Interaction of growth hormone with androgen/estrogen on beef carcass characteristics, and chemical, physical and palatability properties of longissimus muscle of steers

Abdullah Nasser Al-Owaimer

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Interaction of growth hormone with androgen/estrogen on beef carcass characteristics, and chemical, physical and palatability properties of longissimus muscle of steers

by

Abdullah Nasser Al-Owaimer

A dissertation submitted to the graduate faculty in partial fulfillment of the requirements for the degree of DOCTOR OF PHILOSOPHY

Major: Meat Science

Major Professors: Steven L. Nissen and Frederick C. Parrish

Iowa State University

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This is to certify that the doctoral dissertation of

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x

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GENERAL INTRODUCTION

The increase in consumer demand for lean meat products has led the meat industry and producers to develop leaner animals. The main goal of animal producers has been to maximize the quantity of desirable and marketable products while minimizing economic inputs to support this production. Thus, it has led to the use of growth promotants to produce more efficient and leaner meat animals. Anabolic hormones are widely used in the beef cattle industry to improve growth performance and produce a leaner carcass (Hancock et al., 1991; Muir, 1985; Trenkle, 1987).

There has been increased concern by consumers about fat and its linkage to cardiovascular diseases, and the costs of producing excess fat and removing trimmable fat from carcasses. Over two billion pounds of fat are currently trimmed from carcasses of animals used for meat-production in the United States each year (Beermann, 1994). The growth hormone somatotropin has been demonstrated to increase average daily gain and improve feed efficiency while decreasing carcass fat deposition (Enright et al., 1990; Fabry et al, 1987; Moseley et al., 1992; Peter, 1986). Growth hormone has been called a repartitioning promotant because it shifts the absorbed nutrients from fat synthesis to other tissues synthesis (lean and bone) (Beermann, 1994). Because anabolic steroid promotants significantly increase the lean in meat
and growth hormone significantly decreases fat deposition, one of the objectives of the current research has been to investigate the interaction between these two factors: the growth hormone and the anabolic steroid hormones.

Another concern of consumers is meat palatability especially, beef tenderness. Therefore, the impact of growth promotants on changes in eating quality (reduced tenderness) is of concern because it impacts on consumer satisfaction. There have been limited and inconsistent reports related to the effects of growth promotants on beef palatability (Gerkan et al., 1995; Ouali et al., 1988; Thonay et al., 1991; Trenkle, 1990). On the other hand, growth hormone has been reported to significantly reduce fat deposition and marbling (Dalke et al., 1992; Preston et al., 1995), and this might have a negative effect on meat palatability. Little and inconsistent information has been reported about the effects of growth hormone on meat quality of beef (Allen & Enright, 1989; Vestergaard et al., 1993). Therefore, another objective of the current research has been to investigate the effect of growth hormone and anabolic steroid hormones and the combination of growth hormone and anabolic steroid hormones on carcass characteristics and quality as well as the physical, chemical and palatability properties of the bovine longissimus muscle.
Dissertation Organization

This dissertation is presented as a general introduction, a general review of literature, an individual paper and concluding summary. All citations of references are in accordance with the style manual of the *Journal of Animal Science* to which a portion of this thesis will be submitted. The individual paper consists of an abstract, introduction, materials and methods, results and discussion, conclusion, and references.
GENERAL REVIEW OF LITERATURE

Methods to Measure Meat Tenderness

Meat tenderness is an important factor for consumer acceptance of meat. Therefore, it is important to find objective or subjective methods to measure meat tenderness. Mechanical devices, sensory evaluation and myofibril fragmentation index methods are recognized methods of determining meat tenderness. A combination of subjective and objective methods to measure meat tenderness is desired to obtain results having a higher degree of accuracy than any one of these alone.

Sensory evaluation

Sensory evaluation is a subjective method carried out by humans to measure and analyze meat attributes or characteristics. Because it is carried out by humans, it is influenced by many aspects such as traditions, cultures and personal preferences. To increase the accuracy of a subjective test, the following must be observed: (1) The room must be comfortable for the panelist by controlling the temperature and the humidity, and the preparation area should be separate from the panelist area; (2) Extraneous odors from the preparation area should be controlled, and each panelist should be placed in an individual place to eliminate the communication between panelists; (3) The
sample served to the panelist should be uniform in temperature and size and
the serving containers should be the same; (4) The room light should be
uniform; (5) The panelist should rinse their mouths between samples; (6)
Room temperature water and one of the unsalted cracker, apples, celery, and
bread should be used by the panelist between samples to remove any flavor
from remaining in the mouth from the previous sample; and (7) The sample
presented to the panelists should be coded in a way that the identity of the
sample is not revealed to the panelists. The recommended method of coding
the sample is using three digit numbers (Larmond, 1973). By controlling all of
these factors, errors interference in sensory testing would be minimized.

The sensory perception of a sample consists of a combination of flavor,
appearance, and kinesthetic. Flavor combines four basic tastes: sweet, sour,
salty, and bitter and aroma (Meilgaard et al., 1987). Appearance is defined by
color, size, and shape of the sample whereas kinesthetic refers to texture,
viscosity, and mouth feel (Meilgaard et al., 1987). In addition, there are
different sensory testing methods: ranking, scaling (e.g., graphic or line scales,
verbal scales, and numerical scales), estimation of magnitude, and descriptive
al. (1974) described a method which can eliminate the biases of the panelist
when they report their scores. They reported that a 15 cm long, unstructured
line that anchored by 1.25 cm from the two ends. The panelist recorded their
perception of the attribute by marking a vertical line and converting their vertical line into a number.

Because of the subjective nature of measurement and the necessity to obtain precise measurement, panelists should be trained (AMSA, 1995). A trained sensory panel usually consists of a small number (about 10) of people smaller than consumer panel (50-100). Screening is recommended in the selection of candidates for the panel that have 1) Normal sensory acuity; 2) Interest in sensory evaluation; 3) Ability to discriminate and reproduce results, and 4) Appropriate panelist behavior such as cooperation, motivation and promptness (AMSA, 1995). The purpose of screening is to obtain 10-12 panelists who have high values among the candidates. Persons serving on panel should be willing and have an average sensitivity, and be in good health (Larmond, 1970). When the panelists are selected, they convince to be trained before the actual panel sessions are conducted. The purpose of the training sessions are to familiarize panelists with the attributes and sensory form of the product and the terminology. By doing this, panelists become more comfortable with the sensory evaluation sheet by understanding the description of each attribute.

**Mechanical methods**

The mechanical evaluation of meat tenderness is an objective method developed to characterize meat palatability attributes. The various types of
instruments used in mechanical evaluation include: penetrometers, masicometers, extruders, and shear devices to measure meat tenderness.

The action of penetrometer is based on the principle of penetration of the sample by a probe or needle to measure the force required for a given depth of penetration. A higher force is created by a greater resistance of the meat to penetration. An Armour Tenderometer is an example of a penetrometer used to evaluate meat tenderness.

The reliability of the Armour Tenderometer is not high. Dikeman et al. (1972) reported a low correlation between the Tenderometer with either shear force or test panel score. Other researchers also reported that the reliability of this device was low and that it was a low indicator of meat tenderness (Carpenter et al., 1972; Henrickson et al., 1972; Parrish et al., 1973a).

Masicometers and extruders have also been tried to detect meat tenderness (Szczeniak, 1973; Szczeniak & Torgeson, 1965). These methods are not popular or extensively used in meat science, especially if one compares them to the use of shear force devices.

The Warner-Bratzler shear device is probably the best known and most widely used device by meat scientists to measure meat tenderness by an objective method. This device was developed by Warner (1928) and Bratzler (1932). It is composed of a 1-mm thick metal blade with a triangular opening in which a cylindrical coring meat sample is inserted. The diameter of the sample is from 1.27 to 2.54 cm. The meat sample core is sheared usually into
two pieces by the blade and the maximum force needed to shear the sample is measured. Recently Instron Universal Testing Machine has been adapted for use with the Warner-Bratzler shear device. The advantages for using the Instron include the ability to run at a constant speed, calibration of the machine and record results.

The reliability of the Warner-Bratzler shear device is high in meat research. Many researchers confirm high correlations between sensory panel evaluation and the Warner-Bratzeler shear device. Crouse et al. (1978) found a correlation -0.62 between sensory evaluation and Warnar-Bratzeler; Culler et al. (1978) found a correlation of -0.90. Field et al., (1966) reported a correlation of -0.75; Goll et al. (1965) found a correlation -0.63; MacBride and Parrish, (1977) found a correlation of -0.88; Moe et al. (1964) reported a correlation of -0.65; and Olson and Parrish, (1977) found a correlation -0.62 between the shear force and sensory evaluation.

On the other hand, some studies have found low correlations between sensory evaluation and the Warner-Bratzler shear device. Parrish et al. (1973a) found a correlation of $r = -0.30$, and Breidenstein et al. (1968) reported that the correlation was -0.33 between shear force and sensory evaluation. Some of the variations in the correlation between the sensory panel and the Warner-Bratzeler shear device could be attributed to the anatomical position within the muscle.
In addition, some studies showed conflicting opinions about the exact location of the most tender area within the longissimus muscle. Alsmeyer et al. (1965) and Tuma et al. (1962) reported that the medial portion of beef longissimus muscle was more tender. On the other hand, Williams et al. (1983) reported that the dorsal region is more tender than the central or lateral portions in longissimus muscle. However, two researcher (Cover et al., 1962; Sharrah et al., 1965) noted lateral region is the most tender for longissimus muscle. Thus, it is important to take a representative sample from the lateral, medial, and dorsal regions of the muscle.

Bouton et al. (1975) analyzed deformation curves of shear force and noted that the curve contained two segments. The first segment represents the initial yield force required to compress and initiate a force fracture plane through a myofibril, depending on the myofibril strength, and the second segment is the difference between the initial yield force and the peak force. This latter measurement could be an indication of the strength of the connective tissue. These investigators reported that the initial yield force values: (1) increased with internal temperatures above 60°C; (2) decreased with postmortem aging; and (3) were not significantly influenced by animal age. However, the difference between initial yield and peak force could be due to connective tissue was: (1) significantly increased with animal age; (2) not significantly affected by postmortem aging of young or old animals; and
(3) significantly reduced by cooking meat to 90°C (Bouton et al., 1975).

**Myofibril fragmentation index**

The breakdown of myofibril into smaller fragments is due to the degradation of its Z-line structure (Goll et al., 1970). This breakdown results in a reduction of isometric tension. Some research studies have reported this Z-line degradation occurred during postmortem aging (Olson et al., 1976) and Goll et al., 1970).

Davey and Gilbert (1969) reported that the Z-line degradation occurred during the postmortem aging. Bouton and Harris (1972), Takahashi et al. (1967) and Davey and Gilbert (1967) also reported similar results. Parrish et al. (1973c) reported that the more tender meat had smaller myofibril fragments and concluded that myofibril fragmentation is the most important tissue factor related to meat tenderness.

Olson and Parrish (1977) studied the relationship between myofibril fragmentation index (MFI), Warner-Bratzler shear device and sensory tenderness in veal, and samples for A-maturity and B-maturity carcasses. They reported that the correlation coefficients were -0.95 between MFI and Warner-Bratzler, and 0.97 between MFI and sensory tenderness for veal longissimus muscle. The correlations coefficients for A-maturity longissimus muscles were -0.73 and 0.75, and for C-maturity the correlations were -0.65
and 0.72 between MFI and Warner-Bratzler and sensory tenderness. Consequently, about 50 percent of the variation in tenderness was attributed to MFI. Culler et al. (1978) used four different maturates (A, B, C, and E) and reported correlations of 0.75 and -0.72 between MFI and tenderness and Warner-Bratzler shear device. They indicated that MFI accounted for more than 50% of the variation of loin steak tenderness, and concluded that the MFI could be an excellent predictor of tenderness in broiled steak.

Olson et al. (1976) were able to develop a method to measure myofibril fragmentation of raw meat using the basic procedure reported by Davey and Gilbert (1969) which used spectrophotometric equipment. Modifications were made by Olson et al (1976) to develop a new procedure to measure myofibril fragmentation.

**Marbling**

Marbling is the intramuscular lipid deposit associated with the perimysial connective tissue. It is subjectively measured by visual appraisal of the a cross section of the muscle between twelfth and thirteenth ribs. Marbling can be classified into nine degrees (abundant, moderately abundant, slightly abundant, moderate, modest, small, slight, traces, partially devoid) (Boggs and Merkel., 1993). It is important to the USDA beef quality grading system and has some relation to meat palatability, (Boggs and Merkel., 1993).
Some studies have shown variations on the effect of marbling on meat palatability. Blumer (1963) and Parrish (1974) reviewed marbling and its relationship to palatability of meat and both reported a low correlation between palatability and marbling. Goll et al. (1965) found that marbling had no effect on tenderness, juiciness, or flavor. Nevertheless, other researchers reported that marbling has a wide variation in relation to tenderness. For example, Kropf and Graf (1959) reported that marbling accounted for 36% of the variation on tenderness and 11% of the variation was reported by Blumer (1963). Smith et al. (1984) used 1,005 beef carcasses to investigate the relationship of USDA marbling group to palatability of cooked beef. They reported that 33% and 7% of the variation in tenderness was due to marbling in loin and round steaks, respectively. However, marbling accounted for less than 1% of the variation in beef tenderness (Goll et al., 1965). Romans et al. (1965) reported that marbling had no significant effect on tenderness, but meat that had more marbling was juicier. Parrish et al. (1973b) reached the same conclusion, in that marbling had no significant effect on tenderness, juiciness, flavor, and overall acceptability. They also reported that there was no interaction between marbling and internal cooking temperature. Savell et al. (1987) used untrained consumer in three different locations and reported that higher marbling meat had higher palatability. Another study by Smith et al. (1987) concluded that samples from the loin and round of Prime carcasses steaks were significantly more palatable than carcasses of Choice through
Canner (7 grades). Berry and Leddy (1990) compared two different methods of cooking on six marbling groups, rapid restaurant method and research broiling method. They reported that steaks cooked by rapid method were more tender, juicy and flavorful and had lower shear force and cooking loss values. Steaks with slight degree of marbling and cooked by rapid method had higher or equivalent score for tenderness, juiciness and flavor than those steaks with moderate degree of marbling. Campion et al. (1975) concluded that a 2.9% accumulation of fat in the muscle is sufficient for acceptability, and the amount corresponds to a slight degree of marbling.

In summary, marbling has a positive effect on meat palatability and consumer satisfaction, and it is included in the USDA beef grading system.

Collagen

The total protein of most mature mammalian species is comprised of 30% collagen (McCormick, 1989). Collagen is the largest protein concentration found in mammalian bodies and is a major component of connective tissue. Even though collagen is found in tissues such as the skin, tendons, bone cartilage, and muscle, the distribution of collagen is not uniform among tissues. The level of collagen in individual muscles increases with physical activity. Therefore, muscle from limbs contain more collagen than muscle around the spinal column, and those muscles from the limbs tend to be less tender (Judge et al., 1989).
Collagen contains high concentration of three amino acids: glycine, proline, and hydroxyproline. Glycine makes up one-third of the collagen and occurs in every third residue in the collagen polypeptide chain. Proline and hydroxyproline make up another third of collagen (Judge et al., 1989). Hydroxyproline found in collagen is approximately 13-14 percent of the total amino acid composition; therefore, collagen is usually determined by measuring the amount of hydroxyproline (Judge et al., 1989).

Tropocollagen is the basic molecular unit of collagen. It contains three polypeptide chains coiled together in a superhelix to form collagen molecules (Dutson, 1976). Tropocollagen molecules are formed into fibrils that consist of five tropocollagens arranged in a quarter stagger array comprised of crosslinks, intermolecular, and intramolecular crosslinks.

The collagen content of skeletal muscle is 1-6% (Bendall, 1967). Cross et al. (1973) concluded that the crosslinks that form during maturation have a negative effect on tenderness. As an animal's age increases, the solubility of the collagen decreases and the tenderness of the meat also decreases. The number of cross linkages is less in muscle of younger animals than in older ones (Judge et al., 1989). Bailey (1989) reported that crosslinks contribute to the strength of collagen by formation of intermolecules covalent with time.

Researchers have noted that the amount of soluble collagen in the muscle is more important for determining meat tenderness than the amount of collagen (Hill, 1966; Kruggel et al., 1970). Some researchers have reported
that the amounts of soluble collagen decreases as animal age increases (Cross et al., 1973; Goll et al., 1964; Hill, 1966). The cross linkages are fewer in number, and easy to break in younger animals. The number of the cross linkage increases, and the easily broken linkages are converted to stable linkage when the animal age increases.

Collagen fiber undergoes denaturation when meat is cooked. Some researchers believe that collagen is not important in meat tenderness because meat collagen denatures when cooked and is converted to gelatin (Davey & Gilbert, 1974). Seideman and Koohmaraie (1987) concluded that there are no significant relationships between total collagen and soluble collagen and shear force or sensory tenderness. Thus, most researchers call the collagen effect on meat tenderness is the background toughness which meat collagen imposes a certain threshold level of tenderness.

**Water-holding Capacity**

Water is important to the meat industry because it constitutes approximately 75% of the weight of lean meat. Usually meat and meat products are sold by weight in which any loss of water from meat will result in economic loss. Water also contributes to meat palatability, tenderness, color, and some processing characteristics (Hamm, 1960).

Water in muscle exists as three types: bound, immobilized, and free water (Judge et al., 1989). Bound water constitutes approximately 4-5% of the
meat water. It is tightly bound and can be removed under the application of severe mechanical or physical force. Immobilized water is far from the reactive group and becomes loosely water. Free water is held by weak forces (Judge et al., 1989).

Several factors affect water-holding capacity. The minimal water-holding capacity occurs when the pH reaches the isoelectric point and emits a minimal charge on the protein (Hamm, 1960). Bouton et al. (1971) studied the effect of pH on water-holding capacity by injecting epinephrine in sheep before slaughter. The researchers found that juiciness increased and cooking losses decreased as the pH increased. Honikel et al. (1981) reported that pH accounts for one-third of the total postmortem decrease in water-holding capacity while the other two-thirds are due to the development of rigor mortis.

The effect of age on water-holding capacity was examined by Bouton et al. (1972) who reported that animal age has no significant effect on water-holding capacity or residual bound water. Bouton et al. (1972) also studied the effect of contraction on water-holding capacity and reported water-holding capacity in contracted muscle was significantly less than in stretched muscle.

Temperature is another factor affecting water-holding capacity. Hearne et al. (1978) concluded that a slow heat rate increases cooking loss and evaporation in contrast to a fast heat rate. They also found that the higher the end point, the higher evaporation and total cooking loss.
Glycolytic rate during postmortem period has some effect on water-holding capacity. Dark cutting beef has a low glycogen reserve; therefore the ultimate muscle pH will be high (above 5.8) the meat is also high in water-holding capacity (Price et al., 1987). Pale, soft, and oxidative muscle has a rapid rate of glycolysis during early postmortem, and therefore a low water-holding capacity (Price et al., 1987).

Another factor affecting water-holding capacity of muscle is salt. Hamm (1960) reported that adding salt to meat will increase the pH and water-holding capacity, of muscle causing the muscle to swell.

Several techniques are used to measure water-holding capacity. One of the most widely used is the hydraulic press method. Gran and Hamm. (1953) developed this method. Since then, there have been some modifications made, which make it a simpler and faster method. An amount of 0.3 grams of the sample is placed on filter paper. Then 3,000 psi are placed on plexiglass for three minutes. The filter paper is removed and water and the meat areas are measured to calculate the ratio between the meat and water.

Centrifugal action is another method used for measuring water-holding capacity in muscle. Four grams of muscle sample are centrifuged at 100,000 xg for one hour in a stainless steel tube. The meat sample is then removed and dried to determine the liquid loss (Bouton et al., 1972).
**pH**

After slaughtering the animal, pH of skeletal muscle declines and this is a natural occurrence. The rate of pH, the ultimate pH (24 h postmortem), and the temperature at which the pH drops has an effect on meat palatability (Judge et al., 1989). When an animal is slaughtered, its blood is removed thus, oxygen is no longer available to the cells, and there is no energy available to the cell as well.

In addition, after slaughtering, the oxygen supply becomes depleted and the aerobic metabolism shifts to anaerobic metabolism. The energy that is available is in the form of ATP, glycogen, and creatine phosphate. Creatine phosphate and glycogen will be used to form ATP until they are depleted due to the muscle’s entering rigor mortis (Judge et al., 1989).

After death, a cell loses its ability to remove cell metabolites which accumulate in the form of lactic acid. Thus, there is a drop in the pH of the muscle, from 7.0 to between 5.3 and 5.8 during a 24-hour period of time. The ultimate pH of the muscle depends upon two factors: (1) the amount of glycogen in the muscle at the time of death; and (2) the animal’s condition before and at the time of slaughter.

There is some controversy about the effect of pH on meat tenderness. Some researchers believe that the ultimate pH has an effect on meat tenderness. Purchas (1990) reported that the ultimate pH of meat is the most
important factor affecting meat tenderness. However, Pike et al. (1993) contended that the pH after three hours postmortem has an optimum tenderness at the pH of 6.0. Pike et al. also reported that the rate of glycolysis is important to meat tenderness reaching a pH of 6 within three hours. Smulders et al. (1990) studied different rates of glycolysis and reported that a higher tenderness was achieved at an intermediate glycolytic rate (with a pH of 5.9 at three hours).

**Fiber Types**

**Classification of fiber types**

The earliest record of an attempt to classify fiber was in 1678, Stefan Lorenzini suggested that fiber type could be based on color such as red and white (Dubowitz et al., 1973). Since then fiber types have been based on color; however, recent classifications are more often based on different characteristics of fiber. For example, red, intermediate and white classifications have been used very commonly. Table 1 illustrates the classification of fiber type as given by several researchers.

**Physiological and biochemical characteristics**

Needham (1926) reported that muscle speed contraction correlates to muscle color. Needham also noted that in different kinds of species, white
Table 1. Classification of fiber type

<table>
<thead>
<tr>
<th>Researcher</th>
<th>Type of fiber</th>
<th>Type of fiber</th>
<th>Type of fiber</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peter et al. (1972)</td>
<td>slow-twitch oxidative</td>
<td>fast-twitch oxidative</td>
<td>fast-twitch glycolytic</td>
</tr>
<tr>
<td></td>
<td></td>
<td>oxidative glycolytic</td>
<td></td>
</tr>
<tr>
<td>Ashmore and Doerr (1971)</td>
<td>beta-red (βR)</td>
<td>alpha-red (αR)</td>
<td>alpha white (αW)</td>
</tr>
<tr>
<td>Brooke and Kaiser (1970)</td>
<td>I</td>
<td>IIA</td>
<td>IIB</td>
</tr>
<tr>
<td>Guth et al. (1970)</td>
<td>beta</td>
<td>alpha-beta</td>
<td>alpha</td>
</tr>
<tr>
<td>Stein and Padykula (1962)</td>
<td>C</td>
<td>B</td>
<td>A</td>
</tr>
</tbody>
</table>

muscle was faster than red muscle in their speed of contraction. Whereas not all red muscles were slow, all white muscles were fast in contraction.

In another study conducted by Reis et al. (1970), 24 muscles from cats were used. It was found that the blood flow was three times greater in red muscle than white muscle, and the time of contraction was two to three times longer in red muscle than in white muscle. The difference between fiber type speed contraction was on the reliance on energy.

Beatty et al. (1963) reported that the white muscle fibers of rats had less oxidation enzymes and a high glycolytic activity (anaerobic metabolism). On the other hand, red fiber had a high oxidative (aerobic metabolism) with less glycolytic enzyme activity.

Reis et al. (1970) reported that the blood flow was three times greater in red muscle than white muscle of cats. The myoglobin concentration ranged
from 0.88 to 3.91 mg/g muscle, and myoglobin concentration of red muscle is greater than the myoglobin concentration of white muscle which is related to the difference in color.

Domokos et al. (1961) and Domokos and Latzkovits (1961 a,b) studied the metabolism of the tonic (red) muscle and titanic (white) muscle, and reported that titanic muscle forms lactate from pyruvate more than tonic muscle. Titanic muscle consumes more glycogen than tonic muscle, and the oxygen consumption of the tonic muscle is about three times more than that found in titanic muscle. On the other hand, tonic muscle consumes more pyruvate and α-ketoglutarate than titanic muscle.

Beatty et al. (1970) reviewed the comparative biochemical differences in several species, and reported that red muscle had higher enzyme activities of a citric acid cycle (Kreb cycle), whereas white muscle had more glycogen metabolizing enzyme activities than red muscle. Beatty et al. also reported that the phosphorylase enzyme breakdown of glycogen was higher in activity in white muscle. Bocek et al. (1966) concluded that phosphorylase is higher in white muscle and glycogen synthetase is higher in red muscle

**Muscle fiber and meat quality**

Ashmore et al. (1971, 1972) conducted studies using lambs, calves and pigs. They reported that intermediate fibers have the ability to be transformed to white fiber. This transformation was accompanied with an increase in fiber
size. They proposed that this transformation will affect meat quantity when intermediate fibers become transformed to white fiber because the white has a larger size. On the other hand, transformation from intermediate to red fibers will affect meat quality, because red fiber correlates with marbling.

The relationship between tenderness and fiber diameter was reported by Hiner et al. (1953). These researchers used beef muscle has different ages, from 10-week-old veal calves to 9-year-old cows. The coefficients of correlation for veal calves was +0.50, whereas for mature cows, it was +0.77 between tenderness (shear resistance) and fiber diameter.

Reddy (1971) found that there were significant correlations between marbling, percentage of white fiber and final quality grade (May et al., 1977). However, Melton et al. (1974) found that there was no significance between fiber type percentage and quality grade on palatability, except for juiciness. A negative relationship was found by Herring et al. (1965) between tenderness and fiber diameter. Calkins et al. (1981) noted that white muscle fiber was negatively correlated with marbling and tenderness while intermediate and red were positively correlated with tenderness and marbling. Calkins et al. (1981) also reported that fiber type composition was more highly related to marbling than tenderness, which may be use to predict the marbling score.
Factors affecting fiber size, number, and distribution

The muscle fiber is the physiological unit of skeletal muscle. Fibers comprise 75 to 90% of the total muscle mass (Hegarty, 1971). Fiber number is fixed at birth, and an increase of muscle is due to an increase in fiber size (Ashmore et al., 1972). There is some difference in fiber diameter between the same muscle in different species and between different muscles in the same species (Hegarty, 1971).

Breed affects fiber diameter. David et al. (1975) reported that Chorolais steers have larger fiber diameters and areas than Angus for all fiber types. In addition, they found that, as feeding time increased, the red fiber diameter increased.

An animal's age also has an effect on muscle fiber size. Tuma et al. (1962) reported that fiber diameter increases as animal age increases in cattle. The plane of nutrition also has an effect on muscle diameter. As the plane of nutrition decreases, the muscle diameter decreases. This can be reversed by feeding the animal a high nutrition plane (Hegarty, 1971). Rowe et al. (1969) studied the difference between males and females in five different muscles. They found that the fiber number for all muscles was constant; however, male mice had a greater muscle diameter than did the female mice. Miller et al. (1975) found that gilts had larger fiber diameter than barrows. They also found that an increase in diameter of any fiber type was accompanied by an
increase of the other two fiber types. Hiner et al. (1953) noted that male
animals have larger fibers, whereas castrated males have intermediate size
fibers and females have the smallest. Ockerman et al. (1984) reported that
steers had a slightly higher percentage of white fibers and smaller mass fiber
diameter than bulls.

Exercise has an effect on fiber size. Walker (1966) found that exercise
increases fiber diameter in different muscles of mice. He reported that
duration of the exercise affected fiber size more than the intensity.

Muscle fiber type distribution is also affected by some factors. While red
fiber is red at any stage, intermediate fiber has the ability to transform to both
white and red. Ashmore et al. (1972) reported the muscle that maintains
posture and used by animal frequently has a high proportion of red fiber,
whereas muscles that are inactive have a higher proportion of white fiber.

**Histochemistry**

Enzyme reactions have been used for different purposes. Muscle fiber
typing can be determined by the reaction to different enzymes. The detection
of muscle diseases can also be used by enzyme reaction.

The ATPase enzyme has been used for a long time to determine fiber
types by many researchers. Guth et al. (1970) purified the myosin from fast
and slow cat muscles and reported that fast muscle had four-fold greater
ATPase activity than slow muscle. They also reported that you can
differentiate between fast and slow fibers because the slow fiber is acid stable and alkali labile, whereas the fast fiber is alkali stable and acid labile.

Samah et al. (1970) demonstrated that the cat fast fiber had four times more ATPase activity than slow fiber, and when exposed to an alkaline pH at room temperature, the slow fiber lost 64% of its normal ATPase activity while fast fiber lost only 6%. By exposing the fast and slow to a pH of 4.35, the slow fiber lost 47.6% of its ATPase activity whereas, fast fiber lost 83.6% of its ATPase activity.

Padykula and Herman (1955) reported that the ATPase enzyme is associated with myosin. They also noted that the optimum pH for a good stain was 9.4 when using an unfixed frozen muscle section of rats.

Brooke et al. (1969) used normal human tissue and reported that the ATPase reaction is stronger with type II fiber, whereas it is moderate with type I fiber without pre-incubation. They concluded from different pH preincubations that, at pH 10.3, type II fiber develops a strong reaction, whereas type I has no reaction. On the other hand, at a pH of 4.3, type I fiber develops a strong reaction whereas type II fiber has no reaction.

The correlation between histologic staining and muscle characteristics were reported by Barnard et al. (1972). The fiber was classified as fast-twitch red, fast-twitch white, and slow-twitch intermediate. This correlated to the specific activity of myosin ATPase enzymes (Peter et al., 1972). In another study by Barny et al. (1967), it was shown that ATPase activity correlated
with maximum shorting velocity of different types of muscles (Thomason et al., 1986).

The difference in myofibril ATPase activity between fast and slow twitch has been studied. Holt et al. (1975) conducted a study using chickens. Fast twitch and slow twitch muscles were observed. They found that there were three components from fast-twitch and two from slow-twitch muscles, however, while each component from the same muscle had the same ATPase activity, the components from fast-twitch muscles were 2.2 times higher than the slow ones. The researchers suggested that these components of myosin are isozymes, three are fast and one is slow, and they are related to ATPase activity of the fibers. Thomoson et al. (1986) used adult rat hind limb muscle and found that there were four myosin isozymes. Three are for fast type and one for slow type, and these were related to ATPase activity of the fibers.

**The effect of growth promotants on muscle fiber type**

Growth agents are used to increase meat production, growth rate, and feed conversion. There were some reports regarding muscle fiber type and growth promoters.

Fox et al. (1973) used 1-Methyl-2-mercaptopimidazole (TAPZOLE) to increase growth rate and reported that control steers have slightly more type I fiber than steers treated with TAPZOLE. In addition, type I fibers were
larger in treated animals, whereas type II fibers were larger in control animals.

Clancy et al. (1986) reported that anabolic agents (resocyclic acid lactone, trebolone acetate, estradiol denzoate and progesterone) did not alter the percentage of red fiber and the treated steers had 26% more \( \alpha R \) fiber and 8% less \( \alpha W \) white fiber compared to the control group. Fiber area was significantly greater for red fiber in treated steers than untreated steers. The intermediate fibers increased with treatment but white fiber had no change. Some studies were conducted to observe the effect of porcine somatotropin on pigs. Solomon et al. (1988) reported that porcine somatotropin had no effect on the percentage of muscle fiber types.

Solomon et al. (1990) studied the effect of sex and exogenous porcine somatotropin and reported that the control group of gilts and boars had more \( \alpha W \) and fewer \( \alpha R \) than the treatment group, whereas barrows had no change in fiber percentage. The fiber size had increased in all three fiber types for all sexes: barrows (31.8%), gilts (27.8%) and boars (9.3%). Lefaucher et al. (1992) reported the same conclusion as Solomon et al. that somatotropin increased the size of all three fibers and had little effect on fiber types.

**Bovine Somatotropin (Growth Hormone)**

Animal growth is controlled by different hormones. These hormones include somatrotropin, thyroid hormone, somatostatin, androgens, insulin,
glucocorticoids, and prolactin (Scanes and Lauterio, 1984). Somatotropin is a large complex polypeptide containing 191 amino acids with two disulfide bonds. It is a naturally occurring hormone whose absence results in little or limited growth.

The secretion of somatotropin is controlled by the hypothalamus (Scanes and Lauterio, 1984). Somatostatin and a growth-hormone-releasing factor regulate the release of somatotropin from the anterior pituitary gland. Somatomedins are produced by the liver and other tissues including skeletal muscle, adipose tissue, the heart, and the kidneys. Somatotropin has three mechanisms of action: (1) a direct effect on the target tissue; (2) an indirect effect whereby somatotropin stimulates the liver to produce somatomedin and the somatomedin acts on the target tissue like an endocrine; (3) a direct effect whereby somatotropin stimulates the target tissue to produce somatomedin which acts on the same target tissue like an autocrine or paracrine (Beerman et al., 1991).

Effect of somatotropin on adipose tissue

Somatotropin has been documented to reduce lipid accretion (Goodman et al., 1986). Somatotropin has an anabolic response in most tissue, however, the response of somatotropin in adipose tissue is catabolic. Somatotropin acts in different ways to reduce fat deposition, increase lipolysis, increase fatty acid oxidation, and decrease lipogenesis (Goodman et al., 1986; Peter, 1986).
Somatotropin acts through several pathways including increased lipolysis and fatty acid oxidation, and the decreased fatty acid synthesis to reduce the amount of lipid deposition (Scanes & Lauterio, 1984).

Effect of bST on muscle growth

Somatotropin treatment increases muscle growth. This increase is through cellular proliferation and protein accretion (Boyd & Bauman, 1989). Eisemann et al, (1986) reported that growth hormone treatment increases muscle accretion by increasing muscle protein synthesis, and has no effect on protein degradation in steers. Growth hormone has been documented to increase nitrogen retention (Hart and Johnsson, 1986). In addition to the direct metabolic action of somatotropin, somatotropin has indirect metabolic action on muscle through somatomedin (IGF-I) (Vernon and Flint, 1989).

Effect of bST on growth performance

Bovine somatotropin has the potential to change the efficiency of utilizing the diet by increasing feed efficiency. In 1959, Brumby examined the effect of somatotropin in young Jersey heifers by administering 10 mg daily subcutaneous injections of pituitary bST for 84 days, and reported the average daily gain (ADG) increased by 10% compared with the control group.

In a study by Early et al. (1990), steers weighing 231 kilograms were injected by daily with 20.6 mg bST for 112 days. The ADG increased by 15%
compared to the control group. Feed intake was unaffected but the dressing percentage decreased by 4% because of the visceral and internal organ weight was more than the control animals.

Wagoner et al. (1988) studied the effect of bST on 775 kg beef steers that were injected with 960 mg every 14 days for 140 days. The daily gain and feed efficiency were increased by 9.6% and 22.8%, respectively. The daily feed intake decreased by 9.4% and the dressing percentage decreased by 3%.

A summary of different studies showed growth increased by 8.6% in heifers, and ADG increased by 23-35% in growing heifers (Grings et al., 1987) and in finishing heifers (Farby et al., 1987). Moseley et al. (1992) injected steers at levels of 0, 33, 100, or 300 mg/kg body weight in the first experiment. In the second experiment, steers were injected at levels of 0, 9.25, 16.5, 33, or 60 ug/kg body weight. The ADGs were different by +7.9%, -7.0%, and -37.7% for steers targeted with 33, 100 and 300 ug/kg bST, respectively. The feed efficiency rates were different by +12.1, +6.8, and -35.5% for steers treated with 33, 100, and 300 ug/kg bST, respectively. In experiment 2, the ADGs were -1.0, +9.0, +10.8, and -3.7% from the control group. The feed conversion efficiency was increased by 5.5, 12.6, 15.1, and 9.7% compared with the control group. They concluded that the optimal dosage of bST was between 16.5 and 33 ug/kg of body weight per day. In a similar study Dalke et al. (1992) used 0, 40, 80, and 160mg/wk and reported that the optimum dosage of somatotropin for final weight, daily gain, dry matter intake and feed efficiency was 160
mg/wk. In a summary of 14 studies, the ADG ranged from -6.3 to +26, feed intake ranged from -13 to +21.1 and feed efficiency ranged from -1.2 to -20.3 (Moseley et al., 1992).

In a recent study by Preston et al. (1995) in which steers were treated with 0, 80 or 160 mg/week of bST, it was reported that the ADGs were improved by 3.4, and 4.8% for 80, or 160 mg/wk, respectively. The gains in efficiency of g/kg were improved by 6.5%, and 10% for 80, 160 mg/wk, respectively.

In summary, bST has the potential to increase the average daily gain by 10-15% and reduce dressing percentage. Feed efficiency is improved by 10-20% by using bST.

**Effect of bST on carcass characteristics**

Bovine somatotropin has the potential to alter important aspects of meat quality in treated cattle. Several research studies were conducted on the use of bST in beef. Sejrsen et al. (1986) reported that somatotropin increased heifers body weight and leanness by 1.7, and 2.2%, respectively, and decreased fat by 7%. Sandles and Peel (1987) used identical twin pairs of four heifers per treatment and reported that body weight increased by 9%, lean did not change, and fat decreased by 17%.

Farby et al. (1987) reported that there were no significant differences when using somatotropin; however, body weight increased by 3%, lean by 2%,
and fat decreased by 2% on heifer. Wagner et al. (1988) investigated the effect of bST on fifty-eight 375 kg beef steers. They were injected with 960 mg/two weeks for 140 days. They found that protein and bone increased by 10 and 10% respectively, fat was reduced by 24%. The dressing percentage was reduced by 3%.

Moseley et al. (1992) performed two experiments on finishing beef steers with different doses. The first one used 33, 100, and 300 mg/kg of body weight/day. Longissimus muscle (rib-eye) area was increased by 7.4, 7.2, and 6.6%, and the backfat thickness was reduced by 9.3, 28.4 and 62.4% for 33, 100, and 300 ug/kg BW/day. In the second experiment, 0, 8.25, 16.5, 33, and 66 rbST ug/kg BW/day were used and the longissimus muscle was increased by 4.1, 7.8, 8.8, and 7.0%, and the backfat was reduced by 6.0, 6.5, 4.7 and 22% for 8.25, 16.5, 33, and 66 ug/kg BW/day of rbST, respectively.

Dalke et al. (1992) used different dosages on steers: 0, 40, 80, and 160 mg/wk of rbST and reported that the hot carcass weights were improved by 0, 1.5, 1.8%, the rib-eye area was improved by 3.6, 2.5, and 4.1% and the backfat was reduced by 2.1, 1.4 and 19% for 40, 80, 160 mg/wk; respectively. The marbling score was 5.1, 4.9, 4.6, 4.4 (slight =4, small =5, modest =6), the quality grade was 7.0, 6.9, 6.4, and 5.8 (select = 5, select + = 6, choice- = 7), and the yield grade was 3.1, 2.9, 3.0, and 2.6 for 0, 40, 80, and 160 mg/wk, respectively. They concluded that the maximum dosage response of somatotropin is 160 mg/week (22.8 mg/d).
In a recent study by Preston et al. (1995), 0, 80, and 160 mg/wk of recombinant bovine somatotropin (rbST) was used on crossbred steers. It was reported that the final weight improved by +.3, and +.7%, hot carcasses were improved by +.9, and +.6% the longissimus muscle area was larger by 2.1 and 1.3%, backfat thickness was reduced by 8 and 15%, and kidney, pelvic and heart fat was reduced by 16 and 27%, for animals which received 80 and 160 mg/wk of rbST, respectively. Marbling score was 4.9, 4.7, and 4.6 (5 = small), yield grade was 2.4, 2.2, and 2.1, and the percent choice was 25, 17, and 4.5 for 0, 80, and 160 mg/wk, respectively. These studies demonstrated strong evidence that somatotropin decreased fat and increased lean while having little effect on body weight.

Early et al. (1990) injected steers with 20.6 mg/rbST for 112 days. No significant difference was found in weight gain of bone and lean muscle in the hip, loin, ribs, chuck, brisket, plate, and shank. Although the weight of water, crude protein and ash were greater, they were not significant. Dalke et al. (1992) used different dosage of bST and reported that the response of bST was in the carcass and not in the noncarcass components.

Few studies have been conducted on the effects of somatotropin with beef and lamb. On the other hand, several studies conducted with swine showed that somatotropin decreased lipid content and marbling scores. From these studies, it was concluded that bST reduce backfat, kidney, pelvic, and heart fat, marbling score and quality grade of the treated animals, and it
increased rib eye area of the longissimus muscle. This reduction of intramuscular fat may have an effect on the value of beef animals in the United States where marbling is an important factor in determining quality grade, and market value of the carcass.

Effect of somatotropin on meat quality

Consumer satisfaction is one of the most important factors for which both producer and meat industry are concerned. For the last several decades, the livestock and meat industry have been trying to reduce carcass fat because of the higher costs of the production, and removing the excess fat from carcass by trimming. On the other hand, some marbling is desirable. The use of repartitioning agents, such as somatotropin, reduce fat content in a carcass. This will reduce the cost for trimming and improve the efficiency of production by increasing the lean and decrease the fat. But this might also reduce consumer acceptability because marbling is also reduced and may negatively influence palatability of the meat. The following is a summary of the effect of studies of somatotropin on meat characteristics.

The effect of somatotropin on meat quality has been evaluated in many studies on pork (Beermann et al., 1988; Boles et al., 1991; Goodland et al., 1993; Knight et al., 1991; Prusa et al., 1989; Solomon et al. (1988; 1991). On the other hand, the effect of somatotropin in beef has few reported studies.
Allen and Enright (1989) reviewed two studies on the effect of somatotropin on meat quality on beef, these studies are summarized below.

In the first study reported by Adam et al. (1985), they used daily injections of 50 ug GH/kg BW for 19 week. They reported that the collagen percentage was 2.25 and 2.53%, for control and treated animals, respectively. The pH showed no change (5.7). The percent of juice extraction was 24.5 and 28.4, and the Warner-Bratzler shear force was 5.9 and 5.8 kg, for control and treated animals, respectively. In the conclusion, there were no significant differences in these parameters.

In a second study, Wagner et al. (1988) used 204ug/kg GH for 20 week on beef steers. They reported that the shear force of the control and treated animals was 2.5 and 2.3 kg, and the tenderness was 11.2 and 10.4, respectively, while the overall acceptability was 11.0 and 10.2, for control and treated animals, respectively. However, the tenderness and overall acceptability were significantly different (p < .05).

Vestergaard et al. (1993) studied the effect of bovine growth hormone on growth, carcass composition, and meat quality of dairy heifers by using 100 ug/kg of GH for 16 weeks, they reported that the total collagen and soluble collagen percentages were 0.23, 0.22%, and 18.4 and 19.2% for control and treated animals, respectively. The pH remained unchanged (5.48). The color lightness was 37.9 and 37.4, and the shear force was 7.9 and 8.6 kg, for control and treated animals, respectively. Sensory panel scores for control and
treated animals were: color (3.2 and 3.3); taste (2.7 and 2.9); tenderness (1.1 and 1.1); juiciness (2.6 and 3.0); and overall acceptability (1.6 and 1.7), (+5 was liked the most and -5 the least). There were no significant differences between control and treated animals again, the taste panel reported no significant differences between control and treated animals.

From these studies, there were no consistent results for the effect of somatotropin on meat quality, and only one study (Vestergaard et al., 1993), did a comprehensive assessment of meat quality.

From these studies, it was concluded that the bovine growth hormone (bST) had little effect on meat quality.

**Anabolic Implants**

Anabolic implants have been used by the beef cattle industry for 40 years to improve growth performance and produce a leaner carcass (Hancock et al., 1991). Anabolic agent treatment usually increases the growth rate, feed efficiency and the total protein accretion of the animals. Anabolic has been concluded to improve animal performance, especially with castrated male cattle (Roche and Quirke, 1986). Several anabolic agents are available for cattle producers: Synovex-S; Synovex-H; Ralgro; MGA; Compudose; Steer-oid; Synovex-C; Heifer-oid; Finaplix-S; Sinaplix-H; and Revalor-S (Hancock et al., 1991). Each has a different chemical composition and mode of action. Anabolic implants are classified as estrogenic, androgenic, or a combination of the two.
Producers should know the physiological and metabolic effects of these growth promotants to be able to derive the maximum benefits from their uses.

**Estrogenic anabolic implant**

Estrogenic anabolic implants are growth promotants used to increase nitrogen retention, feed efficiency, and animal performance. The mode of action of the estrogen is mediated though the circulating hormones. Research supports that the action of estrogen enhances the growth or hormone concentrations (Gopinath & Kitts, 1984; Hancock et al., 1991; Preston, 1975). Hancock et al. (1991) and Trenkle (1970) found that growth hormone concentration and secretion increases as well as anterior pituitary weight due to estrogen treatment. Enright et al. (1990) reported that Estradiol 17-B significantly (P> .01) increases plasma concentrations of growth hormone and insulin-like growth factor (IGF-I) in implanted steers.

Another mode of action for estrogenic anabolic action is the role of catechol estrogen formation (Hancock et al., 1991). Catechol estrogens have structural similarities to catecholamines which stimulate growth hormone releasing hormone and growth hormone secretion.

The direct effects of estrogenic anabolic implants on muscle were reported by Hancock et al. (1991). They reported that presence of estrogen receptors in ovine and bovine skeletal muscle.
Androgenic anabolic implants

Androgenic anabolic implants are most commonly used as growth promotants to increase animal performance and protein accretion. Trenbolone acetate (TBA) is a synthetic steroid which has a structure similar to testosterone, but it has 8-10 times greater anabolic potency than testosterone Trenkle. (1990).

TBA has both direct and indirect effects to increase animal growth and protein accretion. The direct effect of androgen is through muscle cell which contains androgen receptors (Sauerwen and Meyer, 1989) The indirect effect of androgen is through alteration of endogenous hormones. These include: corticosteroids, thyroid hormones, insulin, and estrogen (Hancock et al., 1991). Corticosteroids has a catabolic effect on protein metabolism by decreasing protein synthesis and increasing protein degradation, however, androgen has a competitive binding effect to the receptor of the corticosteroids and this will decrease the catabolic effect of the corticosteroids (Hancock et al., 1991).

Combination of androgen and estrogen

The combination of both estrogenic and androgenic growth promotants results in additive effects on performance and protein accretion. Trenkle (1987) summarized five studies and reported that the combination between TBA and estrogen improved growth performance and carcass composition more efficiently than the compound used alone. A combination of implants do not
alter growth hormone concentration when compared to control groups (Hayden et al., 1992; Henricks et al., 1988). Lee et al. (1990) reported that combination implants of trenbolone acetate and estriadiol resulted in a significantly (P > .05) increased serum concentration of IGF-1 levels when compared to nonimplanted controls. Byers et al. (1994) reported that IGF-I concentrations were higher (P > .0001) in implanted steers than in non-implanted steers. The results of these studies demonstrated that growth hormone concentrations are not altered in steers implanted with the combination of TBA and estrogen.

Effect of anabolic implants on growth performance

Anabolic implants are used in cattle production to increase body weight, feed conversion, and average daily gain. Several studies examined these parameters. Bartle et al. (1992) used different dosages of TBA and estradiol (E2) (140 mg/0, 0/30 mg, 20 mg/4 mg, 80 mg/16 mg, and 140 mg/28 mg) on steers and reported that TBA alone (140mg/0) had no significant effect on final weight, average daily gain (ADG) and feed efficiency. Estradiol (E2) increased final weight, ADG, and feed efficiency by 2.8%, 7%, and 3%, respectively, compared with control group. A 20/4 dosage increased final weight, ADG, and feed efficiency by 2.8%, 7%, and 3.3%, respectively, compared with control group. The 80 mg/16 mg dosage had a final weight, ADG, and feed efficiency of 5.5, 14, and 8.2, respectively, compared with control group. Finally, the 140 mg/28 mg (5:1) dosage had the greatest effect in final weight, ADG, and feed
efficiency with an increase of 6.4, 17.8, and 10.5, respectively, when compared with control group.

In a similar study by Hayden et al. (1992), estradiol alone or estradiol combined with TBA, increased body weight gain. The skeletal muscle protein depositions were 72, 75, 95 and 120 g/d for control group, TBA, E₂, and TBA + E₂, respectively. It was concluded that the combination has a synergistic effect and androgen should be implanted along with estrogen to receive full potential in growth response.

Perry et al. (1991) studied the effect of Revalor (Trenbolone acetate and Estradiol 5:1) implant on different breeds fed for different numbers of days (Holstein = 210, Angus = 143, Angus × Simment 123) and reported final weights increased by 4.1%, 8.1%, and 1.1%, respectively. The ADG increased by 17%, 26%, and 21%, respectively. These results were similar to a study reported by Trenkle (1990) who found that the ADG increased by 21% and improved feed conversion by 13% over control group. Earlier, Trenkel (1987) summarized five studies in five locations and reported that the ADG increased by 19.9% with an improved feed conversion of 21.1% compared with control group.

A summary of seven studies (technical manual, 1996) conducted on a total of 723 steers in five different locations (Iowa, Colorado, Kansas, Texas, and Nebraska) to determine the effect of Revalor (24 mg estradiol + 120 mg
trenbolone acetate) on body weight, ADG, feed conversion, and hot carcass weight revealed increases in all five areas. The initial body weight was 325 kg and 324 kg for control and implanted steers. The final weight was 532 kg and 572 kg, representing weight gains of 207 kg and 247 kg, respectively, or an ADG of 1.37 kg and 1.62 kg, respectively, for control and implanted steers. The feed conversion for control and implanted steers was 6.25 and 5.61, respectively, while hot carcass weight for control and implanted steers was 333 kg and 358 kg, respectively. Similarly, another summary (Preston et al., 1993) of six trials of 350 steers conducted over 140 days showed Revalor implants increased ADG by 20%, and gain efficiency by 11% compared to non implants. It can be concluded that the Revalor has the potential to increased ADG, weight gain and feed conversion of the animal. Therefore, it will be beneficial in feedlot use.

**Effect of anabolic Revalor implants on carcass composition**

Cattle producers have used anabolic implants to increase skeletal muscle protein and body weight. Anabolic implants have the potential to change carcass composition. Apple et al. (1991) used Holstein steers and reported that TBA increased hot carcass weight by 2.4%, dressing percentage decreased by 0.5, backfat thickness decreased by 12 mm, longissimus muscle area increased by 5.1 cm², kidney, pelvic and heart fat increased by 14%, and
the United States Department of Agriculture (USDA) yield grade decreased by 0.2 compared to control group.

Perry et al. (1991) used three different breeds: Holstein, Angus, and Angus × Simmental steers, and found that Revalor-s had no significant effect on marbling score, dressing percentage, backfat, and longissimus muscle area. The effect of TBA, estradiol and Revalor (combination of 140 mg TBA and 28mg of estradiol) used on 1,296 steers was reported by Bartle et al. (1992), who reported a dressing percentage of 62.0, 61.8, 61.8, and 62.4; longissimus muscle areas of 78.4, 79.1, 78.4, and 82.7 cm²; backfat of 11.0, 10.6, 11.2, and 11.2 mm; kidney, pelvic and heart (KPH) fat of 2.27, 2.27, 2.22, and 2.11%; marbling score of 5.6, 5.4, 5.4, and 5.3; and a percentage of USDA Choice of 78.1, 70, 77.5, and 62.7 for control, TBA, estradiol and Revalor-s, respectively.

In a summary of six trials using 274 steers in different states (technical manual, 1996), backfat thickness was 11 and 11.9 mm; KPH percent was 2.14 and 1.99; loin-eye area was 78.8 and 82.3 cm²; marbling score was 4.5 and 4.7 (4 = small, 5 = modest), choice and USDA Prime was 62% and 48%; and yield grade was 2.7 and 3.2, respectively, for control and implanted animals. Generally, Revalor reduced carcass quality by reducing marbling and yield grade, and choice and prime percentage.

Trenkle (1987) summarized the effect of estradiol + TBA on steers for five trials and reported that dressing percentage was not significantly different
in control and experimental animals. On the other hand, marbling and quality grade were lower in experimental animals than control, back fat thickness decreased by 7.7%, and kidney, pelvic, and heart fat was reduced by 2.5%. Trenkle concluded that implants tend to promote growth through increases in protein accumulation rather than fat deposition to produce a leaner carcass.

In general, Revalor tended to increased carcass lean and reduced fat, including marbling. This reduction of marbling may have some effect on lowering quality grade of carcass.

**Effect of Revalor on meat quality**

Meat quality is the most important factor for consumers. The quality of a beef carcass depends primarily on the quality grade and yield grade, thus, producers attempt to maximize live weight by using anabolic implants, however, this may decrease meat quality. Following is a summary of studies that report the effects of anabolic Revalor on meat quality.

Ouali et al. (1988) studied the effect of Revalor on meat quality in two different muscles: longissimus dorsi and triceps brachii. They found that there was a significant difference in tenderness in longissimus muscle. On the other hand, there were no significant differences for total collagen, soluble collage, juiciness, flavor intensity, and ultimate pH in both muscles. Trenkle (1990) studied the effect of Revalor on sensory attributes of steaks from steers. It was reported that there were no significant differences between implant and
control groups on tenderness, juiciness, flavor intensity, overall flavor, and shear force.

Thonney et al. (1991) studied the effects of Revalor on sensory panel evaluation and reported that tenderness, juiciness and flavor intensity were significantly different, whereas flavor and overall acceptability were not significantly different. Perry et al. (1991) studied the effect of Revalor on sensory evaluation on three different breeds: Holstein, Angus, and Angus x Simmental, and reported that there was no significant difference between implant and non implant animals on tenderness, juiciness, flavor, flavor intensity, and overall acceptability.

A recent investigation by Gerken et al. (1995), who used genetically identical steers to study three different muscles (Strip loin, Top sirloin, and Top round), found that using either TBA or Revalor had no significant effect on beef tenderness when shear force measurement and sensory panel evaluation were made. Total collagen and soluble collagen were also measured, but there was no significant difference between treatments and implanted animals with either TBA or Revalor on longissimus muscle.
INTERACTION OF GROWTH HORMONE WITH ANDROGEN/ESTROGEN ON BEEF CARCASS CHARACTERISTICS, AND CHEMICAL, PHYSICAL AND PALATABILITY PROPERTIES OF LONGISSIMUS MUSCLE OF STEERS

ABSTRACT

The objectives of this study were to investigate the effects of recombinant bovine somatotropin (bST), Revalor and the combination of the two on beef carcass characteristics, quality and physical, chemical and palatability attributes of bovine longissimus (loin eye) muscle. Crossbred steers (n = 20) were blocked by body weight and allotted in a 2 × 2 factorial arrangement of treatments: control, Revalor-S® (Trenbolone acetate 120 mg+estradiol 24 mg) implanted in ear on day 1 and 97, bST (160 mg/wk), and Revalor-S® + bST and fed for 140 days. Loin eye was removed from left side, cut into 2.4 cm steaks and postmortem aged for 13 days. Revalor treatment increased (p<.05) body, hot carcass, longissimus and semitendinosus weights and loin eye area; however, bST had no effect (p< .05) on these variables. Backfat, KPH fat %, and dressing percentage were not affected (p< .05) by either Revalor or bST. Carcass composition was physically separated into lean, fat, and bone. Lean, fat, and bone were increased (p<.05) by Revalor; however,
bST had no effect (p < .05) on lean, bone was increased (p < .05), and fat was reduced by 14.8% (p < .13). Revalor tended to reduce marbling, and yield and quality grades; however; bST reduced marbling and quality grade (p < .05, and .15) and had no effect on yield grade. Revalor had no effects on meat color, pH, drip and cook losses and water holding capacity; however, bST reduced cook losses (p < .01). Revalor increased (p < .05) protein, reduced (p < .05) fat and had no effect on moisture; however, bST had no effect on these variables.

Revalor decreased (p < .05) total collagen and increased (p < .26) soluble collagen. bST increased total collagen (p < .01) and had no effects on soluble collagen. Revalor decreased (p<.05) initial tenderness and myofibril fragmentation index (MFI), increased (p < .05) shear force, and had no effects on juiciness and flavor intensity. Both bST had no effect on sensory attributes, shear force, and MFI. bST and Revalor had no effects (p<05) on fiber percentages. The percentage of intermediate fiber was increased and the percentage white fiber was decreased by either Revalor or bST. Revalor and bST had an additive effect for all of the measurements; however, there were interactions between Revalor and bST on semitendinosus weight (p < .05), quality grade (p < .08) and degree of marbling (p < .04).
INTRODUCTION

There has been a consumer demand for leaner meat products and an increased conscientiousness about fat and its link to cardiovascular disease. Also, the higher cost of fat production and the cost of trimming fat from carcass have led the beef industry and meat producers to focus on increasing lean meat and reducing fat coupled with high quality eating characteristics.

Research has been conducted using growth promotants to increase lean meat and decrease fat. Anabolic promotants, Revalor (Trenbolone acetate-120 mg and Estradiol-24 mg), have been used to increase body weight, average daily gain, and improve feed efficiency (Perry et al., 1991; Preston et al, 1993.; Hayden et al., 1992; Trenkle, 1987, 1990). Research on changing carcass quality, longissimus muscle area increase, marbling score not significantly effected, quality and yield grade reduced, and no effect on backfat and dressing percentage by Revalor has been observed (Apple et al., 1991; Bartle et al., 1992; Perry et al., 1991; Trenkle, 1987, 1990).

On the other hand, little and conflicting studies have been reported about the effect of Revalor on physical, chemical, and palatability properties of implanted beef. Ouali et al. (1988) found implanted animals had a significant reduction in tenderness of longissimus muscle, but there was no difference in total and soluble collagen, juiciness and flavor intensity. Thonney et al. (1991) found that Revalor significantly decreased tenderness, juiciness, and flavor
intensity, and had no effect on number of chews. Perry et al. (1991) and Trenkle (1990) found no significant difference on sensory evaluation of beef meat from implanted animals.

Growth hormone has been demonstrated to increase average daily gain and improve feed efficiency (Dalke et al., 1992; Moseley et al., 1992; Preston et al., 1995; Wagner et al., 1988). Growth hormone also affects carcass characteristics as follows: lean and longissimus muscle area were increased, but not significant, backfat, marbling and fat were reduced, quality and yield grade were reduced by growth hormone (Dalke et al., 1992; Ferby et al., 1987; Moseley et al., 1992; Preston et al., 1975; Sandis & Peel, 1987).

On the other hand, there have been limited studies reported on the effects of growth hormone on physical, chemical and palatability properties of meat treated with growth hormone. Allan and Enright (1989) found that growth hormone had no significant effect on pH, shear force and percent of juice extracted. Another report by Allen et al. (1989) found no significant difference in shear force, but there were differences in tenderness and overall acceptability (P < .05). A study by Vestergaard et al. (1993) found no significant difference in collagen, pH, color, shear force and taste panel. Therefore, the objective of the current study was to determine the effects of growth hormone, Revalor and a combination of these two on carcass characteristics, quality and yield grade, and physical, chemical and palatability properties of beef.
MATERIALS AND METHODS

Animals

Twenty animals, predominantly Simmental and Charolais crossbred castrated male cattle, were used in this experiment. The initial weight of the animals was 360.3 kg (SEM = 14.9). The animals were blocked by body weight and allotted in a 2 x 2 factorial design to the following treatments: control, n = 5; Revalor-S® implant, n = 5; recombinant bovine somatotropin (bST, Posilac®), n = 5; and Revalor-S® + bST, n = 5. Animals were implanted with Revalor-S® (Trenbolone acetate 120 mg+estradiol 24 mg) on day one and reimplemented on day 97. bST was injected on a weekly basis in the neck region of 160 milligrams/week.

Animal Housing

The animals were housed in an open-fronted building and fed individually using a Calan® gate feeding system. Animals were trained for the use of the Calan® gate for two weeks as they adjusted to the high grain diet. The animals were fed twice daily with a high-energy corn-based diet containing 18% crude protein on a dry matter basis and had free access to water. The diet composition is presented in Table 1.
Table 1 Composition of the diet

<table>
<thead>
<tr>
<th>Ingredient</th>
<th>Percent of dry matter</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cracked corn</td>
<td>70.84</td>
</tr>
<tr>
<td>Soybean meal</td>
<td>13</td>
</tr>
<tr>
<td>Dehydrated pelleted alfalfa</td>
<td>12</td>
</tr>
<tr>
<td>Cane molasses</td>
<td>2</td>
</tr>
<tr>
<td>Urea</td>
<td>.715</td>
</tr>
<tr>
<td>Limestone</td>
<td>.95</td>
</tr>
<tr>
<td>Sodium chloride</td>
<td>.3</td>
</tr>
<tr>
<td>Elemental sulfur</td>
<td>.024</td>
</tr>
<tr>
<td>Trace mineral premix</td>
<td>.024</td>
</tr>
<tr>
<td>Vitamin A premix</td>
<td>.08</td>
</tr>
<tr>
<td>Tylan premix</td>
<td>.05</td>
</tr>
<tr>
<td>Rumensin premix</td>
<td>.018</td>
</tr>
<tr>
<td>Total</td>
<td>100.00</td>
</tr>
</tbody>
</table>

Trace mineral premix: supplied by Calcium Carbonate Division of J. M. Huber Co., Quincy, Illinois.
Vitamin A premix: 1.400 IU of vitamin A per pound of dry matter. Supplied by Hoffman-LaRoche, Inc., Nutley, New Jersey.
Tylan premix: supplied by Elanco Products, Indianapolis, Indiana.
Rumensin premix: 14.4 mg of sodium monensin per pound of dry matter. Supplied by Elanco Products, Indianapolis, Indiana.
The dry matter diet is formulated to contain 18% crude protein, 1.33 Mcal/IB metabolizable energy, .6% Ca, .3% P, and .9% K.

Animal Slaughter

Animals were slaughtered at the Iowa State University Meat Laboratory. Live, hot carcass, heart, liver, tail, shanks, head, and hide weights were recorded. Dressing percentage was calculated. Carcasses were placed in 2°C cooler for 24 hours postmortem. Cold carcass weight and kidney-
pelvic-heart fat percentage (KPH) were measured and recorded. Rib-eye area, and fat thickness were measured by using a USDA grid and steel ruler probe, respectively, for subsequent calculation of USDA yield grade. The USDA yield grades were determined by using yield grade equation (Boggs and Merkel 1993). Maturity and marbling were subjectively evaluated and used to determine USDA quality grade. The right side was dissected into lean, fat, and bone, and each was weighed. Longissimus and semitendinosus muscle were dissected, weighed and recorded. Loin eye (longissimus) muscle was removed from the left side of the carcasses, cut into 2.54 cm steaks, vacuumed packaged and postmortem aged for 13 days, and frozen for subsequent sensory evaluation, shear force determinations, myofibril fragmentation index, Hunter color measurements, pH measurements, water-holding capacity, proximate analysis, and collagen determination.

**Sensory Evaluation**

Sensory evaluation was conducted by a panel that consisted of nine members who were trained to evaluate sensory attributes of broiled steak for initial tenderness, juiciness, residual tenderness, and flavor intensity. The panelists were required to attend two training sessions where they learned how to evaluate the initial tenderness and residual tenderness by using two different steaks (round and tenderloin). Juiciness was tested by serving samples of steaks cooked to different end-point temperatures (60°C and 70°C).
Steaks that had been frozen after being aged for 13 days were thawed for 24 hours at 2°C before cooking. Steaks were cooked in a General Electric model CN 02 industrial broiler at distance of 10 cm from heat source. The internal temperature of a steak was monitored with copper-constantan thermocouples inserted in the geometric center of steak. The steaks were turned when they reached 35°C internal temperature and removed from the broiler when they reached 65°C internal temperature. The steaks were weighed before and after cooking to determine cooking loss.

Steaks were then wrapped individually in aluminum foil and placed in a 60°C preheated oven to maintain their temperature so that panelists would receive warm samples. Two representative samples (1 cm cubes) per steak were served in an aluminum pan to the panelists. The time required for serving samples was 3 minutes per sample. The scores were then recorded by the panelists on 15 cm scale lines with anchor points of 1 cm from each end. Panelists were asked to evaluate the sample for each of the following attributes: initial tenderness, residual tenderness, juiciness, and flavor intensity. The scores were recorded in millimeters and had a range from 0 (very hard for initial tenderness, very high for residual tenderness, very dry for juiciness, and bland for flavor intensity) to 150 mm (very soft for initial tenderness, very low for residual tenderness, very juicy for juiciness and intense for flavor intensity). The panelists sat in individual booths having red
lights overhead. They were instructed to cleanse their palates between samples with salt-free crackers and room temperature water (Appendix B).

**Shear Force Determinations**

The steaks used for shear force were cooked in the same manner as those for sensory evaluation. Steaks were then cooled down to room temperature before removing six 1.27 cm diameter cores parallel to the muscle fiber. The cores were from medial, lateral, and central portions of the steaks and sheared through the middle of the core at a speed of 250 mm/min by using an Instron Universal Testing Device, model 4502, with a model 4500 computer-assisted module. A Warner-Bratzler shear device was attached to the Instron. Cores were sheared perpendicular to the fiber direction.

**Myofibril Fragmentation Index**

The Myofibril Fragmentation Index (MFI) was determined by using DePulgar's (1982) procedure. Three 1.27 cm cores from three positions in the raw steak (medial, central, and lateral) were removed and finely minced with scissors. The readily apparent pieces of fat and connective tissue were removed.

Four grams of finely scissors-minced muscle were combined with 40 ml of a 2°C isolating medium (100 mM KCl, 2 mM MgCl₂, 1 mM EGTA, 1 mM NaN₃, and 20 mM potassium phosphate buffer with a pH of 6.85) in a Waring
After 10 seconds of homogenizing, the homogenate was passed through a polyethylene strainer to remove debris and connective tissue. Then 0.25 ml sample of the vortexed homogenate was diluted by adding 9.75 ml of the isolating medium.

The diluted myofibril suspension was vortexed for 10 seconds and then the absorbence of the suspension was measured by using a spectrometer at 540 nm. The average absorbence was multiplied by 200 to give the myofibril fragmentation index.

Drip Loss

Steak was weighed and then stored individually in polyethylene bags for 48 h at 2 °C. The amount of purge resulting from storage at 2 °C was measured and drip loss calculated by dividing the weight of purge that resulted from storage by the steak weight.

Color Measurements

Color measurements were made for uncooked raw steaks by using a Hunter Labscan (Hunter Association Laboratory, Inc. Reston, Virginia). Measurements (lightness, redness, and yellowness) were made on six locations of the steak and the means of three measurements were collected.
**pH Measurements**

The ultimate pH 24 postmortem was determined on raw samples. Ten grams of muscle tissue for each steak were homogenized with 100 ml of deionized water in a Warring blender for 10 seconds. The pH values of the homogenate were then measured with a Radiometer pH instrument.

**Water-Holding Capacity (WHC)**

The hydraulic press method was used to determine water-holding capacity (Grau & Hamm, 1953). An amount of 0.3 gram of muscle was placed onto a piece of dried Whatman filter paper in duplicate.

The sample and filter paper were placed between two plexiglass plates and 3000 psi were applied for three minutes. Then plates were removed from press and water and meat areas were traced. Each of the traced areas was measured using a compensating polar planimeter. A WHC value was obtained by dividing water area by meat area.

**Proximate Analysis**

The raw steaks were trimmed of fat and bone and cut into small pieces. Then small pieces were frozen in liquid nitrogen and pulverized to a fine powder in a Warring blender jar containing liquid nitrogen.

The moisture content was determined in duplicate 5 gram samples using a vacuum pressure gravity oven (AOAC, 1990, #950 46A). The hexane
extract was determined using a Soxhlex extraction apparatus (AOAC, 1990, #960, 39A) and the amount of protein was determined using Kjeldahl (Buchi 316 Distillation unit).

**Collagen Determination**

Collagen was determined by analyzing the hydroxyproline content of samples. For total collagen, 5 gm of pulverized fine powder samples were weighed and poured in a centrifuge bottle containing 50 ml of 6 N HCl. Then the centrifuge bottles were autoclaved for 12 hours at 16-19 psi and 125° C.

The samples were allowed to cool and decolorized with 3 gm at 1:2 (W:W) mixture of activated charcoal and dry Dowex-1-X10 ion exchange resin. The samples were filtered through filter paper and neutralized to phenolphthalein end point with NaOH, and then diluted to 250 ml with deionized water. Two ml of sample were diluted to 10 ml with deionized water, and 1 ml of this dilution was analyzed according to the procedure of Goll et al. (1963). The optical density was read at 557 nm with a spectronic 20 Bausch and Lomb colorimeter. Then the hydroxyproline content was converted to collagen by multiplying it by 7.25 (Goll et al., 1963).

Soluble collagen was determined by using 5 gm of pulverized fine powder and 20 ml of a 0.1 m sodium phosphate buffer (pH 7.0). The mixture was placed in a centrifuge tube and sample was heated in a water bath at 74° C for 25 minutes. The sample was allowed to cool in an ice bath for 10 minutes.
before it was centrifuged at 10,000 xg for 15 minutes. The supernatant was collected and 10 ml of it was placed in a test tube to which 10 ml of 6 N HCl was added. The sample was then autoclaved for 6 hours at 16-19 psi of approximately 125° C (Culler, 1977). It was then allowed to cool and decolorized with 1 gm of a 1:2 (W:W) mixture of activated charcoal and dry Dowex 1-X10 ion exchange resin. The sample was then filtered through filter paper and neutralized to a phenolphthalein end point with NaOH and diluted to 50 ml with deionized water. One ml of diluted sample was analyzed as the total collagen determination. The optical density was read at 557 mm with a spectronic 20 Bausch and Lomb colorimeter. The hydroxyproline was multiplied by 7.25 to get the soluble collagen content.

**Fiber Typing**

**Biopsy procedure**

The first biopsy was taken on 4/7/95. Steer was washed with soap and water. Hair was shaved between 12th and 13th rib of left side. The biopsy site was washed with alcohol. The prepared surface was anesthetized and 2 cm incision was made. The muscle sample was taken by bergstrom muscle biopsy cannula 6 mm (Depuy, Warsaw, Ind) from left side of the longissimus dorsi. Isopentane was immersed in liquid nitrogen to get a temperature of -160° C. The sample was frozen by immersing in isopentane for 15 seconds (Dubowitz
et al., 1973). A frozen section was then removed and wrapped in aluminum foil and stored at -70° C. The second biopsy was taken after slaughter on 8/8, 15, and 22/95. A sample of meat was excised from the 13th rib portion of longissimus muscle 45 minutes after slaughter. The sample was oriented so the direction of fiber was clearly visible. The samples were treated in the same manner as for the first biopsy.

Three sections were cut at 10 micron thickness in a cryostat (A O model 975 C and 976 C Histostat Cryostat microtome) at -20° C and picked up on coverslips and placed in three Columbia jars for analysis. Myosin ATPase staining procedure was followed for the staining at three different preincubation pHs (10.3, 4.6, and 4.3) in three Columbia jars Bubowitz et al. (1973). The procedure used was as follows: (1) an acid preincubation was done for 5 minutes by adding 10 ml of preincubation solution to appropriate pHs of 4.3 and 4.6 for 5 minutes. An alkaline preincubation was made by adding 10 ml of alkaline preincubation solution at a pH of 10.3 for 15 minutes; (2) rinse preincubation solution from coverslips with deionized water; (3) add 10 ml of the incubation solution to each Columbia jar at a pH of 9.4 and incubate in a water bath for 45 minutes at 37° C; (4) rinse with deionized water; (5) incubation was carried out in 1% CaCl₂ for 3 minutes; (6) rinse with deionized water; (7) incubate in 2% cobalt chloride (CoCl₂) for 3 minutes; (8) rinse with deionized water; (9) incubate in 1% ammonium sulfide (NH₄)₂ for 1 minute;
and (10) rinse with deionized water and mount on a slide using premount. The fiber types were then classified and counted by using a microprojector (model tech A-II, Ken-A-vision, MFG.inc), and the percentage of each type was calculated according to this classification (Table 2).

Table 2. Fiber classification

<table>
<thead>
<tr>
<th>Preincubation pH</th>
<th>Red</th>
<th>Intermediate</th>
<th>White</th>
</tr>
</thead>
<tbody>
<tr>
<td>10.3</td>
<td>light</td>
<td>dark</td>
<td>dark</td>
</tr>
<tr>
<td>4.3</td>
<td>dark</td>
<td>light</td>
<td>light</td>
</tr>
<tr>
<td>4.6</td>
<td>dark</td>
<td>light</td>
<td>dark</td>
</tr>
</tbody>
</table>

Bubowitz et al. (1973).

STATISTICAL ANALYSIS

The data were analyzed using the GLM procedures (SAS, 1988) as a randomized block design with a $2 \times 2$ factorial design to obtain the mean, P value and the standard error of the mean. Carcass characteristics also were analyzed using hot carcass weight as a covariant.
RESULTS AND DISCUSSION

The objective of the study was to determine the effect of Revalor, bST and a combination of Revalor and bST on quantitative and qualitative carcass characteristics, and chemical, physical, and palatability properties of longissimus muscle of steers. This study was conducted on the Iowa State University Nutrition Farm and the Iowa State University Meat Research Laboratory during 1995-1996. Two animals receiving bST were removed from the study because they refused to consume their diet; therefore the number of animal for each treatment were control, n = 5; Revalor-S® implant, n = 5; recombinant bovine somatotropin (bST, Posilac®), n = 3; and Revalor-S® + bST, n = 5. Loin-eye steaks of longissimus muscle from control and steers treated with Revalor, bST and the combination were evaluated for physical, chemical and palatability properties.

Body Weight

Data presented in Table 3 show the effect of bST, Revalor and a combination of the two on body weight. There were no significant differences for the initial weight of the four groups. Revalor had, however, significantly increased the final live weight, total gain and hot carcass weight. Other reports found similar results (Bartle et al, 1992; Hayden et a., 1992; Perry et al., 1991; Preston et al., 1993; Technical Manual, 1996; Trenkle, 1987, 1990).
bST had no significant effect on final weight and total gain. Hot carcass weight was not significantly affected by bST treatment. Most studies showed an increase but not significant in body weight, hot carcass, and feed efficiency, with different responses (Dalke et al., 1992; Early et al., 1988; Moseley et al., 1992; Preston et al., 1995). There was no interaction between Revalor and bST on growth performance.

Table 3. The effect of bST, Revalor and the combination of bST and Revalor on body weight gain (kg)

<table>
<thead>
<tr>
<th>Item</th>
<th>Treatment means</th>
<th>Main effects P(value)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Control Rev bST</td>
<td>Rev *</td>
</tr>
<tr>
<td>Initial wt</td>
<td>355 359 356 367</td>
<td>6.9 .25 .58 .44</td>
</tr>
<tr>
<td>Final wt</td>
<td>508 611 516 602</td>
<td>6.9 .001 .58 .75</td>
</tr>
<tr>
<td>Total gain (140</td>
<td>153 252 160 235</td>
<td>40.0 .001 .69 .52</td>
</tr>
<tr>
<td>days)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hot carcass</td>
<td>318 383 318 384</td>
<td>12.8 .001 .80 .90</td>
</tr>
</tbody>
</table>

Carcass Characteristics

The effect of bST and Revalor on carcass characteristics are shown in Table 4. Revalor significantly increased loin-eye area but had no significant effect on backfat, KPH fat, and dressing percentage. This result is in agreement with other reports (Apple et al., 1991; Bartle et al., 1992; Trenkle,
Table 4. The effect of bST, Revalor and the combination of bST and Revalor on carcass and muscle characteristics.

<table>
<thead>
<tr>
<th>Item</th>
<th>Control</th>
<th>Rev</th>
<th>bST</th>
<th>Rev *</th>
<th>SEM</th>
<th>Rev</th>
<th>bST</th>
<th>Rev *</th>
</tr>
</thead>
<tbody>
<tr>
<td>Loin-eye area, cm^2</td>
<td>75</td>
<td>91</td>
<td>76</td>
<td>87</td>
<td>4.2</td>
<td>.01</td>
<td>.70</td>
<td>.60</td>
</tr>
<tr>
<td>backfat, cm</td>
<td>.61</td>
<td>.70</td>
<td>.43</td>
<td>.57</td>
<td>.08</td>
<td>.32</td>
<td>.17</td>
<td>.80</td>
</tr>
<tr>
<td>KPH fat*, %</td>
<td>2.1</td>
<td>1.8</td>
<td>2</td>
<td>1.5</td>
<td>.32</td>
<td>.38</td>
<td>.40</td>
<td>.90</td>
</tr>
<tr>
<td>Dressing percentage %</td>
<td>61.5</td>
<td>61.9</td>
<td>60.8</td>
<td>62.7</td>
<td>.70</td>
<td>.39</td>
<td>.58</td>
<td>.67</td>
</tr>
<tr>
<td>Longissimus muscle^a (kg)</td>
<td>5.6</td>
<td>6.8</td>
<td>5.9</td>
<td>6.9</td>
<td>.23</td>
<td>.001</td>
<td>.45</td>
<td>.80</td>
</tr>
<tr>
<td>Semitendinosus muscle^a (kg)</td>
<td>2.1</td>
<td>2.7</td>
<td>2.4</td>
<td>2.7</td>
<td>.26</td>
<td>.002</td>
<td>.09</td>
<td>.05</td>
</tr>
</tbody>
</table>

* Kidney, pelvic and heat fat
* The muscle weight of one side

1987). On the other hand, some research studies reported that Revalor had no significant effect on backfat, KPH fat and dressing percentage (Apple et al., 1991; Foutz et al., 1990; Perry et al., 1991; Trenkle, 1987, 1990)

bST had no significant effect on loin-eye area, backfat, KPH fat, and dressing percentage. This result is supported by studies done by Dalke et al. (1992) and Vestergaard et al. (1993). However, Preston et al. (1995) reported that even though bST has no significant effect on longissimus muscle area, it significantly decreased backfat and KPH fat. Schwarz et al. (1993) reported that dressing percentage was not affected by bST, whereas kidney fat was significantly reduced by bST. Moseley et al. (1992) found that bST did not
significantly increase longissimus muscle area, but it significantly decreased backfat thickness.

There were no interactions between Revalor and bST on longissimus muscle area, backfat thickness, dressing percentage, and KPH fat percentage. These results conform with Preston et al. (1995) who found no interactions between bST and Estradiol benzoate-progesterone and trenbolone acetate. When testing longissimus muscle area, backfat, KPH percentage and dressing percentage to hot carcass weight as a covariant, the differences between groups were removed. Revalor had significantly increased the weight of the two muscles and bST increased weight of the semitendinosus more than the longissimus muscle, but both of the increases were not statistically significant. There was no interaction between Revalor and bST on longissimus muscle weight, but there was an interaction on semitendinosus weight.

Carcass Composition

Data in Table 5 show the effect of Revalor, bST and the combination of bST and Revalor on carcass composition. Revalor significantly increased lean, fat, and bone. The increases were 23.4, 21.4 and 10% due to the Revalor treatment for lean, fat and bone, respectively. However, most of the differences were removed when the differences in hot carcass weights were removed from the measurements by covariance.
bST had no significant effect on lean and fat. It tended to increase lean by 3% while decreasing fat by 14.8%. However, bone was significantly (p< .05) affected by bST. bST increased bone by 9.6%. Early et al. (1990) reported that bST increased lean 8.3%, bone 4%, and decreased fat by 11.5%. However, there were no significant effects on fat, lean and bone due to bST. Vestergaard et al. (1993) reported that salable meat in the carcass increased (P < 0.003), whereas percentage of carcass fat trim was reduced (P < 0.001), but the percentage of bone in the carcass was not affected by bST. There were no interactions between Revalor and bST on lean, fat and bone mass.

Table 5. The effect of bST, Revalor and the combination of bST and Revalor on carcass composition (kg per side)

<table>
<thead>
<tr>
<th>Item</th>
<th>Control</th>
<th>Rev</th>
<th>bST</th>
<th>Rev*</th>
<th>SEM</th>
<th>Rev</th>
<th>bST</th>
<th>Rev*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lean</td>
<td>88</td>
<td>109</td>
<td>91</td>
<td>112</td>
<td>4.1</td>
<td>.001</td>
<td>.4</td>
<td>.8</td>
</tr>
<tr>
<td>Fat</td>
<td>39.9</td>
<td>46.9</td>
<td>33.4</td>
<td>42.2</td>
<td>2.8</td>
<td>.03</td>
<td>.13</td>
<td>.8</td>
</tr>
<tr>
<td>Bone</td>
<td>25.7</td>
<td>29.3</td>
<td>29.2</td>
<td>31.1</td>
<td>.90</td>
<td>.01</td>
<td>.05</td>
<td>.7</td>
</tr>
</tbody>
</table>

Hide and By-products

The effect of bST, Revalor and the combination of bST and Revalor on hide and by-products are shown in Table 6. Revalor significantly increased hide and head weight, whereas it had no significant effect on shank and tail.
However, all of the differences were removed when they were compared as percentages of hot carcass weight. A study by Hutchison et al. (1994) agreed with the present study's results in that Revalor had no significant effect on the percentage of head and tongue, feet, hide, and tail. Additionally, Trenkle (1990) reported that Revalor had no effect on the hide as a percentage of carcass weight. bST had no significant effect on hide, head, shanks and tail weights. However, bST had increased the hide by 6.1% as a percentage of the hot carcass. The present finding agrees with Early et al. (1990) who found that bST had no significant effect on hide, feet plus tails weights, but head weight was increased (P < .05) over the control group. There were no interactions between Revalor and bST on hide, head, feet and tail weights.

Table 6. The effect of bST, Revalor and the combination of bST and Revalor on hide and by-products (whole body kg)

<table>
<thead>
<tr>
<th>Item</th>
<th>Control</th>
<th>Rev</th>
<th>bST</th>
<th>bST</th>
<th>SEM</th>
<th>Rev</th>
<th>bST</th>
<th>bST</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hide</td>
<td>44.4</td>
<td>52.5</td>
<td>47.0</td>
<td>54.5</td>
<td>1.3</td>
<td>.003</td>
<td>.16</td>
<td>.86</td>
</tr>
<tr>
<td>Head a</td>
<td>15.6</td>
<td>17.8</td>
<td>16.3</td>
<td>18.0</td>
<td>.5</td>
<td>.003</td>
<td>.65</td>
<td>.89</td>
</tr>
<tr>
<td>Shank b</td>
<td>10.4</td>
<td>12</td>
<td>11.7</td>
<td>12.1</td>
<td>.41</td>
<td>.1</td>
<td>.22</td>
<td>.35</td>
</tr>
<tr>
<td>Tail c</td>
<td>1.1</td>
<td>1.2</td>
<td>1.2</td>
<td>1.3</td>
<td>.07</td>
<td>.28</td>
<td>.34</td>
<td>.77</td>
</tr>
<tr>
<td>Total wast</td>
<td>71.1</td>
<td>83.5</td>
<td>76.2</td>
<td>85.9</td>
<td>2.3</td>
<td>.005</td>
<td>.24</td>
<td>.78</td>
</tr>
</tbody>
</table>

a Head without skin  
b Shank with skin  
c Tail weight without skin
Internal Visceral Organs

Data presented in Table 7 show the effect of Revalor, bST and the combination of bST and Revalor on the gastrointestinal tract (GI) tract, liver, heart, and lungs. Revalor significantly increased liver and heart weights, but had no significant effect on the GI tract and lungs. Revalor had a tendency to increase the weight of GI tract by 12.2% compared to control group. However, these differences were removed when compared as a percentage of the carcass with exception of the lungs. Lungs were decreased (P < 0.01) by expressing them as a percentage of carcass weight. These results agreed with Trenkle (1990) who reported no difference in liver weight expressed as a percentage of carcass by Revalor compared to control group. Additionally, Hutchison et al. (1994) found that empty GI tract was increased by (P < .1) by Revalor compared with control group whereas lungs, heart and trachea were not affected by Revalor when the data were expressed as a percentage of shrunk body weight. bST had no significant effect on the GI tract, liver, heart and lungs. It had a tendency to decrease heart weight by 8.12% compared with control group. The present study agreed with the results of Vestergaard et al (1993) who found that bST had no effect on liver and heart weight compared with control group. Early et al. (1990) reported that bST had no significant effect on rumen plus intestines and heart. However, liver and lungs plus trachea were increased (P < 0.5) by bST compared with control group.
Table 7. The effect of bST, Revalor and the combination of bST and Revalor on internal visceral organs (kg)

<table>
<thead>
<tr>
<th>Item</th>
<th>Control</th>
<th>Rev</th>
<th>bST</th>
<th>bST*</th>
<th>SEM</th>
<th>Rev*</th>
<th>bST</th>
<th>bST*</th>
</tr>
</thead>
<tbody>
<tr>
<td>GI tract*</td>
<td>49.1</td>
<td>58.5</td>
<td>48.7</td>
<td>51.2</td>
<td>3.2</td>
<td>.09</td>
<td>.27</td>
<td>43</td>
</tr>
<tr>
<td>Liver</td>
<td>5.7</td>
<td>6.7</td>
<td>5.5</td>
<td>7.2</td>
<td>.52</td>
<td>.04</td>
<td>.9</td>
<td>.59</td>
</tr>
<tr>
<td>Heart</td>
<td>2.2</td>
<td>2.5</td>
<td>1.8</td>
<td>2.5</td>
<td>.14</td>
<td>.007</td>
<td>.4</td>
<td>.21</td>
</tr>
<tr>
<td>Lungs</td>
<td>6.6</td>
<td>7.2</td>
<td>6.7</td>
<td>6.7</td>
<td>.33</td>
<td>.37</td>
<td>.6</td>
<td>.48</td>
</tr>
</tbody>
</table>

* An empty whole GI tract weight.

Moseley et al. (1992) and Schwarz et al. (1993) found that bST increased liver significantly (P < 05) compared with control. There were no interactions between Revalor and bST on visceral organs: GI tract, liver, heart and lungs.

Color

The loin-eye of longissimus muscle was aged for 13 days postmortem and measured for meat color by using Hunter lab to determine the values of lightness, redness and yellowness of raw steaks. There was no significant difference on color by either Revalor or bST, also the interaction between Revalor and bST was not significant as shown in Table 8. This study supports the previous results of Allen et al. (1989) who reported that bST had no significant effect on meat color. Additionally, Vestergaard et al. (1993) found no significant effect of bST on longissimus muscle color of raw or cooked
Table 8. The effect of bST, Revalor and the combination of bST and Revalor on loin-eye (longissimus muscle) color of surface aged steaks.

<table>
<thead>
<tr>
<th>Item</th>
<th>Control</th>
<th>Rev</th>
<th>bST</th>
<th>bST</th>
<th>SEM</th>
<th>Rev*</th>
<th>bST</th>
<th>bST</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lightnessa</td>
<td>24.7</td>
<td>23.7</td>
<td>23.8</td>
<td>24.7</td>
<td>.86</td>
<td>.66</td>
<td>.66</td>
<td>.51</td>
</tr>
<tr>
<td>Rednessb</td>
<td>7.1</td>
<td>7</td>
<td>6.9</td>
<td>6.9</td>
<td>.14</td>
<td>.41</td>
<td>.46</td>
<td>.88</td>
</tr>
<tr>
<td>Yellownessc</td>
<td>3.7</td>
<td>3.3</td>
<td>3.2</td>
<td>3.5</td>
<td>.19</td>
<td>.97</td>
<td>.3</td>
<td>.35</td>
</tr>
</tbody>
</table>

* Light = 100, black 0, b redness = +, gray = 0, and greenness = -.  
* Yellowness = +, gray = 0, and bluness = -.  
* The higher number, the higher intensity of color.

steaks. Foutz et al. (1990) also concluded that Revalor had no effect on meat color score compared with control group.

pH

Table 9 shows the mean and the P values of the ultimate pH 24 postmortem of longissimus muscle. As shown in the table, Revalor and bST had no significant effect on ultimate pH of longissimus muscle.

Table 9. The effect of bST, Revalor and the combination of bST and Revalor on ultimate pH 24 postmortem of longissimus muscle.

<table>
<thead>
<tr>
<th>Item</th>
<th>Control</th>
<th>Rev</th>
<th>bST</th>
<th>bST</th>
<th>SEM</th>
<th>Rev*</th>
<th>bST</th>
<th>bST</th>
</tr>
</thead>
<tbody>
<tr>
<td>pHa</td>
<td>5.60</td>
<td>5.60</td>
<td>5.66</td>
<td>5.58</td>
<td>.03</td>
<td>.71</td>
<td>.39</td>
<td>.39</td>
</tr>
</tbody>
</table>

* Ultimate pH 24 postmortem
Furthermore, there was no interaction between Revalor and bST on ultimate pH of longissimus muscle of steers.

The findings of this study confirm those of Vastergaard et al. (1993) who found no change in the final pH of longissimus dorsi muscle between control group and bST-treated animals. Moreover, Allen et al. (1989) reported that pH showed no change between control group and bST-treated animals. Foutz et al. (1990) found no change in ultimate pH using Revalor compared with control group. Ouali et al. (1989) also found that Revalor had no significant difference on pH of longissimus muscle.

Marbling, Yield, and Quality Grade

The means and P values of the marbling, yield grade and the USDA quality grade are shown in Table 10 and Figure 1. As shown in the table, marbling was reduced significantly (P < .05) by bST. This reduction of marbling was expected because bST decreases fat accretion of animal tissue. The reduction was 12.04% in the experimental group as compared with control group. This result agrees with finding of Preston et al. (1995) and Dalke et al. (1992). Preston et al. (1995) experimented with different dosages of 0, 80, 160 mg/wk of bST and reported that marbling decreased by 4.1 and 6.1% for 80 and 160 mg/wk of bST, respectively. On the other hand, Dalke et al. (1992) reported that marbling was reduced in bST samples at 160 mg/wk by 14%.
Table 10. The effect of bST, Revalor and the combination of bST and Revalor on marbling score, and beef carcass yield and quality grades

<table>
<thead>
<tr>
<th>Item</th>
<th>Control</th>
<th>Rev</th>
<th>bST</th>
<th>bST</th>
<th>SEM</th>
<th>Rev</th>
<th>bST</th>
<th>bST</th>
</tr>
</thead>
<tbody>
<tr>
<td>Marbling a</td>
<td>4.5</td>
<td>4.2</td>
<td>3.6</td>
<td>4.1</td>
<td>.41</td>
<td>.91</td>
<td>.02</td>
<td>.04</td>
</tr>
<tr>
<td>Yield grade</td>
<td>2.6</td>
<td>2.4</td>
<td>2.3</td>
<td>2.34</td>
<td>.18</td>
<td>.53</td>
<td>.69</td>
<td>.76</td>
</tr>
<tr>
<td>Quality grade b</td>
<td>6.8</td>
<td>6.2</td>
<td>5.1</td>
<td>6.2</td>
<td>.46</td>
<td>.72</td>
<td>.15</td>
<td>.08</td>
</tr>
</tbody>
</table>

*Marbling: slight = 4, small = 5.

Quality grade: standard = 4, select- = 6, select + = 8.

Figure 1. The effect of bST, Revalor and the combination of bST and Revalor on marbling score, and beef carcass yield and quality grades.
As a consequence, the reduction of marbling score resulted in a reduction of quality grade of the carcass. In the present study, Revalor did not significantly reduce marbling score. Previous studies reported that Revalor had no significant effect on lowering the marbling of a carcass (Apple et al., 1991; Gerken et al., 1995; Perry et al., 1991; Trenkle, 1987). However, Bartle et al. (1992) reported that Revalor significantly reduced marbling (p < .01).

Whereas Revalor caused a reduction in marbling, the effect was less than bST which might have some effect on carcass value. There was a negative interaction between Revalor and bST (P = .05) on degree of marbling. The value of marbling score of the combination of Revalor and bST was 4.04, whereas it was 3.56 with bST and 4.18 (traces = 3; slight = 4; and small = 5), with Revalor used alone. Preston et al. (1995) also reported the additive effect for Estradiol benzoate-progesterone and trenbolone acetate and bST. However, the results in the present study indicated a significant reduction in marbling for bST but not for Revalor.

The effects of Revalor, bST and the combination of bST and Revalor on yield grade are shown in Table 10 and Figure 1. There was a reduction in USDA yield grade (higher percentage of retail product) in steers implanted with Revalor or injected with bST, however, the reduction was not significantly different from control group. In addition, there was no interaction between Revalor and bST. These results conform with those of Preston et al. (1995).
Other studies noted a reduction of yield grade due to the effects of Revalor (Apple et al., 1991; Gerken et al., 1995; Thonney et al., 1991; Trenkle, 1987). On the other hand, studies by Trenkle (1990) and Bartle et al. (1992) found Revalor had no effect on yield grade.

Studies have noted a decreased yield grade of carcass due to bST (Dalke et al., 1992; Preston et al., 1993). These researchers found a linear decrease in carcass fat and quality grade due to an increased dosage of bST.

In the present study, the effect of Revalor, bST and a combination of the two on quality grades were varied (Table 10 and Figure 1). While Revalor decreased the quality grade by 3.4%, bST had higher reduction of quality grade by 12.5%. This reduction in quality grade would have an effect on carcass value.

Quality grade is affected by two factors: the degree of marbling and the stage of maturity. In this study, marbling was low and this resulted in a low quality grade. Previous reports support the reduction of quality grade due to Revalor (Apple et al., 1991; Gerken et al., 1995; Trenkle, 1990).

The addition of bST resulted in a lower quality grade because of its tendency to reduce fat deposition in longissimus muscle between the 12\textsuperscript{th} and 13\textsuperscript{th} rib. Dale et al. (1992) noted that quality grade decreased linearly with bST dosages (0, 40, 80, and 160 mg/wk), with a 17\% decrease with 160 mg/wk compared to control group.
**Proximate Analysis**

The effect of Revalor, bST and the combination of bST and Revalor on the percentage of protein, moisture and fat of longissimus muscle are shown in Table 11 and Figure 2. Revalor significantly (P < .05) increased protein of the longissimus muscle of steers. However, it had no significant effect on moisture, and fat was decreased by Revalor. This agrees with the observation of Foutz et al. (1990) who reported that Revalor significantly increased moisture and protein content of longissimus muscle, and decreased lipids, but not significantly from control group.

The effect of bST was no significant increase in protein and moisture while there was reduced fat content in longissimus muscle. Also, there was no interaction noted between Revalor and bST on the percentage of protein, moisture and fat of longissimus muscle.

**Total Collagen and Soluble Collagen**

Table 12 and Figure 3 show the effect of Revalor, bST and the combination of bST and Revalor on total collagen content of longissimus muscle of steers. Revalor caused a decrease in total collagen by 11.6% in the present study; however, other researchers found a small increase of total collagen. Gerken et al. (1995) found no effect (P > .05) of Revalor on total collagen in longissimus muscle of steers, but they did find an increase of 2.5% with Revalor as compared with control group.
Table 11. The effect of Revalor, Somatotropin and the combination of bST and Revalor on proximate analysis of longissimus muscle (%).

<table>
<thead>
<tr>
<th>Item</th>
<th>Control</th>
<th>Rev</th>
<th>bST</th>
<th>Protein</th>
<th>SEM</th>
<th>P(value)</th>
<th>Rev</th>
<th>bST</th>
<th>bST</th>
</tr>
</thead>
<tbody>
<tr>
<td>Protein</td>
<td>20.6</td>
<td>21.6</td>
<td>21.1</td>
<td>21.8</td>
<td>.29</td>
<td>.02</td>
<td>.32</td>
<td>.5</td>
<td></td>
</tr>
<tr>
<td>Moisture</td>
<td>73.1</td>
<td>73.4</td>
<td>73.7</td>
<td>73.5</td>
<td>.31</td>
<td>.84</td>
<td>.27</td>
<td>.39</td>
<td></td>
</tr>
<tr>
<td>Fat</td>
<td>3.3</td>
<td>2.6</td>
<td>3.1</td>
<td>2.1</td>
<td>.3</td>
<td>.05</td>
<td>.28</td>
<td>.74</td>
<td></td>
</tr>
</tbody>
</table>

Figure 2. The effect of Revalor, Somatotropin and the combination of bST and Revalor on proximate analysis of longissimus muscle (%)
Table 12. The effect of bST, Revalor and the combination of bST and Revalor on collagen content (mg/g) of longissimus muscle aged for 13 days.

<table>
<thead>
<tr>
<th>Item</th>
<th>Control</th>
<th>Rev</th>
<th>bST</th>
<th>bST</th>
<th>SEM</th>
<th>Rev</th>
<th>bST</th>
<th>bST</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total collagen mg/g</td>
<td>3.3</td>
<td>3.1</td>
<td>3.8</td>
<td>3.2</td>
<td>.12</td>
<td>.008</td>
<td>.01</td>
<td>.16</td>
</tr>
</tbody>
</table>

Figure 3. The effect of bST, Revalor and the combination of bST and Revalor on collagen content (mg/g) of longissimus muscle (%).
The percentage of soluble collagen affected by Revalor, bST and the combination of bST and Revalor is shown in Table 13 and Figure 4. Revalor had no significant effect on the percentage of soluble collagen which is similar to the results of a study by Gerken et al. (1995). However, in the present study, it was noted that Revalor caused a decrease in total collagen, and an increase in soluble collagen which would eliminate collagen as a factor affecting meat tenderness in this study. Whereas bST increased total collagen (P < .05) in longissimus muscle, it also caused an increase in total collagen by 11.1% compared with control group. While there was no effect by bST on the percentage of soluble collagen compared with control, there was an increase in soluble collagen by 1.95%. Other reports showed inconsistent results. Allen and Enright (1989) reported from a study conducted by Adams (1985) where collagen was increased (by 12%), but not significantly by bST over control group. Another study by Vestergaard et al. (1993) reported that total collagen and soluble collagen were not significantly changed compared with control group. However, Vestegaard et al did find a decrease in collagen by 4.3% and increase in soluble collagen by 4.3% as well. There was no interaction between Revalor and bST on either total collagen or soluble collagen of longissimus muscle of steer.
Table 13. The effect of bST, Revalor and the combination of bST and Revalor soluble collagen content % of total collagen of longissimus muscle aged for 13 days

<table>
<thead>
<tr>
<th>Item</th>
<th>Treatment means</th>
<th>Main effects</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Control</td>
<td>Rev</td>
</tr>
<tr>
<td>Soluble collagen^a %</td>
<td>7.47</td>
<td>9.41</td>
</tr>
<tr>
<td>Insoluble collagen^a %</td>
<td>92.5</td>
<td>90.6</td>
</tr>
</tbody>
</table>

\* It is a percentage of total collagen

Figure 4. The effect of bST, Revalor and the combination of bST and Revalor soluble collagen content (%) of longissimus muscle.
**Drip and Cooking Losses**

The data in Table 14 and Figure 5 show the effect of Revalor, bST and the combination group on drip and cooking losses of longissimus muscle. Revalor had no effect on drip losses and cooking losses compared with control group. However, there was an increase in water loss even though it was not significant ($P < .05$) compared with control group. No study is available on effect of Revalor on water losses.

While bST had no significant effect on drip losses, cooking losses were significantly reduced which would contribute to juiciness of muscle of these steaks. Allen and Enright (1989) reported an increase in cooking losses from treated animals compared with control, but this increase was not significant. Another study by Vestergaard et al. (1993) showed similar results due to the effect of bST on cooking losses. There was no interaction between Revalor and bST on longissimus muscle of treated steers.

**Water-holding Capacity**

The data on water-holding capacity are shown in Table 15. The effect of Revalor on water-holding capacity was not significant in this study. However, there was a decrease in water-holding capacity with Revalor (the higher value the lower water holding capacity), whereas bST had a tendency to increase water-holding capacity. This increase was also not significantly different from control group. In addition, there was no interaction between Revalor and bST
Table 14. The effect of bST, Revalor and the combination of bST and Revalor on water losses (%) of beef loin eye steaks.

<table>
<thead>
<tr>
<th>Item</th>
<th>Control</th>
<th>Rev</th>
<th>bST</th>
<th>bST</th>
<th>SEM</th>
<th>Rev</th>
<th>bST</th>
<th>bST</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drip losses</td>
<td>.6</td>
<td>2.4</td>
<td>3.3</td>
<td>2.6</td>
<td>72</td>
<td>.3</td>
<td>.13</td>
<td>.18</td>
</tr>
<tr>
<td>Cook losses</td>
<td>27.5</td>
<td>29.4</td>
<td>25.2</td>
<td>26.3</td>
<td>.88</td>
<td>.20</td>
<td>.01</td>
<td>.53</td>
</tr>
</tbody>
</table>

Figure 5. The effect of bST, Revalor and the combination of bST and Revalor on water losses (%) of beef loin-eye steaks.
Table 15. The effect of bST, Revalor and the combination of bST and Revalor on water holding capacity of beef loin-eye steaks.

<table>
<thead>
<tr>
<th>Item</th>
<th>Control</th>
<th>Rev</th>
<th>bST</th>
<th>Rev*</th>
<th>SEM</th>
<th>Rev</th>
<th>bST</th>
<th>Rev*</th>
</tr>
</thead>
<tbody>
<tr>
<td>WHC</td>
<td>3.6</td>
<td>3.8</td>
<td>3.5</td>
<td>3.9</td>
<td>1.3</td>
<td>.18</td>
<td>.75</td>
<td>.8</td>
</tr>
</tbody>
</table>

WHC = ratio of total water area divided by meat area after pressing 3000 psi on 0.3 g for 3 minutes

Sensory Evaluation

The effects of Revalor, bST and the combination of bST and Revalor on sensory evaluation of loin-eye steaks (longissimus muscle) are shown in Table 16 and Figure 6. Revalor showed an effect on initial tenderness (P < .05) compared with control; therefore, it did not have a significant effect (P < .05) on residual tenderness, juiciness and flavor intensity. Revalor tended to decrease total collagen and increase soluble collagen which would result in a consistently small change in residual tenderness. This result agrees with a study by Thonney et al. (1991) who found significant differences in tenderness, but not in number of chews and chewing related to connective tissue. Gerken et al. (1995) found that Revalor had little appreciable effect on tenderness of top sirloin and top round. Perry et al. (1991) also found no difference in taste
Table 16. The effect of bST, Revalor and the combination of bST and Revalor on sensory attributes of beef loin eye steaks

<table>
<thead>
<tr>
<th>Item</th>
<th>Control</th>
<th>Rev</th>
<th>bST</th>
<th>bST</th>
<th>SEM</th>
<th>Rev</th>
<th>bST</th>
<th>bST</th>
</tr>
</thead>
<tbody>
<tr>
<td>In. tenderness</td>
<td>10.5</td>
<td>8.9</td>
<td>11.2</td>
<td>8.1</td>
<td>.87</td>
<td>.02</td>
<td>89</td>
<td>.3</td>
</tr>
<tr>
<td>Re. tenderness</td>
<td>9.5</td>
<td>8.2</td>
<td>10.2</td>
<td>8.5</td>
<td>.76</td>
<td>.06</td>
<td>.41</td>
<td>.58</td>
</tr>
<tr>
<td>Juiciness</td>
<td>8.9</td>
<td>7.9</td>
<td>8.1</td>
<td>7.1</td>
<td>.5</td>
<td>.1</td>
<td>.32</td>
<td>.9</td>
</tr>
<tr>
<td>Flavor</td>
<td>8.5</td>
<td>7.9</td>
<td>8.1</td>
<td>8.4</td>
<td>.38</td>
<td>.6</td>
<td>.8</td>
<td>.37</td>
</tr>
</tbody>
</table>

intensity

^ Number represents means from values collected on a 15 cm scale: (0 = minimum, 15 = maximum).

Figure 6. The effect of bST, Revalor and the combination of bST and Revalor on sensory attributes of beef loin eye steaks (%)
panel evaluation on three different breeds of Holstein, Angus and Angus × Simmental. Work reported by Apple et al. (1991) and Trenkle (1990) agree with study of Perry et al. (1991). There was no significant effect of bST on initial tenderness, residual tenderness, juiciness and flavor intensity (Table 16 and Figure 6) compared with control group. These results agree with finding of Vestergaard et al. (1993) who noted that trained panelists found no difference between control group and bST treated animals on taste, tenderness, juiciness, and overall acceptance. However, another report by Allen and Enright (1989) found that bST had a significant effect in tenderness and overall acceptability (P < .05). On the other hand, they did not find any difference in shear force values. Moreover, there was no interaction between Revalor and bST on sensory evaluation of longissimus muscle of steers.

Shear Force

The results of the effect of Revalor, bST and the combination of bST and Revalor on shear force of longissimus muscle of steers are shown on Table 17 and Figure 7. Revalor increased shear force of muscle significantly compared to control group, and shear force value (3.7 kg) is less than threshold value (3.9 kg) (Shackelford et. al. 1991). The increase in shear force is parallel to a reduction of initial tenderness due to Revalor. This decrease in tenderness is likely due to the effect on myofibril degradation rather than connective tissue content or solubility. However, other researchers found no effect of
Table 17. The effect of bST, Revalor and the combination of bST and Revalor on shear force of beef loin-eye steaks (kg)

<table>
<thead>
<tr>
<th>Item</th>
<th>Control</th>
<th>Rev</th>
<th>bST</th>
<th>Rev*</th>
<th>bST</th>
<th>SEM</th>
<th>Rev</th>
<th>bST</th>
<th>bST</th>
<th>P(value)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shear force</td>
<td>3.1</td>
<td>3.7</td>
<td>2.7</td>
<td>3.7</td>
<td>.29</td>
<td>.01</td>
<td>.28</td>
<td>.31</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Steaks were cooked to 65 °C internal temperature

Figure 7. The effect of bST, Revalor and the combination of bST and Revalor on shear force of beef loin-eye steaks (kg)
Revalor on shear force. Trenkle (1990) found an increase of shear force value, but it was not significant (2.86 vs. 3.41 kg). Foutz et al. (1990) observed an increase of shear force value (4.01 vs. 4.32 kg) for control and Revalor, respectively. A recent study by Gerken et al. (1995) reported an increase in W-B shear force for three different steaks: strip loin, top sirloin and top round, but it was not significant. While bST had no significant effect on shear force value, it tended to decrease shear force value. This reduction paralleled to taste panel evaluation which noted that bST increased initial tenderness and residual tenderness. Nevertheless, none of these changes in shear force were significantly different. The present results are in agreement with those of other studies. Allen and Enright (1989) reported two studies. In the first one by Adam et al. (1985), shear force value was reduced by 5.9 vs. 5.8 kg for steaks from control and treated animals, respectively. However, the results were not significantly different. In the second study by Wagoner et al., shear force was reduced by 2.5 vs. 2.3 kg for control and treated animals, respectively, but they were also not significantly different. On the other hand, Vestergaard et al. (1993) noted higher shear values of 7.9 and 8.6 kg for steaks from control and treated animals, respectively, but these also were not significantly different. These results were inconsistent, however, they all were not significantly different from controls. There was no interaction between Revalor and bST on shear force of longissimus muscle of steers.
Myofibril Fragmentation Index

The effect of Revalor, bST and the combination of bST and Revalor on myofibril fragmentation index is shown in Table 18 and Figure 8. Revalor significantly reduced myofibril fragmentation index value compared with control group. This result was parallel to decrease of initial tenderness and increase of shear force by Revalor treatment. The decrease in myofibril fragmentation index and initial tenderness and increase of shear force by Revalor treatment could explain reduction of breakdown of myofibril during postmortem storage and resultant tougher meat. Whereas bST had no effect on myofibril fragmentation index, there was also no interaction between Revalor and bST on myofibril index. However, there have been no other studies conducted on effect of Revalor or bST on myofibril fragmentation index.

Fiber Typing

Two biopsies were taken one on 4/7/95 and the other at time of slaughter after approximately 125 days from the first one. The effect of Revalor, bST and the combination of bST and Revalor on fiber typing is shown in Table 19 and Figure 9. Revalor had no significant effect on three types: red fiber, intermediate fiber and white fiber compared with control group, whereas red fiber had no change, intermediate fibers increased by 5.4% and white fiber decreased by 1.55% due to the effect of Revalor. On the other hand, bST had no
Table 18. The effect of bST, Revalor and the combination of bST and Revalor on myofibril fragmentation index (MFI) of raw steak.

<table>
<thead>
<tr>
<th>Item</th>
<th>Control</th>
<th>Rev</th>
<th>bST</th>
<th>SEM</th>
<th>Rev*</th>
<th>bST</th>
<th>SEM</th>
<th>Rev*</th>
<th>bST</th>
</tr>
</thead>
<tbody>
<tr>
<td>MFI*</td>
<td>71.2</td>
<td>50.3</td>
<td>67.6</td>
<td>49.6</td>
<td>5.6</td>
<td>.006</td>
<td>.92</td>
<td>.97</td>
<td></td>
</tr>
</tbody>
</table>

*Absorbency at 540 nm* 200 = MFI

Figure 8. The effect of bST, Revalor and the combination of bST and Revalor on myofibril fragmentation index (MFI).
significant effect on all three types of fibers. It increased red fiber and intermediate by 15% and 3.3%, respectively, and decreased white fiber by 12%. There was no interaction between Revalor and bST on red fiber and white fiber. However, there was an interaction on intermediate fiber (p<.01). A comparison between the first and the second biopsy showed intermediate increased by 15% for both Revalor and bST, white fiber decreased by 10%, and 15.3% for bST and Revalor, respectively. Red fiber was reduced by 7% and 4% for control and bST groups respectively. In general, bST and Revalor tended to increase intermediate fiber at the expense of white fiber, however, no studies have been conducted using bST or Revalor in steers. Nevertheless, Soloman et al. (1988,1991) and Oksbjerg et al. (1994) reported that porcine somatotropin did not have a significant effect on percentage of fiber types. Clancy et al. (1986) implanted steers with resorcylic acid lactone and trenbolone acetate and observed no significant effect on red fiber percentage. However, they found a 26% increase in intermediate fiber and an 8% decrease in white fiber compared with control group.
Table 19. The effect of bST, Revalor and the combination of bST and Revalor on fiber typing of longissimus muscle (% fiber of total)

<table>
<thead>
<tr>
<th>Item</th>
<th>Treatment means</th>
<th>Main effects P(value)</th>
<th>SEM</th>
<th>Rev*</th>
<th>bST</th>
<th>bST</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Control</td>
<td>Rev</td>
<td>bST</td>
<td>bST</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Red fiber</td>
<td>26.6</td>
<td>21.8</td>
<td>29.7</td>
<td>23.8</td>
<td>1.7</td>
<td></td>
</tr>
<tr>
<td>4/7/1995a</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>.02</td>
</tr>
<tr>
<td>Red fiber</td>
<td>22.5</td>
<td>22.3</td>
<td>25.6</td>
<td>26.2</td>
<td>1.4</td>
<td></td>
</tr>
<tr>
<td>8/15/1995b</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>.84</td>
</tr>
<tr>
<td>Intermediate</td>
<td>32.4</td>
<td>23.4</td>
<td>24.7</td>
<td>24.4</td>
<td>2.7</td>
<td></td>
</tr>
<tr>
<td>4/7/1995a</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>.15</td>
</tr>
<tr>
<td>Intermediate</td>
<td>34.3</td>
<td>38.6</td>
<td>40.2</td>
<td>35.3</td>
<td>22</td>
<td></td>
</tr>
<tr>
<td>8/15/1995b</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>.32</td>
</tr>
<tr>
<td>White fiber</td>
<td>41.1</td>
<td>54.4</td>
<td>45.2</td>
<td>51.6</td>
<td>3.8</td>
<td></td>
</tr>
<tr>
<td>4/7/1995a</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>.04</td>
</tr>
<tr>
<td>White fiber</td>
<td>43.2</td>
<td>39.1</td>
<td>34.2</td>
<td>39.2</td>
<td>3.1</td>
<td></td>
</tr>
<tr>
<td>8/15/1995b</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>.59</td>
</tr>
</tbody>
</table>

aAfter 7 days of treatment
bAfter approximately 140 days of treatment
Figure 9. The effect of bST, Revalor and the combination of bST and Revalor on fiber typing (% fiber of total) of longissimus muscle.
Figure 10. Summary of meat tenderness measurements.
CONCLUSIONS

Results of this study suggest that implanting animals with Revalor was an effective method for increasing body weight and lean meat, and this may be due to decreased protein degradation because Revalor decreases protein synthesis and degradation with a greater in degradation, but this treatment had a negative effect on eating quality by reducing tenderness of beef loin steaks. This toughness likely due to reduction in myofibril fragmentation, and not to collagen. This reduction in MFI may be due to reduction in calpain activity or increases in calpastatin activity during postmortem as indicated by MFI. Consequently, more research should be done to improve meat tenderness of Revalor treated meat by using CaCl₂ solutions to inject meat to activate calpain and inactivate calpastatin, as well as using mechanical methods of tenderization. bST treatment tended to change body composition by reducing carcass fat, including marbling score, and improve yield grade of edible products, while eating quality of beef loin steaks was unaffected. Therefore, because bST changes both composition and palatability positively, bST meat could be suitably used by consumer, especially those who are conscious about animal fat in their diet and potential health problems. There were no interactions between Revalor and bST and this suggests an independent mode of action.
REFERENCES


GENERAL SUMMARY

The main goal for cattle producers and the meat industry is to increase lean and decrease fat to produce leaner animal to get maximum profit. Growth hormone and anabolic implants have been used to decrease fat and increase lean, but the use of these hormones may have a negative effect on meat palatability. The objective of this study was to measure the effects of growth hormone, Revalor and interaction of growth hormone and Revalor on carcass characteristics, and physical, chemical and palatability properties of longissimus muscle.

Twenty animals, predominantly Simmental and Charolais crossbred, castrated male cattle (mean weight 360.3 kg, SEM = 14.9) were used. Animals were blocked by body weight and allotted in a 2 x 2 factorial design to the following treatments: control, n = 5; Revalor-S® implant, n=5; recombinant bovine somatotropin (bST, Posilac®), n = 5; and Revalor-S® * bST, n = 5. Animals were implanted with Revalor-S® on day one and reimplemented on day 97. bST was injected on a weekly basis in the neck region of 160 milligrams/week for 140 days. Animals were slaughtered, and body, visceral organs, and by-products weight were collected. Loin-eye (longissimus) muscles were removed from left side and cut into 2.4 cm steaks and postmortem aged for 13 days and analysis for physical, chemical and palatability attributes.
The data showed that Revalor significantly increased weight of body, hot carcass, lean, fat, bone, longissimus, and semitendinosus muscles, hide, head, liver, heart, and G I tract, and loin-eye area. The significant effects were removed by adjusting to hot carcass weight, or as percentage of carcass weight. Furthermore, bST significantly increased bone weight, but had no significant effect on other measurements, and decreased fat as percentage of carcass weight.

Marbling was significantly reduced by bST and had no significant effect on yield grade and quality grade; however, Revalor had no significant effect on marbling, yield and quality grade. There was an interaction (P < .04) between Revalor and bST on marbling. Revalor and bST had no effect on color and pH of longissimus muscle. Revalor significantly increased protein and reduced fat and had no effect on moisture; however, bST had no significant effect on proximate composition.

Collagen content was significantly reduced by Revalor and increased by bST and soluble collagen was not significantly affected by either Revalor or bST. Drip losses, cook losses, and water holding capacity were not significantly affected by Revalor or bST; however, bST significantly decreased cook losses. Sensory attributes were not significantly affected by bST; however, Revalor significantly reduced initial tenderness.

Shear force was significantly increased by Revalor. bST had no significant effect on shear force. Revalor significantly decreased MFI, whereas
bST had no affect. Fiber types were not affected by either Revalor or bST, however; bST and Revalor tended to increase intermediate fiber and decrease white fiber. There were no interactions between Revalor and bST in most of these parameters; however, there were interactions on degree of marbling, weight of semitendinosus muscle weight, and quality grade.

The results of this study suggest that Revalor has the potential to increase lean meat, but it has a negative effect on tenderness. Consequently, more research can be done by using CaCl$_2$ or NaCl/phosphate to maximize meat tenderness and to obtain more tender meat. bST reduced fat in meat and had no effect on meat palatability; therefore, Meat from cattle given bST could be suitably used by consumer, especially those conscious about fat in their diet and potential health problems.
## APPENDIX A. ADJUSTED TABLES

**Table A1.** The effect of bST, Revalor and the combination of bST and Revalor on hide and by-products as percentage of hot carcass weight

<table>
<thead>
<tr>
<th>Item</th>
<th>Control</th>
<th>Rev</th>
<th>bST</th>
<th>bST</th>
<th>SEM</th>
<th>Rev</th>
<th>bST</th>
<th>bST</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hide</td>
<td>13.9</td>
<td>13.7</td>
<td>15.1</td>
<td>14.2</td>
<td>.008</td>
<td>.47</td>
<td>.14</td>
<td>.75</td>
</tr>
<tr>
<td>Head</td>
<td>4.9</td>
<td>4.6</td>
<td>5.07</td>
<td>4.7</td>
<td>.014</td>
<td>.13</td>
<td>.76</td>
<td>.90</td>
</tr>
<tr>
<td>Shank</td>
<td>3.2</td>
<td>3.1</td>
<td>3.7</td>
<td>3.1</td>
<td>.001</td>
<td>.13</td>
<td>.34</td>
<td>.54</td>
</tr>
<tr>
<td>Tail</td>
<td>.33</td>
<td>.31</td>
<td>.33</td>
<td>.33</td>
<td>.002</td>
<td>.26</td>
<td>.52</td>
<td>.83</td>
</tr>
</tbody>
</table>

**Table A2.** The effect of bST, Revalor and the combination of bST and Revalor on internal vicar organs as percentage of hot carcass weight (kg)

<table>
<thead>
<tr>
<th>Item</th>
<th>Control</th>
<th>Rev</th>
<th>bST</th>
<th>bST</th>
<th>SEM</th>
<th>Rev</th>
<th>bST</th>
<th>bST</th>
</tr>
</thead>
<tbody>
<tr>
<td>GI tract</td>
<td>15.3</td>
<td>15.2</td>
<td>15.2</td>
<td>13.4</td>
<td>.006</td>
<td>.32</td>
<td>.14</td>
<td>.41</td>
</tr>
<tr>
<td>Liver</td>
<td>1.77</td>
<td>1.73</td>
<td>1.72</td>
<td>1.82</td>
<td>.001</td>
<td>.62</td>
<td>.85</td>
<td>.38</td>
</tr>
<tr>
<td>Heart</td>
<td>.68</td>
<td>.65</td>
<td>.58</td>
<td>.67</td>
<td>.001</td>
<td>.57</td>
<td>.45</td>
<td>.25</td>
</tr>
<tr>
<td>Lung</td>
<td>2.07</td>
<td>1.88</td>
<td>2.09</td>
<td>1.77</td>
<td>.001</td>
<td>.01</td>
<td>.55</td>
<td>.48</td>
</tr>
</tbody>
</table>
Table A3. The effect of bST, Revalor and the combination of bST and Revalor on carcass characteristics (kg) adjusted to hot carcass weight

<table>
<thead>
<tr>
<th>Item</th>
<th>Treatment means</th>
<th>Main effects P(value)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Control</td>
<td>Rev</td>
</tr>
<tr>
<td>Loin-eye area, cm²</td>
<td>79</td>
<td>89</td>
</tr>
<tr>
<td>KPH fat, %</td>
<td>2.6</td>
<td>1.4</td>
</tr>
<tr>
<td>Dressing percentage</td>
<td>61.8</td>
<td>61.6</td>
</tr>
<tr>
<td>Longissimus dorsi, (kg)</td>
<td>6.1</td>
<td>6.4</td>
</tr>
</tbody>
</table>

Table A4. The effect of bST, Revalor and the combination of bST and Revalor on carcass composition as percentage of hot carcass weight (kg)

<table>
<thead>
<tr>
<th>Item</th>
<th>Treatment means</th>
<th>Main effects P(value)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Control</td>
<td>Rev</td>
</tr>
<tr>
<td>Lean</td>
<td>27.6</td>
<td>28.7</td>
</tr>
<tr>
<td>Fat</td>
<td>12.5</td>
<td>12.2</td>
</tr>
<tr>
<td>Bone</td>
<td>8.1</td>
<td>7.6</td>
</tr>
</tbody>
</table>
APPENDIX B. SENSORY EVALUATION FORM

Name ----------------- Date -----------------

SENSORY ANALYSIS OF BEEF

INSTRUCTIONS: Place a vertical mark across the horizontal line according to the intensity of the attribute you are testing. Please put the number of the sample above the vertical line when you make it.

Initial tenderness: measure of how easily the sample compresses between the molars and fragment into smaller pieces.

very hard                      very soft
|-------------------------------------------|

Residual tenderness: The amount of material remaining after thorough mastication.

very high                      very low
|--------------------------------|

Juiciness: The sensation of free fluid released from the meat during the first few chews.

very dry                      very juicy
|--------------------------------|

Flavor intensity: Degree of any flavor perceived in the sample.

bland                          intense
|--------------------------------|

COMMENTS:
Table C1. The effect of age on body weight (kg)

<table>
<thead>
<tr>
<th>Item</th>
<th>12 month</th>
<th>15 month</th>
<th>17 month</th>
<th>P (value)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Body weight</td>
<td>367</td>
<td>464</td>
<td>508</td>
<td>.0003</td>
</tr>
<tr>
<td>Carcass weight</td>
<td>210</td>
<td>281</td>
<td>321</td>
<td>.0001</td>
</tr>
<tr>
<td>Dressing percentage</td>
<td>57.2</td>
<td>60.5</td>
<td>63.2</td>
<td>.011</td>
</tr>
</tbody>
</table>

Table C2. The effect of age on carcass and muscle characteristics

<table>
<thead>
<tr>
<th>Item</th>
<th>12 month</th>
<th>15 month</th>
<th>17 month</th>
<th>P (value)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Loin-eye area cm²</td>
<td>62.2</td>
<td>87.1</td>
<td>75.4</td>
<td>.006</td>
</tr>
<tr>
<td>Fat thickness cm</td>
<td>.216</td>
<td>.298</td>
<td>.612</td>
<td>.008</td>
</tr>
<tr>
<td>KPH, %</td>
<td>1.6</td>
<td>1.4</td>
<td>2.1</td>
<td>.15</td>
</tr>
<tr>
<td>Longissimusdors (kg)</td>
<td>3.9</td>
<td>5.7</td>
<td>5.7</td>
<td>.0002</td>
</tr>
<tr>
<td>Semitendinosus (kg)</td>
<td>1.69</td>
<td>2.18</td>
<td>2.08</td>
<td>.008</td>
</tr>
</tbody>
</table>
Table C3. The effect of age on carcass composition (kg)

<table>
<thead>
<tr>
<th>Item</th>
<th>12 month</th>
<th>15 month</th>
<th>17 month</th>
<th>P (value)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lean</td>
<td>63.8</td>
<td>83.2</td>
<td>87.6</td>
<td>.0001</td>
</tr>
<tr>
<td>Fat</td>
<td>19.3</td>
<td>31.2</td>
<td>39.6</td>
<td>.004</td>
</tr>
<tr>
<td>Bone</td>
<td>18.8</td>
<td>21.9</td>
<td>25.7</td>
<td>.0002</td>
</tr>
</tbody>
</table>

Table C4. The effect of age on hide and by-products (kg)

<table>
<thead>
<tr>
<th>Item</th>
<th>12 month</th>
<th>15 month</th>
<th>17 month</th>
<th>P (value)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hide</td>
<td>31.7</td>
<td>42.6</td>
<td>44.4</td>
<td>.0006</td>
</tr>
<tr>
<td>Head</td>
<td>11.3</td>
<td>14.6</td>
<td>15.6</td>
<td>.0001</td>
</tr>
<tr>
<td>Shank</td>
<td>8.6</td>
<td>10.1</td>
<td>10.4</td>
<td>.01</td>
</tr>
<tr>
<td>Tail</td>
<td>.56</td>
<td>.93</td>
<td>1.06</td>
<td>.001</td>
</tr>
</tbody>
</table>

Table C5. The effect of age on internal viscera organs (kg)

<table>
<thead>
<tr>
<th>Item</th>
<th>12 month</th>
<th>15 month</th>
<th>17 month</th>
<th>P (value)</th>
</tr>
</thead>
<tbody>
<tr>
<td>GI tract</td>
<td>35.9</td>
<td>41.8</td>
<td>48.3</td>
<td>.02</td>
</tr>
<tr>
<td>Liver</td>
<td>5.5</td>
<td>5.6</td>
<td>6.3</td>
<td>.33</td>
</tr>
<tr>
<td>Heart</td>
<td>1.5</td>
<td>2.2</td>
<td>2.2</td>
<td>.003</td>
</tr>
<tr>
<td>Lung</td>
<td>4.5</td>
<td>5.8</td>
<td>6.6</td>
<td>.0002</td>
</tr>
</tbody>
</table>
Table C6. The effect of age on loin-eye steak color

<table>
<thead>
<tr>
<th>Item</th>
<th>12 month</th>
<th>15 month</th>
<th>17 month</th>
<th>P (value)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lightness</td>
<td>26.5</td>
<td>27.3</td>
<td>24.8</td>
<td>.41</td>
</tr>
<tr>
<td>Redness</td>
<td>6.4</td>
<td>6.7</td>
<td>7.1</td>
<td>.02</td>
</tr>
<tr>
<td>Yellowness</td>
<td>3.9</td>
<td>4.5</td>
<td>3.6</td>
<td>.15</td>
</tr>
</tbody>
</table>

Table C7. The effect of age on myofibril fragmentation index of beef loin-eye steaks

<table>
<thead>
<tr>
<th>Item</th>
<th>12 month</th>
<th>15 month</th>
<th>17 month</th>
<th>P (value)</th>
</tr>
</thead>
<tbody>
<tr>
<td>MFIa</td>
<td>62.2</td>
<td>63.6</td>
<td>71.8</td>
<td>.14</td>
</tr>
</tbody>
</table>

*a Absorbency at 540 nm*200.

Table C8. The effect of age on meat pH of beef loin-eye

<table>
<thead>
<tr>
<th>Item</th>
<th>12 month</th>
<th>15 month</th>
<th>17 month</th>
<th>P (value)</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH</td>
<td>5.70</td>
<td>5.56</td>
<td>5.60</td>
<td>.015</td>
</tr>
</tbody>
</table>
Table C9. The effect of age on sensory attribute of beef loin-eye steaks

<table>
<thead>
<tr>
<th>Item</th>
<th>12 month</th>
<th>15 month</th>
<th>17 month</th>
<th>P (value)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial tenderness&lt;sup&gt;a&lt;/sup&gt;</td>
<td>8.4</td>
<td>10.4</td>
<td>10.5</td>
<td>.16</td>
</tr>
<tr>
<td>Residual tenderness&lt;sup&gt;a&lt;/sup&gt;</td>
<td>7.9</td>
<td>9.7</td>
<td>9.5</td>
<td>.14</td>
</tr>
<tr>
<td>Juiciness&lt;sup&gt;a&lt;/sup&gt;</td>
<td>8.1</td>
<td>8.4</td>
<td>8.9</td>
<td>.47</td>
</tr>
<tr>
<td>Flavor intensity&lt;sup&gt;a&lt;/sup&gt;</td>
<td>8.5</td>
<td>8.6</td>
<td>8.6</td>
<td>.99</td>
</tr>
</tbody>
</table>

<sup>a</sup> Means from values collected on a 15 cm scale (0 = minimum, 15 = maximum).

Table C10. The effect of age on beef carcass quality grade and marbling score

<table>
<thead>
<tr>
<th>Item</th>
<th>12 month</th>
<th>15 month</th>
<th>17 month</th>
<th>P (value)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quality grade&lt;sup&gt;a&lt;/sup&gt;</td>
<td>7.8</td>
<td>6.8</td>
<td>6.8</td>
<td>.49</td>
</tr>
<tr>
<td>Marbling&lt;sup&gt;b&lt;/sup&gt;</td>
<td>494</td>
<td>454</td>
<td>446</td>
<td>.43</td>
</tr>
</tbody>
</table>

<sup>a</sup> Quality grade: standard = 4, select = 6, select+ = 8.
<sup>b</sup> Marbling: slight = 400, small = 500.

Table C11. The effect of age on meat losses (%) of beef loin-eye

<table>
<thead>
<tr>
<th>Item</th>
<th>12 month</th>
<th>15 month</th>
<th>17 month</th>
<th>P (value)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drip losses</td>
<td>4.28</td>
<td>.51</td>
<td>.21</td>
<td>.0003</td>
</tr>
<tr>
<td>Cooking losses</td>
<td>36.2</td>
<td>32.3</td>
<td>27.6</td>
<td>.007</td>
</tr>
</tbody>
</table>
Table C12. The effect of age on shear force of beef loineye steaks (kg)

<table>
<thead>
<tr>
<th>Item</th>
<th>12 month</th>
<th>15 month</th>
<th>17 month</th>
<th>P (value)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shear force</td>
<td>4.1</td>
<td>3.0</td>
<td>3.1</td>
<td>.02</td>
</tr>
</tbody>
</table>

Table C13. The effect of age on collagen content (mg/g) of longissimus muscle

<table>
<thead>
<tr>
<th>Item</th>
<th>12 month</th>
<th>15 month</th>
<th>17 month</th>
<th>P (value)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Collagen</td>
<td>2.70</td>
<td>3.22</td>
<td>3.27</td>
<td>.166</td>
</tr>
</tbody>
</table>

Table C14. The effect of age on soluble collagen content % of total collagen of longissimus muscle

<table>
<thead>
<tr>
<th>Item</th>
<th>12 month</th>
<th>15 month</th>
<th>17 month</th>
<th>P (value)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soluble collagen</td>
<td>10.56</td>
<td>9.94</td>
<td>7.48</td>
<td>.08</td>
</tr>
</tbody>
</table>
Table C15. The effect of age on water holding capacity (water:meat) of beef loin-eye.

<table>
<thead>
<tr>
<th>Item</th>
<th>Age means</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>12 month</td>
</tr>
<tr>
<td>WHC (^a)</td>
<td>24.3</td>
</tr>
</tbody>
</table>

\(^a\) WHC = ratio of total water area divided by meat area.

Table C16. The effect of age on proximate analysis (%) of beef loin-eye steak

<table>
<thead>
<tr>
<th>Item</th>
<th>Age means</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>12 month</td>
</tr>
<tr>
<td>Protein</td>
<td>20.9</td>
</tr>
<tr>
<td>Moisture</td>
<td>74.9</td>
</tr>
<tr>
<td>Fat</td>
<td>1.6</td>
</tr>
</tbody>
</table>
APPENDIX D. SOME WAYS TO IMPROVE TENDERNESS

1. Breed selection: meat from the Brahman breed has been shown to be tougher than that from British breeds; also there are strain variations within breed that increase meat tenderness. Selecting tender breed is important factor to obtain tender meat.

2. Sex: sex has some effects as bulls produce tougher meat than steers and heifers, but the differences are not noticeable until about 15 months of age.

3. Using growth promotants: B-agonists and combination of trenbolone acetate and estrogen have been used to increase growth rate through decreasing protein degradation increase in living animal. This reduction has some effect on meat tenderness in postmortem by decreasing activity of calpain enzymes and increase calpatistaten enzymes (inhibitor to calpain). One way to improve tenderness is by increasing calpain activity by using CaCl₂.

4. Connective tissue: total and soluble collagen have an effect on meat tenderness. Cooking at higher temperature above 80 °C, collagen will be soluble and the meat become more tender. Improve growth rate will end with low collagen and this end up to tender meat like in double muscled cattle.

5. Nutrition: Faster growing animals are less tender than normal animals. This is may be due to less enzymes activity during postmortem.
6. High plane nutrition increases meat tenderness and grain diet is more tender than grass diet. This is may be related to fat content. The flavor of the meat, however, is better for the grass diet.

7. Restricted feeding and maintenance feed will end to less tender meat, because intercellular decrease and collagen increase.

8. Feeding certain nutrient such as carotene and lysine will decrease hydroxyproline and this is related to collagen formation. Also ascorbic acid decreases collagen synthesis.

9. Treating animal before slaughter:
   - Injecting animal with adrenalin hormone before slaughter will decrease postmortem glycogen content, and this will increase pH and WHC, and improve meat tenderness.
   - Injecting papain, ficin and CaCl₂ before slaughter will improve meat tenderness by degrading myofibril and increase calpain activity and end to tenderness improvement.

10. Treating meat in postmortem to increase meat tenderness:
    - Marinating meat in acid solution
    - Injecting papain, ficin and CaCl
    - Pressure treatment to disrupt myofibril and release enzymes.

11. Optimize enzymes activity by controlling pH range of enzymes; calpain pH 6.0-8.5, cathepsine B.L pH 3-6.5, cathepsine D pH 2.5-4.5
12. Manipulation of protein regulation enzymes in living animals will have an effect on meat tenderness in postmortem.

- By increasing protein synthesis and degradation with greater rate in synthesis than the degradation will result may be to increase calpain activity in postmortem and improve meat tenderness. This will increase the energy demand to support this process.

- Feed and factors that have related to increase calpain and decrease calpatestaten can be given to the animal before slaughter to improve meat tenderness

13. Muscle structure:

- Factors that weaken the structural integrity of myofibril can be used before slaughter to improve meat tenderness
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