; however, other muscles in the beef carcass are inherently different from the longissimus and any study involving various methods of carcass handling should include a variety of muscles.

The purpose of this research was to examine the effects of vacuum packaging aging and retail display on various quality traits of beef produced on four nutritional regimes.

CHAPTER II - REVIEW OF LITERATURE

FACTORS AFFECTING TENDERNESS

Many factors influence meat tenderness. Matz (1962) suggested that the perception of tenderness or toughness may be affected by meat juiciness, protein water holding capacity or amount and distribution of fat. One reason for the conflicting results regarding the factors affecting tenderness is that tenderness is not a simple but rather a multi-component system (Cover, 1962). Marsh (1977) stated that two muscle components determine the tenderness of meat, collagen and the contractile apparatus.

Myofibrillar factors:

Ramsbottom and Strandine (1949) reported that pre-rigor muscle cooked at two hours postmortem was more tender than if cooked at any other time up to two and six days postmortem. The exact cause of toughening during the course of rigor mortis was not known but it now appears to be associated with muscle shortening (Pearson, 1971). Locker (1960) noted that if muscles are detached from the skeleton at death, considerable shortening may occur and that partially contracted muscles are less tender than relaxed muscles.

Sarcomere length of post-rigor muscle can be altered by various postmortem methods. Hostetler et al. (1970) suspended beef sides from the ischium by placing a hook through the obturator foramen (hip suspension). The semimembranosus and longissimus muscles from the hip suspended sides had longer

sarcomeres, lower shear force values, and improved taste panel tenderness scores than those hung by the achilles tendon (leg suspension). The semitendinosus also had longer sarcomeres ($P<.05$) due to hip suspension but no differences in shear force or taste panel tenderness were observed. Increased sarcomere length in these muscles can be explained by the greater stretch produced by hip suspension vs. normal leg suspension. Hostetler et al. (1975) confirmed that muscles from hip suspended carcasses had longer sarcomeres, lower shear force values and higher sensory panel ease of fragmentation ratings. Herring et al. (1965) compared beef sides placed horizontally with legs at right angles to the backline vs. the normal vertical method of suspension. The longissimus, gluteus medius, adductor, biceps femoris and semitendinosus muscles shortened with vertical suspension. No difference in shortening was observed in the semimembranosus. Muscles which increased in sarcomere length also decreased in fiber diameter and shear force. Dransfield and Rhodes (1976) studied the effect of post-rigor muscle length on shear force. Their results indicate that sarcomere length or fiber diameter are not the only factors involved in tenderness. The shear force of cooked muscle was dependent on the interaction of actomyosin and connective tissue components of muscle.

Goll et al. (1964a) compared bovine semitendinosus muscles excised immediately postmortem with those left attached to the skeleton. Attached muscles were least tender immediately postmortem and became more tender during aging. Excised muscles were least tender 6-12 hrs. postmortem and increased in tenderness

thereafter. At 312 hrs. aging, excised muscles were less tender than intact muscles. The excised muscles shortened considerably by six hrs. postmortem, but sarcomere length failed to increase at the longer postmortem times, even though tenderness increased. No observations were recorded on sarcomere length changes for attached muscles. Locker and Hagyard (1963), Gothard et al. (1966), Howard and Judge (1968) and Smith et al. (1971) reported that final state of contraction appears closely associated with tenderness. Gothard et al. (1966) stated that degree of contraction after 7 days aging may be a significant factor influencing tenderness, particularly in unrestrained muscle. Parrish et al. (1973) and Jeremiah and Martin (1976) observed an increase in sarcomere length of beef semitendinosus muscle during the aging period. This increase in sarcomere length in the semitendinosus may be due to increased enzymatic breakdown of actomyosin (Goll et al., 1974).

Jungk et al. (1967) constructed an apparatus for measuring postmortem muscle tension. The period of tension development and cessation parallels the pattern of decreasing and increasing tenderness in excised muscles described by Goll et al. (1964a). The ultimate increase in tenderness may be due to the gradual dissipation of the muscle's tendency to shorten. The relationship between muscle shortening and tenderness was studied by Marsh and Leet (1966). Shortening up to 20% of initial excised length had no effect on tenderness. Beyond this point toughness rapidly increases, reaching a peak at 40% shortening. Tenderness increases upon further shortening and at 55-60% shortening

it is equally as tender as meat which had less than 20% shortening. The cause of this tender-tough-tender sequence appears related to the structural state of the contractile mechanism. Before the muscle has had a chance to shorten, there are few actin-myosin crossbridges formed, resulting in more tender meat. As the muscle shortens, more crossbridges are formed causing increased toughness. Upon further shortening the actin and myosin filaments begin to rupture the myofibril, causing an increase in tenderness.

Ramsey and Street (1940), Fenn (1947) and Marsh and Thompson (1957) have noted a relationship between shortening and fluid exudation in muscle. The 40% shortening that results in peak toughness is also the "delta state" of the muscle (Ramsey and Street, 1940). Shortening by 40% is the elastic limit of the containing muscle membrane and further shortening is possible only after membrane rupture. Marsh and Leet (1966) found that with up to 40% shortening, exudation was low and constant. Between 40-60% shortening, rate of fluid loss increased at an increasing rate with further shortening. Beyond 60% shortening, volume of fluid exuded increased with further shortening but at a constant rate. This increase in cell damage corresponds with increased tenderness after 40% shortening. In ultrastructure examinations by Marsh et al. (1974), widespread fiber fracturing was observed at approximately 50% shortening. This fracturing was sufficient to account for the increase in tenderness.

Cold shortening in beef sternomandibularis muscle was first observed by Locker and Hagyard (1963). They found that unre-

strained muscle shortened more rapidly and to a greater extent at 0 C than at any other temperature between 0 and 43 C. Rate of shortening decreased from 0 to 14 C and began to increase at 19 C. Cold shortening was reversible under certain conditions. Altering muscle temperature from 0 C to 22 C at three hrs. post-mortem caused the muscles to regain their original length. Longer times at 0 C before placing in 22 C environment resulted in less complete recovery. Locker and Daines (1976) observed that raising the temperature to 37 C in the final three to seven hrs. of rigor completely nullified the toughness found in cold shortened sternomandibularis. This reversibility suggests that cold shortening and rigor mortis are not the same. Since cold shortening precedes rigor mortis by many hours, Davey and Gilbert (1974) concluded these two events are quite different and independent phenomena.

Intact skeletal attachments do not prevent cold shortening (Marsh and Leet, 1966). Excised muscles were clamped in a metal frame to prevent changes in over-all length. After insulating the ends of each muscle strip, the muscle was exposed at 2 C air. Cold shortening occurred only in the exposed section with the insulated ends lengthening by a corresponding amount. Marsh et al. (1968) also observed that cold shortening caused a toughening of muscle still attached to the carcass of lambs. Thus, if cold shortening can occur in an attached muscle there may be a stretched area in that muscle also. This characteristic needs to be examined for its possible relationship to tenderness.

Dransfield and Rhodes (1976) allowed pre-rigor beef sterno-mandibularis muscle to pass into rigor in both lengthened and shortened states. After aging four days at room temperature, half of the samples from each group were stretched, the other half were controls. Cooked, pre-rigor shortened samples were tougher than the lengthened ones. Stretching the muscles after aging tenderized the shortened samples but had no effect on the lengthened ones ($P<.05$). These data show that cooked meat tenderness may be due to the combined effects of actomyosin and connective tissue. However, since muscles differ in amount of connective tissue, more work must be done before any generalizations can be made.

Smith et al. (1971) studied various mechanical and physical methods of improving tenderness in beef longissimus muscle. Four of the nine treatments resulted in irregularly shaped carcasses which could present fabrication problems. Of all treatments studied, the ones which involved chilling carcasses at 16 C for 16-20 hr. postmortem appeared the most practical. These treatments also yielded the greatest reduction in shear force. Treatments which increased carcass length (symphysis pubis to the first rib) did not necessarily increase tenderness. Improved tenderness resulting from the 16 C chill for 16-20 hr. may be due to increased proteolysis and greater cathepsin enzyme activity. Will and Henrickson (1976) studied the effects of delayed chilling and hot boning on beef biceps femoris, longissimus and semimembranosus muscles. Tenderness of muscles fabricated 48 hr. postmortem at 1.1 C was

compared with those fabricated three, five and seven hrs. postmortem with carcasses held at 16 C. No major differences in tenderness were found between muscles which were boned at three, five or seven hrs. postmortem and those boned 48 hrs. postmortem. Cold shortening is not likely to occur in the longissimus unless muscles are subjected to blast freezer temperatures while on the carcass or are excised and exposed to 0 to 2 C temperatures (Smith et al., 1971).

Connective Tissue Factors:

Connective tissue includes an arrangement of extracellular fibers in a dense or loosely packed structure (Forrest, 1975). The extracellular fibers include collagen, elastin and reticulin, and of these, collagen is the most abundant and significantly influences meat tenderness. Elastin is not a serious contributor to muscle toughness, however, insufficient attention has been paid to the possible contribution of reticulin to muscle tenderness, which, although otherwise similar to collagen, is not easily broken down by heat (Bendall, 1966). Collagen fibers are present in all muscles and their amount and distribution depends on the physical activity of the muscle. Exercise muscles of the limbs contain more collagen and are less tender than support muscles of the back.

Locker (1960), Cover et al. (1962), Machlik and Draudt (1963), Bouton et al. (1973), Cross et al. (1973a) and McCrae and Paul (1974) have stated that connective tissue contributes to toughness of meat. Total amount of connective tissue is not related

to tenderness differences in beef associated with animal age (Hill, 1966; Kruggel et al., 1970; Cross et al., 1973); however, quantitative differences in collagen influence the variations in tenderness found between different muscles. Dutson et al. (1976) found a significant difference in the amount of collagen between sternomandibularis and psoas major muscles. The sternomandibularis had a greater shear force than the psoas major at all sarcomere lengths. Upon shortening, the sternomandibularis toughened at a faster rate indicating the importance of different amounts of connective tissue between muscles. Cover and Smith (1956), Irvin and Cover (1959), Ritchey and Cover (1962) and Ritchey et al. (1963) found that longissimus muscles contain considerably less collagen than biceps femoris muscles. Herring et al. (1967) reported significantly different collagen content for beef longissimus (4.52 mg/g fresh muscle), semimembranosus (6.11 mg/g) and semitendinosus (8.0 mg/g).

Decreases in tenderness accompanying increasing animal age is most likely due to qualitative changes in connective tissue (Forrest et al., 1975). Although the total amount of connective tissue in a muscle remains relatively constant throughout an animal's life, the number of intermolecular and intramolecular crosslinks in collagen increases with animal age (Wilson et al., 1954; Goll et al., 1964a; Goll et al., 1964b and Vognarova et al., 1968), resulting in reduced collagen solubility, and increased resistance to shearing or chewing. As the animal matures, the rapid increase in muscle fiber size dilutes the existing connective tissue. Thus, market weight cattle at 12 to 18 months of

age (Forrest et al., 1975). At 30 months of age there is considerable toughening due to crosslink formation followed by a further gradual toughening but at a progressively slower rate with increasing age.

Hill (1966) reported the degree of collagen solubility as well as total amount of collagen should be considered when biochemical explanations of toughness in meat are considered. Yield of soluble intramuscular collagen decreased with increasing postmortem aging (McClain, 1969; McClain et al., 1970; Kruggel and Field, 1971). Decreased soluble collagen during aging may be due to molecular changes in the collagen resulting from holding the muscles at a low pH for long periods of time (Kruggel and Field, 1971).

Herring et al. (1967), Kruggel and Field (1971) and Pfeiffer et al. (1972) found increased extractable collagen from stretched muscle. Stretching alone does not affect solubility (Pfeiffer et al., 1972) but facilitates action on collagen by the forces of aging, such as enzymes and pH. Increased collagen solubility is associated with various structural changes, specifically a reduction in the number of intermolecular crosslinks. These alterations in collagen structure have been associated with increased tenderness (Kruggel and Field, 1971; Pfeiffer et al., 1972; and O'Shea et al., 1974). Rowe (1974) observed a change in collagen fiber density and fiber orientation upon muscle contraction, and these in turn determine the overall strength of the collagen system.

Heat Factors:

Cooking effects on beef tenderness are primarily due to the reactions of myofibrillar and connective tissue proteins to heat. Heat can reduce tenderness by causing the myofibrillar proteins to coagulate and harden. Heat induced changes in connective tissue resulting in greater collagen solubilization, increase tenderness. Collagenous connective tissue proteins hydrolyze upon heating (Visser et al., 1960; Hamm, 1966; Draudt, 1972; Forrest et al., 1975). Tenderness of cooked meat is affected to a greater extent by collagen than by elastin, since elastin content in a muscle is small compared to collagen (Winegarden et al., 1952).

The amount of connective tissue present in a cut generally determines the type of cookery used. Dry heat methods are appropriate for tender cuts since heating time is too short to adequately breakdown connective tissue. Moist heat cookery provides sufficient water for complete hydrolysis of collagen to gelatin (Forrest et al., 1975). A new type of cookery, microwave cooking, is currently being examined but its use is not as widespread as the other conventional methods.

The effect of heating time and temperature on shear force was studied for beef semitendinosus muscles by Machlik and Draudt (1963). Low temperature cookery at 56 to 58 C resulted in slow tenderization. Cooking at 62 to 64 C caused more rapid collagen breakdown and tenderness improved with prolonged heating. Temperatures of 72-74 C resulted in the most rapid shrinkage of collagen followed by protein hardening and toughening. However,

continued heating at 72 C ultimately caused gelatin formation resulting in meat tenderization. Beef roasted at very low oven temperatures (66-121 C) for long periods of time was more tender than that roasted at high temperatures (149-163 C) for a short time (Bramblett et al., 1959; Bramblett and Vail, 1964; Bayne et al., 1969; Penfield and Meyer, 1975). Bramblett et al. (1959), Machlik and Draudt (1963) and Paul (1963) have observed that cooking media temperatures of about 57-60 C caused maximum hardening of muscle fibers. Laakkonen et al. (1970) and Penfield and Meyer (1975) suggested that proteolytic and collagenolytic enzyme activity may contribute to the increased tenderness in meat heated at a slow rate.

Various methods of cooking longissimus and biceps femoris muscles were evaluated by Cover et al. (1957). Severe moist heat cookery to an internal temperature of 100 C seemed to toughen the longissimus but tenderized the biceps femoris. Broiling to 61 C resulted in the most temder longissimus. These data indicate that connective tissue is tenderized to the greatest extent by moist heat which results in a more rapid heat transfer than does dry heat cookery. The effect of cooking method on tenderness and collagen solubility was studied by McCrae and Paul (1974). The manner in which the heat energy is applied alters collagen solubility more than the rate of heat penetration. No differences were observed among conventional cooking methods but microwave energy solubilized more collagen ($P<.05$) than dry or moist heat methods. Similar results were observed by Paul et al. (1973).

Internal temperatures as low as 50 C caused slight sarcomere shortening in beef (Schmidt and Parrish, 1971). Hostetler and Landmann (1968) also found small changes in muscle fiber length when heated at temperatures below 60 C. Giles (1969) observed that meat fiber shrinkage and sarcomere shortening were closely related. Temperatures of 60 C produced very little change in length but temperatures above 70 C caused extensive shortening in muscle fibers.

The relationship between myofibrillar contraction state and cooking has not been completely defined. Locker and Daines (1974 a,b) found that cold shortening has no effect on cooking loss. However, Bouton et al. (1972, 1973, 1976) found that cooking loss is greater ($P<.001$) in cold shortened beef.

Differences ($P<.01$) in total cooking loss due to animal nutrition were noted by Graham et al. (1959) but these differences were not completely discussed. Kropf et al. (1975) observed no difference in total cooking loss between steaks from short and long fed cattle. However, steaks from grass fed cattle had a higher ($P<.05$) cooking loss. Wheeling et al. (1975) found cooking losses to be lower in steaks from forage fed cattle compared with steaks from grain fed cattle. Jacobson and Fenton (1956) however, stated that the percent cooking loss was not significantly affected by level of animal nutrition.

Tenderness Variation Among Muscles:

Muscles in a beef carcass vary in composition, function and physico-chemical properties. These inherent variations make it difficult to study only one or two muscles and extend the

results to the entire carcass. Various explanations exist accounting for these muscle to muscle differences and each explanation involves several complex interactions.

The amount of connective tissue in a muscle affects the texture of meat and is generally considered the single most important factor influencing gross differences in tenderness among muscles (Forrest et al., 1975). Muscles such as the semitendinosus and biceps femoris are very active during the animal's life and appear coarse in texture. A muscle such as the psoas major, which is relatively inactive throughout the animal's life, appears fine textured. Exercise muscles develop more connective tissue to support their activity, and if this tissue is not effectively altered during cookery, these muscles will be less tender than fine textured, postural type muscles. Although large amounts of connective tissue tend to increase shear values of muscles, other factors including fatty tissue and protein denaturation significantly affected cooked meat tenderness (Ramsbottom et al., 1945; Bratzler, 1971; Forrest et al., 1975).

The elastin content of various beef muscles was measured by Bendall (1967). Most muscles from the hindquarter contain less than 0.2% elastin on a dry weight basis which is less than 5% of the total connective tissue. The semitendinosus muscle is a unique exception and contains approximately 2% elastin which is about 40% of the total connective tissue. The semitendinosus and biceps femoris muscles had similar amounts of connective tissue and were equally tough, but the semitendisosus contained 15 times more elastin. Thus, elastin and denatured

collagen appeared to be equal in their contribution to connective tissue toughness in cooked meat in Bendall's research.

The relationship between collagen solubility and Warner-Bratzler shear values in biceps femoris and longissimus muscles were examined by Field et al. (1970). Total collagen content and shear values were higher and percent heat labile collagen was lower for biceps femoris than longissimus. Herring et al. (1967) reported higher ($P<.05$) acid soluble collagen in the longissimus than in the semimembranosus muscle. These data show that both the solubility type and the amount of collagen varies between muscles and that both factors definitely influence tenderness variations between muscles.

Paul et al. (1970) studied the response of connective tissue and contractile fibers to heat in the longissimus, trapezius and spinalis dorsi muscles. Both the collagenous connective tissue and the contractile fibers from the three muscles cooked as an intact rib steak, varied in their response to heating. Since the muscles were cooked intact it was impossible to heat all muscles to the same internal temperature. The longissimus muscle reached the lowest internal temperature (75.7 C) but showed the greatest alteration in the collagenous fibers. Contractile fibers in the cooked longissimus showed many fine cracks across the fibrils. Muscle fibers in the trapezius reached the highest internal temperature (81.8 C) and showed no physical disruption while fibers of the spinalis dorsi (heated to 78.8 C) were cracked and granulated and more similar to the longissimus than the trapezius. In this study, the more intact the

contractile structure after heating, the greater the toughness. These variations in tenderness may be due to differences in susceptibility of myofibrillar proteins to heat fracture.

Muscle differences in tenderness also result from variations in the state of myofibrillar contraction (Marsh, 1977). Herring et al. (1965) and Hostetler et al. (1970, 1975) found sarcomere length to increase in various muscles by altering carcass suspension. Muscles which had increased sarcomere lengths due to suspension treatment also showed reduction in shear force.

Muscles vary in their susceptibility to cold shortening (Marsh, 1977). Muscles with more white fibers are less susceptible to cold shortening than muscles containing mostly red fibers. Marsh (1977) states that white fibers have a more highly developed sarcoplasmic reticulum which may more effectively bind calcium during carcass chilling than the sarcoplasmic reticulum of red fibers. Calcium induced cold shortening may also result from the mitochondria responding to postmortem anoxia (Marsh, 1977). White fibers have fewer mitochondria than red fibers and this may further explain the variations in muscle susceptibility to cold shortening. Superficial muscles and muscles with very little fat covering are also most susceptible to cold shortening purely because they have little insulation from the cold (Forrest et al., 1975).

A calcium activated factor involved in z-line degradation was first observed by Busch et al. (1972). Olson et al. (1976, 1977) found that calcium activated factor (CAF) may be responsible for increased myofibrillar fragmentation and decreased

Warner-Bratzler shear force. Total CAF activity was similar in longissimus and semitendinosus muscles, but the psoas major contained less than half the total CAF found in the semitendinosus or longissimus (Olson et al., 1977). Goll et al. (1974) found semitendinosus muscle had 1.5 to 3.0 times greater calcium activated enzymic activity than psoas major muscle. Tenderness of the semitendinosus muscle also increased whereas the psoas major muscle showed no change in tenderness. Moeller et al. (1977) found that other lysosomal enzymes (β-glucuronidase and cathepsin C) play an important role in postmortem tenderization but studies comparing activities of these enzymes in various muscles are lacking.

Most research done previously indicates that intramuscular lipid or marbling contributes less than 12% of the variation in tenderness of beef (Jeremiah et al., 1970 and Forrest et al., 1975).

Effects of Feeding Regime on Beef Palatability:

A major problem in comparing beef from cattle finished on either forage or grain is the lower net energy of the forage which results in slower gains of forage fed cattle. As the amount of grain in a ration is increased, cattle gain faster and require fewer days on feed to produce carcasses of choice quality (Woods and Scholl, 1962; Bidner, 1975). Thus if cattle in these experiments are fed to either a constant weight or similar grade endpoint, age differences up to 250-290 days (Woods and Scholl, 1962) may arise since grain fed cattle would be slaughtered at an earlier age.

Results of previous research comparing forage and grain finished beef are conflicting and inconclusive. Brown (1954) found no consistent differences in color of lean or in organoleptic evaluations of the cooked product when comparing forage and grain fed beef. Fat color was slightly yellow for the forage fed beef. Johnston et al. (1976) fed cattle to a low choice slaughter endpoint on either a growing-finishing ration or a forage regime. Forage finished cattle were heavier at slaughter and had lower shear force values than the grain fed group. Sensory panel evaluations rated forage finished beef equal or superior to that from grain fed cattle. Wheeling et al. (1975) fed cattle to various degrees of marbling on a grain or forage ration and found no significant differences in shear force values and sensory panel evaluations for tenderness, flavor and juiciness within the same marbling group. Young and Kauffman (1976) fed either a high grain, corn silage or a high forage ration until ultrasonic fat thickness reached 1.0 cm. Steers on the high forage ration had to be fed to heavier weights and consequently were older. Sensory panel evaluations for overall desirability were not significantly different indicating that when cattle are fed to similar carcass composition, few if any differences in palatability can be detected.

Consumer acceptability, tenderness, flavor and aroma of beef from cattle fed grain on grass or in dry lot were not significantly different (Malphrus et al., 1962). Sensory panel evaluations also indicated beef from both feeding regimes were fully accept-

able. Huffman (1974) reported a trained sensory panel could not distinguish between forage finished beef and beef finished for 70 days on grain. Warner-Bratzler shear values were not significantly different between the two regimes.

Graham et al. (1959) examined steaks from steers fed a maintenance diet, hay ad libitum, hay plus limited concentrates, and a fattening ration ad libitum. Juiciness and tenderness increased and Warner-Bratzler shear values decreased with increasing plane of nutrition. Jacobson and Fenton (1956) fed Holstein bulls and heifers on three planes of nutrition. Shear force values for the longissimus, psoas major and semimembranosus were not significantly affected by level of nutrition. Only the longissimus had higher tenderness scores with higher levels of nutrition. Flavor in all three muscles was improved with higher levels of nutrition.

Dube et al. (1971) studied hay and corn silage diets fed to steers of various ages but slaughtered at a constant weight endpoint. Flavor of longissimus and biceps femoris steaks was improved by feeding corn silage during earlier feeding periods. Tenderness also improved but they concluded that this was associated more with animal age differences than diet. The early silage rations resulted in higher weight gains than the hay diets, thus the animals were younger when they reached slaughter weight. Similar findings were reported by Garrigus et al. (1969).

Sensory panel evaluations for tenderness, flavor and overall acceptability were highest for long fed beef, intermediate for short fed beef and lowest for grass fed beef (low plane of nutrition from late season bluestem pasture) (Kropf et al., 1975).

Shear force values correlated with sensory panel evaluations for tenderness. Seven out of the ten grass fed carcasses were ranked unacceptable for tenderness. Data by Reagan et al. (1976) revealed more variation in taste panel tenderness and flavor scores of grass fed beef than grass-grain fed beef. Shinn et al. (1976) evaluated steers on three finishing regimes; fescue pasture for 200 days, 200 days pasture plus 56 days grain, and 200 days pasture plus 112 days grain. Sensory panel evaluations for flavor and tenderness increased ($P<.05$) and Warner-Bratzler shear values decreased ($P<.05$) when cattle were fed grain. No significant differences between the two grain fed treatments were found. Schupp et al. (1976) stated these results were not unexpected since the grass fed group only gained 2 kg during the entire trial. Bowling et al. (1976) also reported grain finished beef was more desirable in flavor ($P<.05$) and tenderness than forage finished beef. Schupp et al. (1976) found that sensory panel evaluations for flavor, juiciness, and overall acceptability were lowest on loin steaks from forage fed steers. Tenderness, flavor, juiciness, and overall acceptability of round steaks from forage fed cattle were equal or superior to the grain fed treatments. Household panel data showed that flavor was more important than tenderness in determining overall acceptability. This may indicate that more emphasis should be placed on the etiology of grass fed beef flavor.

Most cooking data obtained in these studies were from steaks cooked by dry heat. Kropf et al. (1975) pointed out that com-

parisons of grass fed beef with other feeding regimes should include roast cuts and cuts cooked by moist heat. The majority of the studies quoted previously would not apply to other cuts and different methods of cookery. Previous research also states that grass finished beef is inferior to grain finished beef in palatability characteristics but little mention was given as to whether grass fed beef was unacceptable.

EFFECTS OF VACUUM AGING ON BEEF PALATABILITY

In 1972, retail stores of corporate chains received 65.6% of their beef as prefabricated primals and subprimals and of this, over 43% of the subprimals were received in vacuum packages. Use of vacuum packaging for subprimals is expected to rise to over 65% by 1977 (Shaw, 1973). Current trends indicate that nearly two-thirds of the beef going to the retail store is expected to be prefabricated and vacuum packaged by 1977 (Wiggins and West, 1975). Thus, any new processing or feeding regime changes will likely have to fit into a vacuum packaged boxed beef, system to be accepted by the industry.

Tenderness in beef muscles significantly improves with increasing postmortem aging time (Pearson, 1971). Deatherage and Reiman (1946), Sleeth et al. (1957, 1958), Wilson et al. (1960 a, b), Smith et al. (1971), Newbold and Harris (1972), Parrish et al. (1973) and Fields et al. (1976) have shown that aging carcasses at elevated temperatures of 12 C to 16 C increases the rate of tenderization. Parrish et al. (1969) found no differences in tenderness between carcasses stored at elevated temperatures

and those chilled at 2 C, further demonstrating that the more efficient, high aging temperature can be used without sacrificing meat tenderness. However, vacuum aging is more widely utilized in the meat industry.

Seideman et al. (1976) packaged beef knuckles at low, intermediate, or high degrees of vacuum and stored them at 1-3 C for 7, 14, 21, 28, or 35 days. Steaks were removed from each primal cut and evaluated by a trained sensory panel. The degree of vacuum had no significant effect on flavor, tenderness, juiciness or overall satisfaction. No significant difference in off-odor related to degree of vacuum or storage time was observed. Since no control was used in this study, conclusions can not be drawn comparing vacuum packaging with non-vacuum packaging.

The physical characteristics of greatest concern in vacuum packaged beef are the amount of purge and surface discoloration (Seideman et al., 1976). Purge is meat fluid which exudes from the cut surface of a muscle and accumulates in air pockets and wrinkles found in conventional nozzle vacuum packaged cuts. This exudate is unattractive, aids in bacterial growth and causes discoloration of surface fat. Surface discoloration is caused by metmyoglobin formation and 1-2% oxygen inside the package can cause significant amounts of discoloration (Ledward, 1970). Seideman et al. (1976) found that use of a high level of vacuum minimizes surface discoloration through greater removal of oxygen from the meat surface and improves the appearance by preventing purge accumulation. Heat shrinking vacuum packages also reduces

purge as well as adding strength to the film. Heat shrunk packages can have up to 50% less purge than a package not heat shrunk (West and Wiggins, 1975). A new system of vacuum packaging, called a dual-chamber vacuum system, has been developed which can draw a higher vacuum and provide a stronger seal faster than the nozzle vacuum system (Holbrook, 1975). Purge and surface discoloration are consequently reduced by the dual-chamber system, thus making vacuum packaging more attractive to the meat industry.

Minks and Stringer (1972) studied the effects of aging beef short loins and ribs in vacuum. No significant differences in flavor, tenderness, juiciness and Warner-Bratzler shear were observed between vacuum packaged and non-vacuum packaged beef aged for seven or 15 days. However, vacuum packaged cuts had lower ($P<.05$) bacterial counts and percent weight loss. Hodges et al. (1974) concluded that vacuum aging of wholesale cuts is a satisfactory method for reducing weight loss during storage. Aging carcasses prior to packaging increased microbial numbers and off-flavor development.

Vacuum aging of grass finished beef was studied by Allen et al. (1976). Vacuum aging 21 days improved ($P<.05$) muscle color brightness. Desirability of fat flavor was similar for both fresh cut steaks and muscles held 21 days under vacuum. Flavor of muscle was most desirable for samples vacuum packaged for 21 days. Tenderness and shear force generally improved after vacuum aging and display. These data suggest that marketing grass finished cattle as boxed beef will improve product flavor, tenderness and color.

EFFECTS OF DISPLAY ON MEAT ACCEPTABILITY

The physical appearance of a retail cut in a display case is the most important factor determining consumer selection of beef products (Danner, 1959; Dunsing, 1959 a, b). Cut appearance is, however, not a good indicator of beef palatability. Only 10% of the variation in flavor and juiciness and six percent of the variation in tenderness could be explained by visual color, marbling and texture scores (Jeremiah et al., 1972b).

Few studies have considered the effects of retail display on beef palatability. The main emphasis has been on how various other treatments affect retail display. Ideally, the display period of a retail cut would be short (one or two days) since retailers would realize a faster return and consumers would receive a fresher product. If this were the case, the effects of display would not require extensive research. However, the price, supply and demand of beef are constantly fluctuating, resulting in conditions where the product may not be merchandised for several days. These conditions warrant the examination of retail display influence on beef palatability.

Discoloration of meat in display can occur in several ways and the final color is usually due to formation of metmyoglobin. Microorganisms utilize available oxygen resulting in deoxygenation of oxymyoglobin and subsequent myoglobin oxidation to metmyoglobin (Ramsbottom, 1971). Salt or detergent contamination, too warm a display case, improper display lighting or limited oxygen in the package can also cause brown discoloration of beef

pigments (Anonymous). Type of packaging material used in display can influence beef palatability since bacterial growth tends to be specific for the packaging material (Halleck et al., 1958). Differences in cooking loss between Dupont 241 and Iolon film after one day of display were observed by Loveday (1974). Exposing muscles to oxygen before and during display resulted in a more desirable and stable color throughout the display period (Landrock and Wallace, 1955; Fredholm, 1963 and Jeremiah et al., 1972a).

The relationship between level of nutrition and retail display was studied by Kropf et al. (1975). All muscles were scored acceptable in appearance after cutting and packaging, but those from long-fed cattle were most attractive. Muscles from grass-fed cattle approached undesirable color after three days display while those from long-fed cattle were still acceptable. These data indicate color instability during retail display may be a problem in marketing grass-fed beef.

Allen et al. (1976) found that five days display decreased flavor and overall acceptability if cuts were vacuum aged before display. When steaks were not vacuum aged, five days display generally improved flavor and overall acceptability. Reagan et al. (1971) and Jeremiah et al. (1972a) have found vacuum packaging and display undesirable for lamb. Tenderness improved with increasing storage time, but retail display after vacuum packaging reduced desirability of odor and flavor and increased psychrotrophic microbial counts.

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CHAPTER III

INTRODUCTION

Vacuum packaging of prefabricated beef is in widespread use throughout the meat industry. In 1972, over 50% of the fresh beef arrived at the retail store as prefabricated primal and sub-primal cuts and the industry expects this use to continue to increase (Shaw, 1973). The survey by Shaw (1973) indicated over 43% of subprimals received by chain stores in 1972 were in vacuum packages and this is expected to rise to over 65% by 1977.

Increased utilization of vacuum packaging is primarily due to its flexibility, protection and yield advantages. As meat prices increase, shrinkage, trim losses due to refacing and downgrading cuts all become a significant profit drain (Wiggins and West, 1975). These same workers reported vacuum packaging enhances merchandising as it improves color, provides longer product life and offers better protection from abuse.

Ball et al. (1957), Minks and Stringer (1972), Hodges et al. (1974) and Schmidt and Keman (1974), indicate that vacuum packaging significantly reduces weight loss during processing and storage of beef. Pierson et al. (1970) indicate little difference in sensory evaluations between fresh beef and beef vacuum packaged for 10 days, but non-vacuum packaged beef steaks were "unacceptable" after four days storage. Minks and Stringer (1972) found no differences in palatability between steaks aged seven or 15 days in a vacuum compared with no vacuum aging.

Schmidt and Keman (1974) observed no significant differences in palatability between hot boned vacuum packaged beef aged seven days and cold boned non-vacuum packaged beef from corresponding sides aged eight days. Hodges et al. (1974) reported shortloins packaged 24 hr postmortem maintained their desirability through 28 days of vacuum storage.

Flucuating prices of grain and cattle have prompted an increasing interest in feeding cattle on a lower plane of nutrition (Bidner, 1975). Current research dealing with nutritional effects on palatability is inconclusive. Brown (1954), Malphrus (1962), Huffman (1974), Wheeling (1975), Johnston et al. (1976) and Young and Kauffman (1976) found no adverse effects on beef palatability due to a lower plane of nutrition. However, Jacobson and Fenton(1956), Graham et al. (1959), Garrigus et al. (1969), Dube et al. (1971), Kropf et al. (1975), Bowling et al. (1976), Reagan et al. (1976), Schupp et al. (1976) and Shinn et al. (1976) reported decreases in beef palatability due to a lower plane of nutrition.

Allen et al. (1976) reported that vacuum storage for 21 days improved palatability of grass finished beef. Since nutritional regime may also affect palatability and shelf life of beef (Kropf et al., 1975), more information is needed on the effects of vacuum aging of beef produced on alternate feeding regimes.

The effects of retail display on beef palatability also merit investigation. Kropf et al. (1975) stated that fat from

cattle finished partly or wholly on grass is likely to be more unsaturated and consequently more susceptible to oxidative rancidity. Oxidative rancidity in lipids is detrimental to the flavor and color of muscle foods (Dugan, 1971). Thus slight flavor deterioration noted at the beginning of display may become undesirable during display. Studies have been conducted concerning the effects of display on beef color in another segment of this project (Harrison et al., 1977). However, little data exists dealing with the effects of display on beef palatability. Allen et al. (1976) found that five days display after 21 days vacuum storage reduced acceptability of beef primarily through flavor deterioration.

The purpose of this investigation is to examine the effects of vacuum aging and display on the palatability of various beef muscles from four nutritional regimes.

MATERIALS AND METHODS

Source of Materials

Thirty-eight crossbred steers of known origin were obtained from the U.S.D.A. Meat Animal Research Center at Clay Center, Nebraska and randomly assigned to four nutritional regimes. All animals were castrated at birth and were initially on a brome and bluestem pasture with their dams. They were wintered on a protein and alfalfa supplement and summer pastured on brome and bluestem grass. Ten animals were slaughtered directly off pasture at the end of summer (grass-fed). Ten were fed 49 days

(short-fed) and eight 98 days (long-fed) on an 80% concentrate - 20% corn silage ration. Ten were fed 98 days on a 40% concentrate - 40% corn silage - 20% alfalfa haylage ration (forage-fed). Steers were slaughtered at approximately 18 mos. of age after fasting overnight (12-15 hrs.).

Treatments and Sample Locations

Approximately 1 hr. postmortem, the right side of each carcass was chilled at 3 C for 48 hrs. prior to fabrication.

The longissimus (LD), biceps femoris (BF), semitendinosus (ST) and semimembranosus (SM) muscles were removed from each side. The anterior half of each muscle was immediately fabricated into steaks (non-vacuum); the posterior half was vacuum packaged (25 inches Hg on machine gauge) in barrier bags (Cryovac B-620) and stored at 0 to 1 C for 21 days prior to fabrication. Beginning at the bisected end of each muscle half, two steaks 3.0 cm thick were removed. One steak was immediately vacuum packaged (pre-display), frozen and stored at -26 C for subsequent taste panel (LD only), shear force and cooking analyses (four muscles); the second steak was analyzed after five days of display (post-display). A third steak 2.5 cm thick was removed from each half for pre-display histological determinations.

Display

Steaks used for display evaluations were allowed to bloom at least 15 min. then placed in a styrofoam tray and overwrapped with polyvinylchloride film. Cuts were displayed for five days

in an open-topped case at 2 C under continuous lighting at an intensity of 1076 lumen/m^2 (100 foot-candles) delux warm white light. After display, steaks were vacuum packaged and stored at -26 C until further analysis.

Shear Force, Cooking Losses and Taste Panel

Steaks for shear force, cooking losses and taste panel measurements were thawed at 2 C for 24 hrs, removed from the vacuum package, blotted, weighed and modified oven broiled (Harrison, 1975) in a rotary gas oven at 163 C to an internal temperature of 66 C. Final internal temperature was monitored by inserting a thermometer in the geometric center of each steak. After cooking, steaks were reweighed, taste panel cores removed and volatile, drip and total cooking losses were calculated. Six cores 1.27 cm in diameter were removed from each steak with a drill press unit (Kastner and Henrickson, 1969) and one Warner-Bratzler shear measurement was made on each core.

Taste panel tenderness, juiciness and flavor of the LD muscle were evaluated by a six member laboratory panel using a nine point scale (1=extremely tough, dry or undesirable flavor; 5=midpoint tenderness, juiciness or flavor; 9=extremely tender, juicy or desirable flavor) for each factor. Panelist selection and training was accomplished by presenting samples differing in tenderness and juiciness and evaluating individual sensitivity for discerning differences using triangle comparisons (Kramer and Twigg, 1970).

Panelists were positioned randomly in individual booths, served half (cut perpendicular to fiber axis) of a warm 1.91 cm diameter core, and instructed to expectorate the evaluated sample and rinse their mouth with water between samples. Samples were randomly presented and no more than two panels were held per day. Choice grade LD samples prepared in the same manner as the test steaks were served first to each panelist as a "warm-up" sample and at random with the test samples as a "hidden reference".

Sarcomere Length

Three cores 1.27 cm in diameter were removed at medial, central and lateral positions from each histological steak. Cores were placed in a plastic bag (air removed), heat sealed and stored at -26 C for subsequent analysis. The center third of each core was removed after thawing at room temperature for 1 hr. and blended at low speed in a Waring Blendor with 40 ml. of cold 0.25 M sucrose solution. Sarcomere lengths were measured using a Wild phase contrast microscope at 750X. The lengths of 10 sarcomeres each from 15 myofibrils were measured with an eyepiece filar micrometer to estimate average sarcomere length.

Statistical Analysis

Experimental design was completely randomized in assignment of animals to treatments in a four way split plot. Data were analyzed using analysis of variance and resultant F-test (Snedecor and Cochran, 1974). Because of the nested design,

separate Least Significant Difference values were computed for treatment comparisons.

RESULTS AND DISCUSSION

Effect of Vacuum Aging

Taste panel and shear: Vacuum aging of the LD muscle improved ($P<.05$) taste panel tenderness, juiciness and flavor scores when averaged over all feeding regimes (Table 1, 1 vs. 2). The effects of vacuum aging on sensory evaluations were not significantly different after display when averaged over feeding regimes (3 vs. 4). Vacuum aging improved ($P<.05$) tenderness for each feeding regime (1 vs. 2), which agrees with data reported by Reagan et al. (1971), Jeremiah et al. (1972b) and Allen et al. (1976). Juiciness and flavor increased ($P<.05$) with vacuum aging (1 vs. 2) for steaks from grass- and short-fed cattle but not for steaks from forage- and long-fed cattle. Allen et al. (1976) also reported improved palatability of grass finished beef with vacuum aging. Hence, vacuum aging may be most beneficial for beef produced on lower nutritional planes.

Vacuum aging for 21 days reduced ($P<.05$) Warner-Bratzler shear values for both pre- and post-display periods when averaged over all four muscles and feeding regimes (Table 2; 1 vs. 2 and 3 vs. 4). Allen et al. (1976) also reported decreased Warner-Bratzler shear values after vacuum storage. However, Minks and Stringer (1972) found no differences in Warner-Bratzler shear values after 15 days of vacuum aging.

Table 1. Effect of vacuum aging and display on taste panel evaluations for longissimus muscles from cattle on four feeding regimes

	Treatments[a]				Comparisons[b]			
	1	2	3	4	Vacuum		Display	
Feeding Regime	Non-vacuum Pre-display	Vacuum Pre-display	Non-vacuum Post-display	Vacuum Post-display	1 vs. 2	3 vs. 4	1 vs. 3	2 vs. 4
			Tenderness[c]					
Grass	4.8[d]	6.7[de]	6.4[d]	6.4[de]	*	ns	*	ns
Short	5.3[f]	7.3[e]	6.5[de]	7.1[e]	*	*	*	ns
Long	6.5[e]	7.7[d]	7.2[e]	7.6[de]	*	ns	*	ns
Forage	5.9[e]	7.0[d]	6.8[de]	7.3[e]	*	ns	*	ns
Mean	5.6	7.1	6.7	7.1	*	ns	*	ns
			Juiciness[c]					
Grass	5.8[d]	6.6	6.5	6.2[d]	*	ns	*	ns
Short	6.2[d]	7.1	6.3	6.2[d]	*	ns	ns	ns
Long	6.4[de]	6.7	6.7	7.1[e]	ns	ns	ns	ns
Forage	6.9[e]	6.5	6.4	6.9[e]	ns	ns	ns	ns
Mean	6.3	6.7	6.5	6.6	*	ns	ns	ns
			Flavor[c]					
Grass	5.9[d]	6.6	5.6[d]	5.7[d]	*	ns	ns	*
Short	6.2[d]	6.9	6.6[e]	6.7[e]	*	ns	*	*
Long	6.9[e]	6.9	6.8[e]	6.4[e]	ns	ns	ns	ns
Forage	6.9[e]	6.9	6.6[e]	6.3[e]	ns	ns	ns	*
Mean	6.5	6.8	6.4	6.2	*	ns	ns	*

[a]Non-vacuum cut at 48 hr postmortem; vacuum aged 21 days at 0-1 C; display at 2 C under 100 foot-candles of deluxe warm white fluorescent light.

[b]*=treatments differ (P<.05); ns=treatments do not differ (P>.05).

[c]Scored on a 9 point scale, 1=extremely tough, dry or undesirable; 5=acceptable tenderness, juiciness or flavor; 9=extremely tender, juicy or desirable flavor.

[d,e,f]Means within same column and trait bearing same or no superscript letter do not differ (P>.05).

Table 2. Effect of vacuum aging and display on Warner-Bratzler shear force values[a] for four muscles from cattle on four feeding regimes

	Treatments[b]				Comparisons[c]			
	1	2	3	4	Vacuum		Display	
Feeding regime	Non-vacuum Pre-display	Vacuum Pre-display	Non-vacuum Post-display	Vacuum Post-display	1 vs. 2	3 vs. 4	1 vs. 3	2 vs. 4
Muscle average								
Grass	4.4	4.3[e]	4.2[de]	3.7	ns	*	ns	*
Short	4.5	4.0[e]	4.2[de]	3.7	*	*	*	*
Long	4.3	3.5[d]	3.9[d]	3.4	*	*	*	ns
Forage	4.5	4.1[e]	4.4[e]	3.9	*	*	ns	ns
Mean	4.4	4.0	4.2	3.7	*	*	*	*
Longissimus								
Grass	2.9	2.1	2.3[d]	1.8	*	ns	*	ns
Short	3.2	2.4	2.9[de]	2.3	*	*	ns	ns
Long	3.4	2.3	2.8[de]	2.0	*	*	*	ns
Forage	3.2	2.4	3.0[e]	2.1	*	*	ns	ns
Mean	3.2	2.3	2.7	2.1	*	*	*	ns
Biceps femoris								
Grass	6.2[de]	5.5[e]	5.9[de]	4.3[de]	*	*	ns	*
Short	6.5[ef]	5.5[e]	6.2[e]	4.5[e]	*	*	ns	*
Long	5.6[d]	4.6[d]	5.3[d]	3.7[d]	*	*	*	*
Forage	6.9[f]	5.3[e]	6.7[e]	4.7[e]	*	*	ns	*
Mean	6.4	5.2	6.1	4.3	*	*	ns	*
Semitendinosus								
Grass	4.1	3.9	4.8	3.7	ns	*	*	ns
Short	4.1	3.7	4.5	3.5	ns	*	ns	ns
Long	3.9	3.3	4.3	3.3	*	*	ns	ns
Forage	3.9	3.9	4.4	3.6	ns	*	ns	ns
Mean	4.0	3.7	4.5	3.5	*	*	*	ns
Semimembranosus								
Grass	4.7	5.5[e]	3.9	5.1	*	*	*	ns
Short	4.4	4.6[d]	3.3	4.7	*	*	*	ns
Long	4.3	4.3[d]	3.4	4.6	ns	*	*	ns
Forage	4.1	4.8[d]	3.7	5.0	*	*	ns	ns
Mean	4.4	4.8	3.6	4.9	*	*	*	ns

[a]Kg per 1.27cm diameter core.

[b]Non-vacuum cut at 48 hr postmortem; vacuum aged 21 days at 0-1 C; display at 2 C under 100 foot-candles of deluxe warm white fluorescent light.

[c]*=treatments differ (P<.05); ns= treatments do not differ (P>.05).

[d,e,f]Means within same column and muscle bearing same or no superscript letter do not differ (P>.05).

Shear values decreased ($P<.05$) after vacuum aging at the pre- and post-display periods for the LD, ST and BF muscles averaged over all feeding regimes (Table 2; 1 vs. 2 and 3 vs. 4). The reduction in shear for the LD due to vacuum aging before display corresponds to the increase in taste panel tenderness scores. However, the taste panel failed to detect significant differences in LD tenderness due to vacuum aging at the post-display period shown by shear values. Shear force values for the SM increased ($P<.05$) during vacuum aging at both display periods. The reason for the SM increase in shear resistance is not clear.

Cooking losses: Total cooking loss increased ($P<.05$) almost three percent after vacuum packaging in both the pre- and post-display treatments when averaged over three muscles and four feeding regimes (Table 3; 1 vs. 2 and 3 vs. 4). Vacuum packaging (pre-display) increased ($P<.05$) total cooking loss in the ST and SM muscles by 4.9 and 2.1 percent, respectively, but had no effect ($P>.05$) on the LD muscle when averaged over all feeding regimes (1 vs. 2).

Vacuum aging increased ($P<.05$) volatile loss 2.5 percent in both pre- and post-display treatments when averaged over all muscles and feeding regimes (Table 4; 1 vs. 2 and 3 vs. 4). Volatile loss is primarily moisture evaporated from the steak; hence, some moisture in vacuum aged cuts apparently is more loosely bound and lost during cooking than in unaged cuts.

Table 3. Effect of vacuum aging and display on percent total cooking loss for three muscles from cattle on four feeding regimes

	Treatments[a]				Comparisons[b]			
	1	2	3	4	Vacuum		Display	
Feeding regime	Non-vacuum Pre-display	Vacuum Pre-display	Non-vacuum Post-display	Vacuum Post-display	1 vs. 2	3 vs. 4	1 vs. 3	2 vs. 4
			Muscle average					
Grass	23.6^{c}	27.7	22.3^{c}	26.1^{c}	*	*	ns	ns
Short	27.5^{d}	28.9	25.3^{d}	29.0^{de}	ns	*	*	ns
Long	27.0^{d}	29.5	26.6^{d}	28.5^{cd}	*	ns	ns	ns
Forage	26.3^{d}	29.8	25.2^{d}	26.8^{cd}	*	ns	ns	*
Mean	26.1	28.9	24.8	27.6	*	*	*	*
			Longissimus					
Grass	17.6^{c}	22.5	16.5^{c}	20.4	*	*	ns	ns
Short	21.2^{d}	22.4	19.3^{cd}	22.4	ns	ns	ns	ns
Long	25.1^{e}	24.7	20.9^{d}	20.3	ns	ns	*	*
Forage	23.4^{de}	23.5	20.7^{d}	20.8	ns	ns	ns	ns
Mean	21.7	23.2	19.3	21.0	ns	*	*	*
			Semitendinosus					
Grass	22.1^{c}	27.0^{c}	23.8^{c}	27.0	*	*	ns	ns
Short	29.7^{d}	33.0^{d}	28.7^{d}	29.9	*	ns	ns	*
Long	25.6^{c}	30.4^{cd}	27.1^{cd}	29.5	*	ns	ns	ns
Forage	25.3^{c}	32.1^{d}	27.9^{c}	29.2	*	ns	ns	ns
Mean	25.7	30.6	26.9	28.9	*	*	ns	*
			Semimembranosus					
Grass	31.2	33.5	26.8^{c}	30.8^{c}	ns	*	*	ns
Short	31.6	31.2	28.7^{cd}	34.9^{d}	ns	*	ns	*
Long	30.3	33.5	31.8^{d}	35.5^{d}	ns	*	ns	ns
Forage	30.2	33.8	27.1^{c}	30.3^{c}	*	*	*	*
Mean	30.9	33.0	28.4	32.7	*	*	*	ns

[a]Non-vacuum cut at 48 hr postmortem; vacuum aged 21 days at 0-1 C; display at 2 C under 100 foot-candles of deluxe warm white fluorescent light.

[b]*=treatments differ (P<.05); ns=treatments do not differ (P>.05).

[c,d,e]Means within same column and muscle bearing same or no superscript letter do not differ (P>.05).

Table 4. Effect of vacuum aging and display on percent volatile loss for three muscles from cattle on four feeding regimes

	Treatments[a]				Comparisons[b]			
	1	2	3	4	Vacuum		Display	
Feeding regime	Non-vacuum Pre-display	Vacuum Pre-display	Non-vacuum Post-display	Vacuum Post-display	1 vs. 2	3 vs. 4	1 vs. 3	2 vs. 4
			Muscle average					
Grass	19.7^{c}	23.1	18.9^{c}	22.3	*	*	ns	ns
Short	23.6^{d}	24.2	22.2^{d}	24.9	ns	*	ns	ns
Long	22.3^{d}	24.7	22.8^{d}	24.8	*	ns	ns	ns
Forage	21.5^{cd}	25.0	21.1^{d}	22.9	*	ns	ns	*
Mean	21.7	24.2	21.2	23.7	*	*	ns	ns
			Longissimus					
Grass	12.9^{c}	16.2	12.9	14.9	*	ns	ns	ns
Short	14.8^{cd}	15.8	14.4	15.7	ns	ns	ns	ns
Long	16.7^{d}	16.6	14.8	14.1	ns	ns	ns	ns
Forage	15.1^{cd}	15.1	13.7	13.7	ns	ns	ns	ns
Mean	14.8	15.9	13.9	14.6	ns	ns	ns	ns
			Semitendinosus					
Grass	18.4^{c}	22.0^{c}	20.5^{c}	23.6	*	*	ns	ns
Short	26.6^{e}	28.0^{d}	25.9^{d}	26.0	ns	ns	ns	ns
Long	23.5^{de}	27.2^{d}	24.8^{d}	26.6	*	ns	ns	ns
Forage	22.0^{d}	28.0^{d}	25.2^{d}	26.5	*	ns	*	ns
Mean	22.6	26.3	24.1	25.6	*	ns	ns	ns
			Semimembranosus					
Grass	27.9	31.1	23.3^{c}	28.2^{c}	*	*	*	ns
Short	29.4	28.9	26.4^{cd}	33.1^{d}	ns	*	*	*
Long	26.5	30.5	28.7^{d}	33.6^{d}	*	*	ns	ns
Forage	27.4	31.8	24.5^{c}	28.4^{c}	*	*	ns	*
Mean	27.9	30.6	25.6	30.7	*	*	*	ns

[a]Non-vacuum cut at 48 hr postmortem; vacuum aged 21 days at 0-1 C; display at 2 C under 100 foot-candles of deluxe warm white fluorescent light.

[b]*=treatments differ (P<.05); ns=treatments do not differ (P>.05).

[c,d,e]Means within same column and muscle bearing same or no superscript letter do not differ (P>.05).

Vacuum aging had no effect (P>.05) on drip loss when averaged over all muscles and feeding regimes (Table 5; 1 vs. 2 and 3 vs. 4). Only the pre-display ST (1 vs. 2) and post-display LD muscles (3 vs. 4) increased (P<.05) in drip loss when averaged over feeding regimes.

Sarcomere length: Vacuum aging before display increased (P<.05) sarcomere length when averaged over all muscles and feeding regimes (Table 6) but this effect is misleading due to individual muscle differences. Sarcomere length decreased (P<.05) in the LD, remained the same (P>.05) in the BF and SM muscles and increased (P<.05) considerably in the ST muscle. Gothard et al. (1966), Stromer et al. (1967) and Takahashi et al. (1967) also observed sarcomere lengthening during postmortem storage. Goll et al. (1974) stated that postmortem storage may cause some modification of the actin-myosin interaction by magnesium-modified ATPase activity, alteration of actomyosin sulfhydryl groups, or alteration of actomyosin due to prolonged storage below pH 7.0. Nevertheless, the cause of such a dramatic increase in ST sarcomere length is unknown.

Effect of Display

Taste panel and shear: Display (Table 1; 1 vs. 3) increased (P<.05) tenderness of non-vacuum aged steaks, but had no effect (P>.05) on flavor and juiciness when averaged over feeding regimes. This increase in tenderness after 5 days of display of continuous lighting is probably due to normal aging effects.

Table 5. Effect of vacuum aging and display on percent drip loss for three muscles from cattle on four feeding regimes

	Treatments[a]				Comparisons[b]			
	1	2	3	4	Vacuum		Display	
Feeding regime	Non-vacuum Pre-display	Vacuum Pre-display	Non-vacuum Post-display	Vacuum Post-display	1 vs. 2	3 vs. 4	1 vs. 3	2 vs. 4
			Muscle average					
Grass	3.9^{c}	4.6	3.4^{cd}	3.8	*	ns	ns	*
Short	3.9^{c}	4.6	3.3^{c}	4.1	*	*	*	ns
Long	4.8^{d}	4.8	3.8^{cd}	3.7	ns	ns	*	*
Forage	4.8^{d}	4.8	4.1^{d}	3.9	ns	ns	*	*
Mean	4.3	4.7	3.6	3.9	ns	ns	*	*
			Longissimus					
Grass	4.7^{c}	6.3^{c}	3.6^{c}	5.4^{c}	*	*	*	ns
Short	6.4^{d}	6.2^{c}	4.9^{d}	6.2^{cd}	ns	*	*	ns
Long	8.4^{e}	8.2^{d}	6.1^{e}	6.2^{cd}	ns	ns	*	*
Forage	8.3^{e}	8.2^{d}	7.0^{e}	7.0^{d}	ns	ns	*	*
Mean	6.9	7.3	5.4	6.3	ns	*	*	*
			Semitendinosus					
Grass	3.7^{d}	5.0^{d}	3.3	3.3	*	ns	ns	*
Short	3.1^{cd}	5.0^{d}	2.8	2.8	*	ns	ns	*
Long	2.1^{c}	3.2^{c}	2.3	2.9	*	ns	ns	ns
Forage	3.3^{d}	4.1^{c}	2.7	2.7	ns	ns	ns	*
Mean	3.1	4.4	2.8	3.2	*	ns	ns	*
			Semimembranosus					
Grass	3.4^{d}	2.5	3.4	2.6	ns	ns	ns	ns
Short	2.1^{c}	2.3	2.3	1.8	ns	ns	ns	ns
Long	3.8^{cd}	3.0	3.0	2.0	ns	ns	ns	ns
Forage	2.7^{cd}	2.0	2.5	1.9	ns	ns	ns	ns
Mean	3.0	2.4	2.8	2.1	ns	ns	ns	ns

[a]Non-vacuum cut at 48 hr postmortem; vacuum aged 21 days at 0-1 C; display at 2 C under 100 foot-candles of deluxe warm white fluorescent light.

[b]*=treatments differ ($P<.05$); ns=treatments do not differ ($P>.05$).

[c,d,e]Means within same column and muscle bearing same or no superscript letter do not differ ($P>.05$).

Table 6. Effect of vacuum aging on sarcomere length (um) for four muscles from cattle on four feeding regimes

Feeding regime	Treatments[a]		Comparison[b]
	Non-vacuum	Vacuum	Non-vacuum vs vacuum
	Muscle average		
Grass	2.00	2.08[c]	*
Short	2.05	2.14[cd]	*
Long	2.04	2.15[d]	*
Forage	2.02	2.08[c]	*
Mean	2.03	2.11	*
	Longissimus		
Grass	2.03	1.90[cd]	*
Short	2.05	1.87[c]	*
Long	2.03	1.98[d]	*
Forage	2.00	1.90[c]	*
Mean	2.03	1.91	*
	Semitendinosus		
Grass	2.17	2.67[c]	*
Short	2.25	2.72[cd]	*
Long	2.21	2.77[d]	*
Forage	2.21	2.68[cd]	*
Mean	2.21	2.71	*
	Semimembranosus		
Grass	1.94	2.00[d]	ns
Short	2.02	2.05[d]	ns
Long	1.94	2.01[d]	ns
Forage	1.97	1.84[c]	ns
Mean	1.97	1.97	ns
	Biceps femoris		
Grass	1.85[c]	1.77[c]	ns
Short	1.89[c]	1.93[d]	ns
Long	2.00[d]	1.93[d]	ns
Forage	1.89[c]	1.82[c]	ns
Mean	1.90	1.86	ns

[a] Non-vacuum cut at 48 hr postmortem; vacuum aged 21 days at 0-1 C.

[b] *=treatments differ (P<.05); ns=treatments do not differ (P>.05).

[c,d] Means within same column and muscle bearing same or no superscript letter do not differ (P>.05).

Display after vacuum aging reduced ($P<.05$) flavor scores (Table 1; 2 vs. 4) when averaged over all feeding regimes. Similar results were reported by Reagan et al. (1971) and Jeremiah et al. (1972 a,b) who found vacuum packaged meat developed off-flavors and odors after three days display.

Display reduced ($P<.05$) shear values for both non-vacuum and vacuum aged cuts when averaged over four muscles and feeding regimes (Table 2; 1 vs. 3 and 2 vs. 4). Shear force values of non-vacuum packaged LD and SM muscles were lower ($P<.05$) after the display period when averaged over all feeding regimes (1 vs. 3). The reduction in shear values due to display for the LD corresponds to the increase in tenderness detected by the taste panel. Display after vacuum aging (2 vs. 4) did not significantly reduce shear values for any of the muscles except the BF muscle. Shear values for the non-vacuum aged ST increased ($P<.05$) during display (1 vs. 3) but shear force tended to decrease after display if the muscles were vacuum aged (2 vs. 4).

Cooking losses: Total cooking loss decreased ($P<.05$) after five days of display in non-vacuum and vacuum packaged treatments by 1.3% when averaged over three muscles and four feeding regimes (Table 3; 1 vs. 3 and 2 vs. 4). Display of non-vacuum packaged cuts reduced ($P<.05$) total cooking loss for LD and SM muscles by 2.4 and 2.5 percent, respectively, but a slight increase (1.2%) occurred for the ST (Table 3; 1 vs. 3). Steaks displayed after vacuum packaging had lower ($P<.05$) total cooking

losses for the LD (2.2%) and ST (1.7%) muscles (2 vs. 4). Data from Loveday (1974) also indicates that cooking losses tended to decrease after five days display.

Display had no effect (P>.05) on volatile loss in both the non-vacuum and vacuum packaged treatments when averaged over three muscles and four feeding regimes (Table 4; 1 vs. 3 and 2 vs. 4). Although some significant differences were observed for volatile loss for individual muscles, no definite trends were noted.

Display of both non-vacuum and vacuum aged cuts reduced (P<.05) drip loss when averaged over three muscles and four feeding regimes (Table 5; 1 vs. 3 and 2 vs. 4). Display after vacuum aging reduced (P<.05) drip loss in the LD and ST muscles by approximately one percent but had no effect on the SM (2 vs. 4).

Effect of Feeding Regime

Taste panel and shear: Tenderness and flavor scores tended to be lower for the non-vacuum, pre-display LD steaks from grass- and short-fed cattle compared with steaks from forage- or long-fed cattle (Table 1). This agrees with findings by Graham et al. (1959), Bowling et al. (1976) and Kropf et al. (1976). Taste panel evaluations of LD steaks from beef fed a forage ration for 98 days were less tender but similar in juiciness and flavor compared with steaks from cattle fed a high concentrate ration for 98 days. Steaks from grass- and short-fed cattle increased

($P<.05$) in tenderness, juiciness and flavor with vacuum aging (1 vs. 2). Vacuum aging also increased ($P<.05$) tenderness of steaks from long- and forage-fed groups but the increase was not as large as that for the other two feeding regimes. Considerably less variation within and between feeding regimes for tenderness, juiciness and flavor was observed after cuts were vacuum aged. Thus, vacuum packaging may be a method for improving palatability of steaks from cattle fed for a shorter time period or on a lower plane of nutrition.

Display for five days after vacuum aging reduced ($P<.05$) flavor scores for steaks from grass-, short- and forage-fed cattle (Table 1; 2 vs. 4). Flavor after vacuum aging and display was similar for steaks from short-, long- and forage-fed cattle (treatment 4) but was significantly less desirable for steaks from grass-fed cattle. Kropf et al. (1975) stated that fat from cattle finished partly or wholly on grass may be more unsaturated and thus more susceptible to oxidative rancidity. This may contribute to flavor deterioration detected in steaks from cattle fed on lower nutritional regimes. Even though vacuum aging improves tenderness, juiciness and flavor of steaks from grass-fed cattle, the desirability of flavor may decrease during prolonged display. However, none of the taste panel evaluations for flavor fell to an undesirable level.

Shear values did not differ significantly between feeding regimes for the non-vacuum, pre-display steaks (Table 2, treatment 1) when averaged over muscles. However, after vacuum aging

steaks from the long-fed group had lower ($P<.05$) shear values (muscle average) than steaks from the other nutritional treatments (treatment 2). Jacobson and Fenton (1956), Graham et al. (1959), Kropf et al. (1975) and Shinn et al. (1976) found lower shear force values in beef from higher levels of nutrition. Shear value differences between feeding regimes were small for the LD, ST and SM muscles (Table 2; treatments 1, 2, 3 and 4). Shear values for the BF, however, were consistantly lowest for the long-fed group. Zinn et al. (1970) reported more days on feed resulted in lower shear values of muscles. However, Jacobson and Fenton (1956) reported that shear force values for the LD and SM were not significantly affected by level of nutrition.

Cooking losses: Steaks from grass-fed cattle had the lowest ($P<.05$) total cooking loss before vacuum aging and display when averaged over three muscles (Table 3; treatment 1). Jacobson and Fenton (1956) reported no relationship between level of nutrition and total cooking loss, whereas Kropf et al. (1975) found slightly higher total cooking losses in steaks from grass- vs. short- or long-fed cattle. Steaks from all feeding regimes but the short-fed increased ($P<.05$) in total cooking loss after vacuum aging (muscle average, Table 3, 1 vs. 2); however, no differences ($P>.05$) between feeding regimes were observed after vacuum aging (treatment 2). Vacuum packaging eliminated variations in total cooking loss between feeding regimes for the LD in both pre- and post-display treatments.

Average total cooking losses were lowest ($P<.05$) for steaks from grass-fed cattle after display (Table 3; treatment 3) while no differences were noted between the other feeding regimes. These differences became smaller and inconsistent when steaks were vacuum aged and displayed (muscle average, treatment 4).

Grass-fed beef tended to have the lowest volatile loss of all feeding regimes (Table 4, treatment 1) when averaged over three muscles. Jacobson and Fenton (1956) reported that volatile losses were not affected by level of nutrition.

Drip loss differences between feeding regimes were greatest for the LD muscle (Table 5). Larger differences of intramuscular and subcutaneous fat between feeding regimes for the LD compared with the other muscles may have accounted for these differences. Drip loss in the LD increased with increasing plane of nutrition. As plane of nutrition increases, marbling and external fat cover increases (Klosterman et al., 1965; Henrickson et al., 1965). No consistent differences in drip loss for the ST and SM muscles were found between feeding regimes.

Sarcomere length: Sarcomere length differences were small between feeding regimes in the non-vacuum treatment (Table 6). After vacuum aging, however, sarcomere length tended to increase with increasing plane of nutrition, except in the SM muscle.

SUMMARY

Vacuum aging for 21 days before display significantly improved taste panel tenderness, juiciness and flavor scores; reduced Warner Bratzler shear values; but increased total and volatile cooking losses when averaged over all muscles and feeding regimes. Drip loss was not affected ($P>.05$) by vacuum aging.

Display after vacuum aging reduced ($P<.05$) taste panel flavor scores, total cooking and drip losses when averaged over all muscles and feeding regimes but, all sensory scores were in the acceptable range. Shear force values of vacuum aged cuts continued to decline ($P<.05$) during display. Volatile loss was not affected ($P>.05$) by display.

Vacuum aging before display reduced ($P<.05$) shear force values in each muscle except the SM which increased ($P<.05$) in shear, and increased ($P<.05$) total cooking loss in each muscle except the LD. Display after vacuum aging reduced only in the BF muscle and decreased drip and total cooking losses in the LD and ST. Sarcomere length increased ($P<.05$) in the ST and decreased ($P<.05$) in the LD during vacuum aging.

Initial taste panel tenderness and flavor scores were lower in steaks from grass- and short-fed cattle. Vacuum aging improved ($P<.05$) tenderness, juiciness and flavor in steaks from grass- and short-fed cattle, but display for five days after vacuum aging reduced scores of steaks from cattle in the grass- or short-fed groups. Shear force values were lowest in unaged steaks from long-fed cattle.

Total cooking and drip losses generally were lowest ($P < .05$) in grass-fed cattle before vacuum aging and display. Vacuum aging increased ($P < .05$) total cooking losses in all steaks except those from the short-fed regime. Vacuum aged cuts had less variation in total cooking loss. Drip loss in the LD increased with increasing plane of nutrition.

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APPENDICES

APPENDIX A. SCORE CARD FOR EVALUATING THE PALATABILITY OF BEEF LONGISSIMUS

Judge_____ Code_____ Date_____

Sample No.	Desirability of Flavor	Juiciness	Tenderness
1			
2			
3			
4			
5			
6			
7			

Desirability of Flavor		Juiciness		Tenderness	
9	Extremely desirable	9	Extremely juicy	9	Extremely tender
8	Desirable	8	Juicy	8	Tender
7	Moderately desirable	7	Moderately juicy	7	Moderately tender
6	Slightly desirable	6	Slightly juicy	6	Slightly tender
5	Acceptable	5	Acceptable	5	Acceptable
4	Slightly undesirable	4	Slightly dry	4	Slightly tough
3	Moderately undesirable	3	Moderately dry	3	Moderately tough
2	Undesirable	2	Dry	2	Tough
1	Extremely undesirable	1	Extremely dry	1	Extremely tough

APPENDIX B. RATION INGREDIENTS AND APPROXIMATE COMPOSITION

Ingredient	International ref. no.	Ration[a] 1	2	3
Corn silage, %	3-02-824	48.0	40.0	0.0
Alfalfa haylage, %	3-08-151	50.0	20.0	20.0
Cracked corn, %	4-02-932	0.0	36.0	75.2
Supplement[b], %		2.0	4.0	4.8
Approximate ration composition, dry matter basis[c]				
Dry matter, %		44.9	60.0	81.2
Crude protein, %		14.6	13.0	13.0
Metabolizable energy, Mcal/kg		2.18	2.84	3.11

[a] Ration 1 = wintering ration prior to placement on grass; ration 2 = forage-fed for 98 days; ration 3 = short- and long-fed for 49 and 98 days, respectively.

[b] Soybean meal (ref. no. 5-04-604) supplement containing calcium, phosphorus, vitamin A and chlortetracycline. Steers also had free choice access to both block salt and a mixture of 1/3 loose salt, 1/3 limestone and 1/3 dicalcium phosphate.

[c] Nutrient composition based on tabular values (N.R.C., 1963) supplemented with limited proximate analyses.

APPENDIX C. ANALYSIS OF VARIANCE FOR TASTE PANEL TENDERNESS, JUICINESS AND FLAVOR

	Tenderness			Juiciness			Flavor		
Variance Source	D.F.	M.S.	F	D.F.	M.S.	F	D.F.	M.S.	F
Feed	3	12.7747	**	3	1.8902	ns	3	8.6189	**
Pooled E(A)	34	2.3222	--	34	1.2108	--	34	.5276	--
Temperature	1	1.2038	ns	1	.0017	ns	1	.0287	ns
T x F	3	.5038	ns	3	.3829	ns	3	.1075	ns
Pooled E(B)	34	.4664	--	34	.2210	--	34	.1557	--
Fabrication	1	65.7789	**	1	3.1124	**	1	1.5220	*
Fa x F	3	.9981	*	3	.6117	*	3	1.2973	**
Fa x T	1	.1720	ns	1	.2808	ns	1	.1553	ns
Fa x F x T	3	.3539	ns	3	.0764	ns	3	.2739	ns
Pooled E(C)	68	.3500	--	68	.2216	--	68	.2604	--
Display	1	13.1350	**	1	.2574	ns	1	6.8026	**
D x F	3	.3528	ns	3	1.3347	*	3	.2415	ns
D x T	1	.6057	ns	1	.4171	ns	1	.0453	ns
D x F x T	3	.2952	ns	3	.1089	ns	3	.2349	ns
D x Fa	1	23.4154	**	1	.1658	ns	1	6.3597	**
D x Fa x F	3	1.6883	**	3	2.7399	**	3	1.2334	**
D x Fa x T	1	.0442	ns	1	.5173	ns	1	.0152	ns
D x Fa x F x T	3	.1943	ns	3	.3060	ns	3	.3375	ns
Pooled E(D)	136	.3520	--	136	.4327	--	136	.2670	--

D = Display F = Feed Fa = Fabrication T = Temperature

ns = non-significant * = (P<.05) ** = (P<.01)

APPENDIX D. ANALYSIS OF VARIANCE FOR WARNER-BRATZLER SHEAR, TOTAL COOKING, DRIP AND VOLATILE LOSSES

	Shear force			Total cooking loss			Drip loss			Volatile loss		
Variance Source	D.F.	M.S.	F	D.F.	M.S.	F	D.F.	M.S.	F	D.F.	M.S.	F
Feed	3	30.4251	ns	3	425.6685	**	3	30.3383	**	3	369.0645	**
Pooled E(A)	34	28.4786	--	34	55.3778	--	34	6.8577	--	34	50.5405	--
Temperature	1	1.2317	ns	1	40.7290	*	1	2.0293	ns	1	60.9409	**
T x F	3	8.1097	**	3	5.3760	ns	3	5.0293	*	3	2.9409	ns
Pooled E(B)	34	1.3426	--	34	9.4266	--	34	1.4937	--	34	12.1586	--
Muscle	3	2165.8140	**	3	8416.2545	**	2	1257.8926	**	2	16151.1431	**
M x F	9	22.7322	**	9	122.6343	**	6	67.3192	**	6	112.5366	**
M x T	3	1.8034	ns	3	10.0379	ns	2	.9468	ns	2	7.5425	ns
M x F x T	9	3.1605	ns	9	9.2553	ns	6	2.0010	ns	6	10.3151	ns
Pooled E(C)	204	3.9010	--	204	14.1184	--	136	2.8264	--	136	14.2810	--
Fabrication	1	415.1400	**	1	1648.9432	**	1	30.4995	**	1	1230.9252	**
Fa x F	3	2.7816	ns	3	27.9619	ns	3	12.2922	**	3	21.0120	ns
Fa x T	1	1.4994	ns	1	2.4047	ns	1	.7864	ns	1	5.9413	ns
Fa x F x T	3	2.4908	ns	3	7.5243	ns	3	.3921	ns	3	11.3706	ns
Fa x M	3	425.7375	**	3	65.3744	**	2	38.5790	**	2	111.5322	**
Fa x M x F	9	3.4303	ns	9	43.0792	**	6	2.0981	ns	6	34.2491	*
Fa x M x T	3	5.7265	*	3	3.3738	ns	2	1.2898	ns	2	8.7710	ns
Fa x M x F x T	9	.5007	ns	9	9.9679	ns	6	1.5304	ns	6	10.5624	ns
Pooled E(D)	272	1.9554	--	272	13.1780	--	204	1.1851	--	204	12.3782	--
Display	1	110.8244	**	1	361.0033	**	1	76.9546	**	1	104.6060	**
D x F	3	4.4266	*	3	11.2567	ns	3	2.5155	*	3	11.3785	ns
D x T	1	.5863	ns	1	0.5037	ns	1	4.6956	*	1	1.9499	ns
D x F x T	3	.5238	ns	3	7.6276	ns	3	.3412	ns	3	4.9751	ns
D x M	3	23.6480	*	3	63.9452	**	2	20.5966	**	2	50.8668	**
D x M x F	9	2.0256	ns	9	69.7544	**	6	3.8859	**	6	77.9386	**
D x M x T	3	1.0996	ns	3	1.1114	ns	2	.0602	ns	2	1.6668	ns
D x M x F x T	3	.2160	ns	9	5.3382	ns	6	.5980	ns	6	4.6272	ns
D x Fa	1	.2027	ns	1	2.2730	ns	1	3.9368	*	1	12.1927	ns
D x Fa x F	3	6.7340	**	3	16.9598	ns	3	.5329	ns	3	13.3108	*
D x Fa x T	1	.2461	ns	1	8.0776	ns	1	.6787	ns	1	13.4394	ns
D x Fa x F x T	3	1.3449	ns	3	6.4192	ns	3	.2638	ns	3	7.7452	ns
D x Fa x M	3	41.4679	**	3	100.3036	**	2	2.1490	ns	2	103.0044	**
D x Fa x M x F	9	1.0255	ns	9	22.4344	ns	6	1.1271	ns	6	25.3083	**
D x Fa x M x T	3	1.4988	ns	3	15.8596	ns	2	3.2010	*	2	5.7398	ns
D x Fa x M x F x T	9	.7860	ns	9	5.0717	ns	6	.7667	ns	6	3.8045	ns
Pooled E(E)	544	1.5395	--	544	11.7603	--	408	.8850	--	408	10.9299	--

D = Display F = Feed Fa = Fabrication M = Muscle T = Temperature ns = non-significant
* = (P<.05) ** = (P<.01)

APPENDIX E. ANALYSIS OF VARIANCE FOR SARCOMERE LENGTH

Variance Source	D.F.	M.S.	F
Feed	3	.0666	ns
Pooled E(A)	34	.0349	--
Temperature	1	.0015	ns
T x F	3	.0155	ns
Pooled E(B)	34	.0054	--
Muscle	3	10.9112	**
M x F	9	.0581	**
M x T	3	.0073	ns
M x T x F	9	.0039	ns
Pooled E(C)	204	.0116	--
Fabrication	1	1.3652	*
Fa x F	3	.0202	*
Fa x T	1	.0107	ns
Fa x F x T	3	.0017	ns
Fa x M	3	3.0377	**
Fa x M x F	9	.0339	**
Fa x M x T	3	.0041	ns
Fa x M x T x F	9	.0060	ns
Pooled E(D)	272	.0076	--

F = Feed Fa = Fabrication M = Muscle

T = Temperature

ns = non-significant * = (P<.05) ** = (P<.01)

APPENDIX F. LSD PROCEDURES FOR COMPARISONS WITHIN AND AVERAGED OVER FEEDING REGIMES FOR INDIVIDUAL MUSCLES AND AVERAGES OVER MUSCLES

Taste Panel Traits, Shear and Cooking Losses

$$t^* = \frac{t(\text{MSE Fab}) + t(\text{MSE Disp})}{(\text{MSE Fab}) + (\text{MSE Disp})} \qquad t = (.05, df)$$

$$\text{LSD} = t^* \sqrt{\frac{(\text{MSE Fab}) + (\text{MSE Disp})}{n}}$$

Sarcomere Length

$$t^* = \frac{t(\text{MSE Fab}) + t(\text{MSE Musc})}{(\text{MSE Fab}) + (\text{MSE Musc})} \qquad t = (.05, df)$$

$$\text{LSD} = t^* \sqrt{\frac{(\text{MSE Fab}) + (\text{MSE Musc})}{n}}$$

Values of n

n = 8	Long-fed, one muscle
n = 10	Grass-, short- or forage-fed, one muscle
n = 24	Long-fed, averaged over three muscles
n = 30	Grass-, short- or forage-fed, averaged over three muscles
n = 32	Long-fed, averaged over four muscles
n = 38	Averages over four feeding regimes for one muscle
n = 40	Grass-, short- or forage-fed, averaged over four muscles
n = 114	Averages over four feeding regimes for three muscles
n = 152	Averages over four feeding regimes for four muscles

APPENDIX F (Cont.). COMPARISONS AND LSD VALUES

Comparisons	Tenderness	Juiciness	Flavor	Shear	Cooking losses			Sarcomere length
					Total	Volatile	Drip	
8 vs. 8	.6	.6	.5	.6	--	--	--	.096
10 vs. 10	.5	.5	.5	.5	--	--	--	.086
38 vs. 38	.3	.3	.2	.3	--	--	--	.044
32 vs. 32	--	--	--	.3	--	--	--	.048
40 vs. 40	--	--	--	.3	--	--	--	.043
152 vs. 152	--	--	--	.1	--	--	--	.022
24 vs. 24	--	--	--	--	2.0	1.9	.6	--
30 vs. 30	--	--	--	--	1.8	1.7	.5	--
114 vs. 114	--	--	--	--	.9	.9	.3	--

APPENDIX G. LSD PROCEDURES FOR TASTE PANEL COMPARISONS BETWEEN FEEDING REGIMES

$$t^* = \frac{t(\text{MSE Feed}) + t(\text{MSE Temp}) + 2t(\text{MSE Fab}) + 4t(\text{MSE Disp})}{(\text{MSE Feed}) + (\text{MSE Temp}) + 2(\text{MSE Fab}) + 4(\text{MSE Disp})} \qquad t = (.05, df)$$

$$\text{LSD} = t^* \times \frac{1}{n_1} + \frac{1}{n_2} \times \sqrt{\frac{(\text{MSE Feed}) + (\text{MSE Temp}) + 2(\text{MSE Fab}) + 4(\text{MSE Disp})}{8}}$$

Comparisons

	LSD
Tenderness	
Long-fed vs. grass-, short- or forage-fed: $n_1 = 8$ and $n_2 = 10$	.74
Grass-fed vs. short-fed vs. forage-fed: $n_1 = 10$ and $n_2 = 10$	.70
Juiciness	
Long-fed vs. grass-, short- or forage-fed: $n_1 = 8$ and $n_2 = 10$	.63
Grass-fed vs. short-fed vs. forage-fed: $n_1 = 10$ and $n_2 = 10$	.60
Flavor	
Long-fed vs. grass-, short- or forage-fed: $n_1 = 8$ and $n_2 = 10$	.50
Grass-fed vs. short-fed vs. forage-fed: $n_1 = 10$ and $n_2 = 10$	.47

APPENDIX H. LSD PROCEDURES FOR COMPARISONS BETWEEN FEEDING REGIMES AVERAGED OVER FOUR MUSCLES

Shear

$$t^* = \frac{t(\text{MSE Feed}) + t(\text{MSE Temp}) + 2t(\text{MSE Fab}) + 4t(\text{MSE Disp})}{(\text{MSE Feed}) + (\text{MSE Temp}) + 2(\text{MSE Fab}) + 4(\text{MSE Disp})} \qquad t = (.05, df)$$

$$\text{LSD} = t^* \times \tfrac{1}{4}\left(\frac{1}{n_1} + \frac{1}{n_2}\right) \times \sqrt{\frac{(\text{MSE Feed}) + (\text{MSE Temp}) + 2(\text{MSE Fab}) + 4(\text{MSE Disp})}{8}}$$

Sarcomere Length

$$t^* = \frac{t(\text{MSE Feed}) + 3t(\text{MSE Temp}) - 2t(\text{MSE Musc}) + 2t(\text{MSE Fab})}{(\text{MSE Feed}) + 3(\text{MSE Temp}) - 2(\text{MSE Musc}) + 2(\text{MSE Fab})} \qquad t = (.05, df)$$

$$\text{LSD} = t^* \times \tfrac{1}{4}\left(\frac{1}{n_1} + \frac{1}{n_2}\right) \times \sqrt{\frac{(\text{MSE Feed}) + 3(\text{MSE Temp}) - 2(\text{MSE Musc}) + 2(\text{MSE Fab})}{4}}$$

Percent Total, Volatile and Drip Cooking Losses

$$t^* = \frac{t(\text{MSE Feed}) + t(\text{MSE Temp}) + 2t(\text{MSE Fab}) + 4t(\text{MSE Disp})}{(\text{MSE Feed}) + (\text{MSE Temp}) + 2(\text{MSE Fab}) + 4(\text{MSE Disp})} \qquad t = (.05, df)$$

$$\text{LSD} = t^* \times \tfrac{1}{3}\left(\frac{1}{n_1} + \frac{1}{n_2}\right) \times \sqrt{\frac{(\text{MSE Feed}) + (\text{MSE Temp}) + 2(\text{MSE Fab}) + 4(\text{MSE Disp})}{8}}$$

APPENDIX H. (Cont.) COMPARISONS AND LSD VALUES

	LSD
Shear	
Long-fed vs. grass-, short- or forage fed: $n_1 = 32$ and $n_2 = 40$	1.07
Grass-fed vs. short-fed vs. forage-fed: $n_1 = 40$ and $n_2 = 40$	1.00
Sarcomere Length	
Long-fed vs. grass-, short- or forage-fed: $n_1 = 32$ and $n_2 = 40$	.05
Grass-fed vs. short-fed vs. forage-fed: $n_1 = 40$ and $n_2 = 40$	.05
Total Cooking Loss	
Long-fed vs. grass-, short- or forage-fed: $n_1 = 24$ and $n_2 = 30$	2.27
Grass-fed vs. short-fed vs. forage-fed: $n_1 = 30$ and $n_2 = 30$	2.13
Volatile Cooking Loss	
Long-fed vs. grass-, short- or forage-fed: $n_1 = 24$ and $n_2 = 30$	2.21
Grass-fed vs. short-fed vs. forage-fed: $n_1 = 30$ and $n_2 = 30$	2.09
Drip Cooking Loss	
Long-fed vs. grass-, short- or forage-fed: $n_1 = 24$ and $n_2 = 30$	.73
Grass-fed vs. short-fed vs. forage-fed: $n_1 = 30$ and $n_2 = 30$	.69

APPENDIX I. LSD PROCEDURES FOR COMPARISONS BETWEEN FEEDING REGIMES WITHIN A MUSCLE

Shear

$$t^* = \frac{t(\text{MSE Feed}) + t(\text{MSE Temp}) + 6t(\text{MSE Musc}) + 8t(\text{MSE Fab}) + 16t(\text{MSE Disp})}{(\text{MSE Feed}) + (\text{MSE Temp}) + 6(\text{MSE Musc}) + 8(\text{MSE Fab}) + 16(\text{MSE Disp})} \qquad t = (.05, df)$$

$$LSD = t^* \times \frac{1}{n_1} + \frac{1}{n_2} \times \sqrt{\frac{(\text{MSE Feed}) + (\text{MSE Temp}) + 6(\text{MSE Musc}) + 8(\text{MSE Fab}) + 16(\text{MSE Disp})}{32}}$$

Sarcomere Length

$$t^* = \frac{t(\text{MSE Feed}) + 3t(\text{MSE Temp}) + 4t(\text{MSE Musc}) + 8t(\text{MSE Fab})}{(\text{MSE Feed}) + 3(\text{MSE Temp}) + 4(\text{MSE Musc}) + 8(\text{MSE Fab})} \qquad t = (.05, df)$$

$$LSD = t^* \times \frac{1}{n_1} + \frac{1}{n_2} \times \sqrt{\frac{(\text{MSE Feed}) + 3(\text{MSE Temp}) + 4(\text{MSE Musc}) + 8(\text{MSE Fab})}{16}}$$

Percent Total Volatile and Drip Cooking Losses

$$t^* = \frac{t(\text{MSE Feed}) + t(\text{MSE Temp}) + 4t(\text{MSE Musc}) + 6t(\text{MSE Fab}) + 12t(\text{MSE Disp})}{(\text{MSE Feed}) + (\text{MSE Temp}) + 4(\text{MSE Musc}) + 6(\text{MSE Fab}) + 12(\text{MSE Disp})} \qquad t = (.05, df)$$

$$LSD = t^* \times \frac{1}{n_1} + \frac{1}{n_2} \times \sqrt{\frac{(\text{MSE Feed}) + (\text{MSE Temp}) + 4(\text{MSE Musc}) + 6(\text{MSE Fab}) + 12(\text{MSE Disp})}{24}}$$

APPENDIX I-1. (Cont.) COMPARISONS AND LSD VALUES

	LSD
Shear	
Long-fed vs. grass-, short- or forage-fed: $n_1 = 8$ and $n_2 = 10$	1.61
Grass-fed vs. short-fed vs. forage-fed: $n_1 = 10$ and $n_2 = 10$	1.52
Sarcomere Length	
Long-fed vs. grass-, short- or forage-fed: $n_1 = 8$ and $n_2 = 10$	.09
Grass-fed vs. short-fed vs. forage-fed: $n_1 = 10$ and $n_2 = 10$	.09
Total Cooking Loss	
Long-fed vs. grass-, short- or forage-fed: $n_1 = 8$ and $n_2 = 10$	3.52
Grass-fed vs. short-fed vs. forage-fed: $n_1 = 10$ and $n_2 = 10$	3.33
Volatile Cooking Loss	
Long-fed vs. grass-, short- or forage-fed: $n_1 = 8$ and $n_2 = 10$	3.44
Grass-fed vs. short-fed vs. forage-fed: $n_1 = 10$ and $n_2 = 10$	3.26
Drip Cooking Loss	
Long-fed vs. grass-, short- or forage-fed: $n_1 = 8$ and $n_2 = 10$	1.17
Grass-fed vs. short-fed vs. forage-fed: $n_1 = 10$ and $n_2 = 10$	1.10

THE EFFECT OF VACUUM AGING, DISPLAY AND LEVEL OF NUTRITION ON BEEF QUALITY

by

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AN ABSTRACT OF A MASTER'S THESIS

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Thirty-eight crossbred steers of known origin were randomly assigned to four feeding regimes. Initially, all were fed on a brome and bluestem pasture and wintered on a protein and alfalfa supplement. Ten animals were slaughtered directly off pasture (grass-fed). Ten were fed 49 days (short-fed) and eight 98 days (long-fed) on an 80% concentrate-20% corn silage ration. Ten were fed 98 days on a 40% concentrate-60% corn silage ration (silage-fed). Steers were slaughtered at approximately 18 mos. of age. The purpose of this research was to examine the effects of vacuum aging and display on various quality traits of beef produced on four nutritional regimes.

Approximately 1 hr. postmortem, the right side of each carcass was chilled at 3 C for 48 hrs. prior to fabrication. The longissimus, biceps femoris, semitendinosus and semimembranosus muscles were removed and bisected. The anterior half of each muscle was immediately fabricated into steaks; the posterior half was vacuum aged for 21 days. One steak from each half was immediately vacuum packaged and frozen for subsequent taste panel, shear force and cooking analysis. Similar analyses were done on a second steak from each half after five days of display under 100 foot-candles of deluxe warm white fluorescent light. A third steak from each half was used for histological determinations.

Vacuum aging improved ($P<.05$) taste panel tenderness, juiciness and flavor scores; reduced Warner-Bratzler shear values and increased total and volatile cooking losses. Taste panel flavor scores were less desirable and drip and total cooking losses

were reduced ($P<.05$) after display of vacuum aged cuts. Shear force values continued to decline ($P<.05$) during display. Sarcomere length increased in the semitendinosus during vacuum aging.

Taste panel tenderness and flavor was less desirable in steaks from grass- and short-fed cattle. Vacuum aging improved ($P<.05$) tenderness, juiciness and flavor in steaks from grass- and short-fed cattle but flavor scores were less desirable in these steaks after they were displayed. Shear force values were lowest in steaks from long-fed cattle.

Total cooking and drip losses generally were lowest ($P<.05$) in steaks from grass-fed cattle. Vacuum aging increased ($P<.05$) total cooking loss in all steaks except those from the short-fed regime. Vacuum aged cuts had less variation in total cooking loss. Drip loss in the longissimus increased with increasing plane of nutrition.