EFFECTS OF TIME-ON-FEED AND CARCASS GRADE TRAITS ON POSTMORTEM MUSCLE CHARACTERISTICS AND BEEF PALATABILITY

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NOMENCLATURE

adg	average daily gain
C	Celcius
cm	centimeters
d	days
df	degrees of freedom
g	grams
h	hour
kg	kilograms
m	milliliter
ml	millimeter
M	Molar
s	seconds

CHAPTER I

INTRODUCTION

Due to an expanding health conscious society, current consumer trends have shifted toward the consumption of leaner beef products. However, at the same time a certain segment of the population does not desire to sacrifice eating quality (Savell et al., 1987). Therefore, the ability to accurately predict beef palatability is of utmost concern and crucial for the assurance of consumer satisfaction.

In general, for beef producers to maximize their profit potential under the current quality grading system they must design their management and marketing procedures toward the production of "U. S. Choice" beef. Unfortunately, the marbling required to attain "U. S. Choice" is a late developing fat depot and, often times these production practices result in the overfattening of slaughter cattle. Additionally, studies have produced conflicting results concerning the ability of the current marbling-based quality grade system to accurately predict palatability (Parrish, 1974).

Recent studies have associated certain carcass, production, and postmortem muscle characteristics with the

enhancement and possible prediction of beef palatability. Time-on-feed (Zinn et al., 1970b; Tatum et al., 1980; Dolezal et al., 1982a), subcutaneous fat thickness (Dolezal et al., 1982b and Tatum et al., 1982), early postmortem muscle temperature (Lochner et al., 1980) and pH (Marsh et al., 1981) are singular traits which have been closely associated with beef palatability, particularly tenderness. Some of these traits have been suggested as possible adjuncts to the current quality grade system (Tatum et al., 1980; NCA, 1981; Allen, 1982; Dolezal et al., 1982b).

While these selected traits have been examined singularly, few attempts have been made to examine the interrelationships between the traits in a comprehensive study.

Therefore, this study was conducted to examine:

1) The interrelationships between time-on-feed, rate of gain, carcass weight, subcutaneous fat thickness, marbling score and beef palatability.
2) The effects of postmortem temperature and pH on longissimus muscle tenderness.

CHAPTER II

LITERATURE REVIEW

Measures Utilized to Determine USDA Quality Grades

The USDA quality grades for beef cattle attempt to predict differences in cooked beef palatability and provide to consumers a reliable guide for identifying beef quality levels (Smith, 1980). The USDA quality grading system for beef utilizes several subjective indicators to determine a carcass's quality grade. The indicators include skeletal maturity of the carcass, marbling, firmness, color, and texture of the lean (USDA, 1980). Research has produced conflicting results concerning the ability of quality grades to accurately predict palatability. Some studies have indicated a significant association between USDA quality grades and beef palatability (Jennings et al., 1978; Davis et al., 1979). However, other researchers have found that the quality grades provide little assurance of beef palatability (Berry et al., 1974; Campion et al., 1975; Dolezal et al., 1982b). Campion et al. (1975) concluded that quality grade indicators accounted for no more than 10 percent of the variation for any of the palatability traits as determined by sensory evaluation.

Maturity

Under the current USDA grading system, marbling and maturity have the most impact on determining the quality grades of beef carcasses. Numerous researchers have investigated the relationship between beef carcass physiological maturity and the palatability characteristics (Romans et al., 1965; Berry et al., 1974; Smith et al., 1982). These researchers found that as maturity increased, carcass palatability decreased, particularly tenderness. Smith et al. (1982) observed a significant relationship between palatability attributes and maturity when evaluated over the full range of maturity classes (A through E). However, maturity appears to have a minimal effect on tenderness within the youthful maturity groups (A and B) (Berry et al., 1974; Reagan et al., 1976; Davis et al., 1979; Smith et al., 1982).

The effect of maturity on palatability has been associated with the connective tissue component of meat. More specifically, the palatability variations due to changes in maturity have been related to the altering of the crosslinks of intramuscular collagen (Shimokomaki et al., 1972 and McClain, 1976). Shimokomaki et al. (1972) indicated that after cattle reach one year of age there is a decrease in the proportion of soluble intramuscular collagen. The relationship of collagen solubility and beef palatability tends to closely parallel the relationship

between physiological maturity and palatability (Cross et al., 1973; Reagan et al., 1976; Davis et al., 1979; Wu et al., 1981; Hall and Hunt, 1982). These studies suggest that maturity does not exert a large influence on palatability among youthful beef carcasses. Accordingly, maturity considerations for determining final quality grades among youthful beef carcasses have been reduced (USDA, 1975).

Marbling

Marbling has the most influence on determining the quality grades for youthful (less than 42 months of age) beef carcasses. This resulted from beliefs by animal scientists in the early 1900's (Tatum, 1981). These scientists noticed that beef cattle fed high energy diets produced fatter carcasses with higher amounts of intramuscular fat and more tender cuts of meat than forage fed cattle (Bull, 1916 and Armsby, 1917). Therefore, these scientists believed that the amount of marbling within muscle played an integral role in meat palatability. Bull (1916) stated that fattening of cattle caused the animal's lean quality to improve via the animal depositing fat between the muscle fibers. Because of this early assumption, intramuscular fat was incorporated into the first USDA quality grades in 1927. Tatum (1981) stated that these conclusions were based on practical observations not supported by experimental data. Consequently, numerous

studies have failed to strongly support the marbling-tenderness theory. Even though many studies have shown a positive correlation between marbling and tenderness, the correlation was low to moderate (Berry et al., 1974; Parrish, 1974; Campion et al., 1975; Tatum et al., 1980; Dolezal et al., 1982a). Furthermore, several studies have indicated that cattle similar in type, fed grain diets for a similar period of time differ little in tenderness despite a large variation in the amount of marbling (Campion et al., 1975; Adams et al., 1977; Harrison et al., 1978; Tatum et al., 1980; and Dolezal et al., 1982a). In a study by Crouse et al. (1978) marbling only accounted for three percent of the variation in taste panel tenderness and six percent of the variation in taste panel acceptance. These findings raise questions about the degree of emphasis placed on marbling as an indicator of beef carcass quality.

Production Traits Associated with Beef Palatability

Growth Rate

Aberle et al. (1981) indicated that the growth rate of cattle may influence certain intrinsic properties of postmortem muscle. Cattle fed high concentrate rations prior to slaughter grew rapidly, and subsequently, had rapid rates of protein degradation and synthesis (protein turnover). The increased protein turnover associated with

the rapid growing cattle produced beef with fewer heat-stable crosslinks, higher collagen solubility and more desirable tenderness values compared to the slower gaining treatment groups (Aberle et al., 1981; Wu et al., 1981; and Hall and Hunt, 1982).

Aberle et al. (1981) also suggested that changes in chilling rate may account for some of the variation in tenderness between treatment groups by enhancing proteolytic enzyme activity. The slower gaining, lighter weight carcasses had less subcutaneous fat covering and therefore, chilled at faster rates than the heavier, fatter carcasses in the faster gaining treatment groups. However, Fishell et al. (1985) observed that variations in beef tenderness associated with the changes in growth rate were not markedly influenced by chilling rate.

Time-on-Feed

Many researchers have investigated production effects and beef palatability. Zinn et al. (1970b) and Campion et al. (1975) observed an increased quality grade with increased time-on-feed. Recent studies have suggested that palatability improved with increased time on a high energy diet (Zinn et al., 1970b; Harrison et al., 1978; Dolezal et al., 1982a). McKeith et al. (1985) stated that longissimus muscle from Angus cattle fed a high energy diet for 56 to 112 days was "acceptable" in tenderness as indicated by sensory panel evaluation. Dolezal et al. (1982a) indicated

that yearling cattle intensively fed for at least 100 days were comparable in palatability regardless of quality grade. Other studies have shown that there is little additional improvement in palatability of steaks from cattle fed grain diets longer than 100 days (Tatum et al., 1980; Dolezal et al., 1982a; McKeith et al., 1985). In fact, Zinn et al. (1970b) pointed out that maturity may be detrimental to cooked beef palatability in cattle fed longer than 180 days. Tatum et al. (1980) suggested the possibility of incorporating feeding history into the current quality grading system. It appears, however, that the practical application of time-on-feed would be difficult to monitor in the current production and marketing system.

Carcass Characteristics Associated with Beef Palatability

Carcass Weight and Fatness

The feeding of high energy diets generally increases both carcass weight and fatness (Bowling et al., 1977; Bowling et al., 1978; Bidner et al., 1981; Dolezal et al., 1982a,b; Tatum et al., 1982; Bidner et al., 1986). Smith et al. (1976) compared lambs fed to three finishing endpoints for palatability differences. The study indicated that the fatter, more massive carcasses were superior in tenderness when compared to the thinner, lighter weight

carcasses. The authors attributed the changes in tenderness values to the insulatory effect of carcass fat which appeared to alter the postmortem chilling rate of the carcasses. Consequently, they suggested that improvements in tenderness may be attributed to enhanced autolytic enzyme activity. Similar results were shown for beef carcasses in a study by Bowling et al. (1977). This study compared palatability differences between grain-fed and grass-fed cattle. The grain finished, heavier, fatter carcasses produced more flavorful and tender steaks than the lighter weight carcasses from grass-fed cattle. These findings caused researchers to examine the possibility that carcasses at a constant weight or fatness may be comparable in palatability regardless of feeding regimen or quality grade.

Bidner et al. (1981,1986) compared palatability differences between steers fed diets that varied in energy level and were slaughtered at constant weights. Shear force measures indicated no difference in tenderness and a consumer sensory panel found no significant difference in palatability between the carcasses. Oltjen et al. (1971) also compared palatability traits of beef from forage-fed versus grain-fed steers slaughtered at similar weights. The forage-fed beef was superior in palatability to the grain-fed beef.

Crouse et al. (1984) examined grain versus grass-fed heifers slaughtered at the same 12th rib fat thickness

(9.6 mm). As anticipated, the heifers fed a forage diet required a longer period of time to reach the desired fat thickness than the grain finished heifers. However, no significant difference in tenderness occurred between the two groups as indicated by Warner-Bratzler shear force values and sensory panel evaluation.

Dolezal et al. (1982b) and Riley et al. (1983) determined that subcutaneous fat thickness has a higher association with tenderness and juiciness than marbling. Furthermore, Dolezal et al. (1982b) stated that palatability improved as the 12th rib subcutaneous fat thickness increased from 2.5 mm to 7.6 mm. Little improvement in palatability has been observed once carcasses attain a minimum of 7.6 mm of fat (Dolezal et al., 1982b; Tatum et al., 1982; Riley et al., 1983). Subcutaneous fat thickness of at least 7.6 mm (Bowling et al., 1977; Dolezal et al., 1982b; Tatum et al., 1982; Crouse et al., 1984) and carcass weights in excess of 227 kg (Schupp et al., 1979) appear to sufficiently insulate the carcass thus preventing the rapid decline of postmortem muscle temperature and cold-induced toughening. NCA (1981) and Allen (1982) suggested incorporating requirements for fat thickness and fat color into the grading standards. They suggested requiring carcasses to have at least 7.6 mm of white subcutaneous fat at the 12th rib.

The 12th rib fat thickness measures could easily be incorporated into the current quality grading standards

because the existing beef yield grades use the same fat thickness measure to predict carcass cutability (USDA, 1980). The fat thickness measure combined with the current quality grade indicators may predict meat palatability more accurately than the current quality grade standards (Dolezal et al., 1982b and Lee et al., 1986).

Postmortem Muscle Characteristics Associated with Tenderness

A study by Locker (1960) showed a close association between muscle shortening (or contraction) and meat tenderness. Marsh and Leet (1966) determined that decreasing muscle length up to 20 percent of the muscle's original excised length did not affect tenderness, however, muscle toughness increased rapidly with continued shortening up to 40 percent. Furthermore, shortening beyond 40 percent caused decreased toughening. Through the use of cow sternomandibularis muscle, Locker and Hagyard (1963) demonstrated the effect of temperature on muscle shortening. Minimal muscle shortening (less than 10 percent) occurred in the temperature range of 14-19 C while muscles exposed to 0 C shortened to 47.7 percent of their original length.

In light of these early studies, several researchers have examined the effect of altered chilling rate on meat tenderness (Davey and Gilbert, 1975; Locker et al., 1975; Moellar et al., 1976; Bowling et al., 1977; Lochner et al.,

1980; and Marsh et al., 1981). These studies associate the improvement in tenderness to the retardation of cold-induced toughening and(or) activation of endogenous proteolytic enzymes.

Current research has indicated that if muscle pH is not below approximately 6.0 before muscle temperature reaches 10-12 C (or lower), cold-induced shortening may result (Lochner et al., 1980). The basic myofibrillar unit of muscle contraction, the sarcomere, is commonly utilized to measure muscle shortening. While several studies have indicated a high correlation between sarcomere length and tenderness (Herring et al., 1965; Marsh and Leet, 1966; Gothard et al., 1966; Smith et al., 1971; Yu and Lee, 1986), other studies have found little or no relationship (Field et al., 1970; Lochner et al., 1980), particularly in well finished beef. Recent studies have suggested that the effect of muscle shortening on tenderness may be more obvious in rapidly chilled, light weight carcasses with little external fat. Lochner et al. (1980) examined the effect of carcass chilling rate on tenderness. Two groups of well finished, heavy weight carcasses (2.6 cm of subcutaneous fat) were chilled at different rates. The steaks from the slower chilled group received higher taste panel tenderness ratings than the faster chilled group. Histological examination revealed no difference in sarcomere length. Lochner et al. (1980) reported that early postmortem temperature (2 h) was most highly

correlated with tenderness values. Within well finished beef carcasses, cold-induced toughening does not appear to be the major factor in determining cooked beef tenderness.

Improvements in tenderness are also noticed in steaks from carcasses in which chilling was delayed early postmortem (Locker et al., 1975; Bowling et al., 1977; Lochner et al., 1980). Tenderness improvements in both situations may be attributed to endogenous proteolytic activity, such as calcium-activated factor (CAF) or lysozomal enzymes (Moellar et al., 1977; Koohmaraie et al., 1984; Yu and Lee 1986). These enzymes alter the myofibril to induce the improvement in tenderness. Several in vitro studies have indicated that both CAF and catheptic enzymes alter the myofibrillar proteins (Penny, 1974; Moellar et al., 1977; Bird and Schwartz, 1977; Koohmaraie et al., 1984).

CAF, an endogenous protease, requires calcium ions for activation. Currently, two forms of the enzyme have been isolated: millimolar CAF and micromolar CAF. The millimolar CAF requires 1-5 millimolar concentrations of calcium ions to be activated and is maximally active at pH 7.5 (Dayton et al., 1976). Micromolar CAF requires a considerably lower concentration of calcium ions for activation and while the maximal activity range occurs at pH 7.5 (Dayton et al., 1981) the enzyme has a broader pH activity than millimolar CAF. Both forms degrade the myofibril similarly as characterized by the disappearance

of the Z-line and the formation of a 30,000 Dalton unit, while leaving actin and myosin unaffected (Dayton et al., 1976; Koohmaraie et al., 1984; Koohmaraie et al., 1986; and Zeece et al., 1986b).

Studies have indicated that both forms could be responsible for changes in tenderness under postmortem muscle conditions (Koohmaraie et al., 1986; Zeece et al., 1986b). However, with low concentrations of calcium ions in postmortem muscle, micromolar CAF may be the major form causing the changes (Koohmaraie et al., 1986).

Catheptic enzymes are normally found in membrane compartments within a muscle (Bechtel, 1986). These enzymes appear to be maximally active in the pH range of 4.0 to 5.3 (Bird and Schwartz, 1977; Zeece et al., 1986a). The activity of these enzymes seems to diminish as the pH increases above 6.3. Under in vitro situations, the site of myofibrillar degradation may vary. However, catheptic enzymes apparently degrade both myosin and actin and cause the disappearance of the M-line (Bird and Schwartz, 1977; Bechtel, 1986).

Measurements such as pH are often used to detect changes in glycolytic activity of muscle after exsanguination (Bechtel, 1986). More specifically, pH reflects lactic acid accumulation (a byproduct of anaerobic glycolysis) within muscle tissue. Therefore, pH provides an approximation of metabolic activity within postmortem muscle. Wismer-Pederson (1959) determined that lactic acid

concentrations are highly correlated (r=.86) with muscle pH.

Currently, there are two commonly used methods for measuring pre-rigor muscle pH. One method is to homogenize a muscle sample in a solution containing iodoacetate. The other procedure directly measures the pH by the use of a puncture-tip electrode (Dutson, 1983a; Solomon, 1986). The rapid rate of glycolysis that occurs in pre-rigor muscle makes measuring pH difficult, particularly when membrane disruption occurs (Dutson, 1983a).

The rate of pH decline is influenced by temperature (Marsh, 1954: Cassens and Newbold, 1967). Cassens and Newbold (1967) determined with the use of sternomandibularis muscle that pH decreases more rapidly at higher temperatures when the temperature range is between 5-37 C. Furthermore, muscles within the same animal have different rates of pH decline (Bendall, 1978). In general, pH in normal beef muscle drops at the rate of .27-.40 units per hour (Bechtel, 1986).

The final pH of muscle that has achieved rigor mortis is termed the ultimate pH (Callow, 1937). The ultimate pH of muscle (approximately 5.4-5.5) is dependent on the glycogen supply in muscle prior to slaughter (Lawrie, 1979). Bouton et al. (1972,1973) determined that ultimate pH is related to muscle tenderness. When ultimate pH was 5.8 to 6.0, muscle tenderness values were lowest, whereas tenderness increased as pH values shifted from 6.0 (Bouton

et al., 1973). A recent study by Yu and Lee (1986) indicated similar results. In the later study, steaks from beef carcasses with high ultimate pH values (higher than 6.3) were the most tender, followed by low pH steaks (lower than 5.8) and then intermediate pH steaks (5.8-6.3).

Marsh (1983) stated that high early postmortem pH was related to tenderness. Yu and Lee (1986) found that high pH meat became tender within 24 h postmortem. These studies suggest that the combination of high muscle temperature and high muscle pH are related to improvements in tenderness. Histological examinations of the myofibril revealed the degradation of the Z-lines and formation of a 30,000 Dalton unit (Yu and Lee, 1986). In addition, the pH range under these conditions would allow CAF to maintain activity. Therefore, Koohmaraie et al. (1986) suggested that the mechanism involved for improving tenderness in this situation can be attributed to CAF or other neutral proteases.

Dutson (1983b), indicated that meat with low pH values during early postmortem resulted in tender meat. In the study by Yu and Lee (1986), low pH meat improved in tenderness with increased aging (1-7 days). The low pH meat had myosin and actin partially degraded. With the low pH values and the degradation of the contractile proteins, the authors contributed the improved tenderness to the lysozomal enzymes.

Intermediate pH meat appears to fall in the pH range in which enzymatic activity is low. Therefore, steaks within this range tend to be toughest (Yu and Lee, 1986).

This review of literature has indicated that there are several carcass, production, and postmortem muscle traits which affect palatability, particularly tenderness. The practical implication of how these traits, or combination of traits, could be utilized to predict palatability is quite challenging. Inferences have been made concerning the singular effects of each trait on palatability, but a study appears to be warranted to examine the interrelationship between these traits with palatability.

CHAPTER III

MATERIALS AND METHODS

Forty-eight Angus X Hereford crossbred steers approximately 16 months of age with similar frame size (medium) and muscle thickness (No. 1) (USDA, 1979) were obtained from a native range stocker operation in northwestern Oklahoma. Care was taken to control age, breed-type, and environmental background.

After an initial 24 h shrink, individual live weights were obtained and the steers were ranked by weight. The steers were then allotted into 16 groups (n=3) with all groups having similar mean live weights. The groups were assigned to one of eight slaughter periods to be serially slaughtered at 28 day (d) intervals (0-196 d). Two replications were performed to facilitate postmortem data collection. All steers were wormed, implanted with Compudose, and fed a high concentrate finishing ration (87.50% dry matter, 83.76 Mcal/kg NEm, 54.11 Mcal/kg NEg) except for the 0 day slaughter period which served as a grass-fed control.

At the end of each feeding period, a live weight was obtained for each steer and a four percent adjustment was

utilized to determine shrunk live weight. The performance data were calculated by utilizing the shrunk live weight.

All steers were conventionally slaughtered at the Oklahoma State University Meat Laboratory. Within 30 minutes postmortem, one randomly assigned side of each carcass was trimmed of subcutaneous fat over the wholesale rib region (5-13th ribs). An equal number of left and right sides were trimmed per slaughter period. All carcasses were then conventionally chilled at 1 $\pm$ 1 C. Longissimus muscle pH and temperature were monitored intermittently for 24 hours (.5, .75, 1, 1.25, 1.5, 2, 2.5, 3, 3.5, 4, 4.5, 5, 6, 12, 18, 24 h). Longissimus muscle temperature was monitored by an Omega temperature logger (Om 302-10) equipped with copper constantan probes. The longissimus muscle pH was measured with portable pH meters (Fisher Accumet mini pH meter, Model 640 A) equipped with colomel combination puncture-tip electrodes. All probes were inserted 4.5-5.5 cm (depending upon diameter) into the medial portion of the longissimus muscle and left inserted for the entire 24 h chilling period. The temperature probe was placed immediately anterior to the ninth rib while the pH electrode was inserted posterior to the ninth rib.

Twenty-four hour (post-rigor) muscle pH was also determined by a Corning 130 pH meter. A 5 g sample was excised from the center of the longissimus muscle adjacent to the 13th rib. The sample was homogenized in 50 ml of deionized distilled water for 30 s. The measurement was

taken after the sample was well mixed, and the pH meter had equilibrated (60 s).

Approximately 24 hours postmortem, both sides of each carcass were ribbed (12-13th rib). Three experienced evaluators scored or measured the traits necessary to determine USDA yield and quality grades (USDA, 1980). Only the traits from the control sides were utilized to calculate the yield and quality grades. Longissimus muscle area and marbling scores, along with scores for longissimus muscle lean (table I) and marbling (table II) characteristics were obtained for sides in both treatment groups.

The wholesale rib was fabricated and the ribeye roll (IMPS 112) was removed from each side for chemical, organoleptic, and histological analysis. A .64 cm slice was removed from the posterior end of the longissimus muscle and trimmed of subcutaneous fat and epimysial connective tissue. The sample was mixed by a Sorvell omni mixer and analyzed for intramuscular fat (ether extract) and moisture by AOAC (1975) procedures.

A 15 cm section corresponding to the 8-9-10-11th rib section was vacuum packaged and aged for 7 days at 2 $\pm$ 1 C. After the aging period, two 2.54 cm thick steaks corresponding to the eighth and ninth ribs were fabricated, vacuum packaged, and frozen at -20 C for subsequent taste panel and Instron shear force determinations. Upon completion of the slaughter phase of the study, the steaks were randomized for evaluation. Prior to cooking, the

TABLE I

SCORING FOR EVALUATING LONGISSIMUS MUSCLE LEAN QUALITY (12-13TH RIB)

	Longissimus muscle characteristic			
Score	Color	Firmness	Texture	Heat ring
8	Light grayish-red or pink	Very firm	Very fine	
7	Very light cherry red	Firm	Fine	
6	Cherry red	Moderately firm	Moderately fine	
5	Slightly dark red	Slightly firm	Slightly fine	None
4	Moderately dark red	Slightly soft	Slightly coarse	Slight
3	Dark red	Moderately soft	Moderately coarse	Small
2	Very dark red	Soft	Coarse	Moderate
1	Black	Very soft	Very coarse	Severe

TABLE II

SCORING SYSTEM FOR EVALUATING MARBLING CHARACTERISTICS (12-13 RIB)

	Marbling characteristic	
Score	Distribution	Texture
8	Very uniform	Very fine
7	Uniform	Fine
6	Moderately uniform	Moderately fine
5	Slightly uniform	Slightly fine
4	Slightly uneven	Slightly coarse
3	Moderately uneven	Moderately coarse
2	Uneven	Coarse
1	Very uneven	Very coarse

steaks were thawed for 24 h in a 4 C cooler. Each steak was then broiled to an internal temperature of 70 C on a Farberware Open-Hearth broiler. Immediately after cooking, the longissimus muscle from the ninth rib steak was sectioned into 1.27 cm X 1.27 cm X 2.54 cm samples for sensory evaluation. An eight-member sensory panel, trained according to American Meat Science Association (AMSA) guidelines for cooking and sensory evaluation of meat (AMSA, 1978), evaluated the ninth rib steak samples for juiciness, overall tenderness, ease of fragmentation, flavor intensity, and amount of connective tissue. The palatability traits were scored utilizing eight point descriptive scales (table III). Instron shear force determination for each eighth rib steak was performed on six 1.27 cm cores which were removed after the cooked steaks had cooled to room temperature (23 C).

A 2.54 cm steak corresponding to the seventh rib was utilized for fiber diameter and sarcomere length measurements. A six gram sample was excised from the center of the longissimus muscle. Sarcomere length was determined by utilizing five grams of the muscle sample homogenized with 30 ml of .25 M sucrose solution. The sarcomeres were measured by the use of phase contrast microscopy according to the procedure outlined by Cross et al. (1981). The remaining one gram sample was used for muscle fiber diameter determination. The sample was fixed in a ten percent buffered formalin solution for a minimum

TABLE III

DESCRIPTIVE SCORING SYSTEM FOR SENSORY EVALUATION

	Palatability trait				
Score	Juiciness	Tenderness	Ease of fragmentation	Flavor intensity	Connective tissue amount
8	Extremely juicy	Extremely tender	Extremely easy	Extremely intense	None
7	Very juicy	Very tender	Very easy	Very intense	Practically none
6	Moderately juicy	Moderately tender	Moderately easy	Moderately intense	Traces
5	Slightly juicy	Slightly tender	Slightly easy	Slightly intense	Slight
4	Slightly dry	Slightly tough	Slightly difficult	Slightly bland	Moderate
3	Moderately dry	Moderately tough	Moderately difficult	Moderately bland	Slightly Abundant
2	Very dry	Very tough	Very difficult	Very bland	Moderately Abundant
1	Extremely dry	Extremely tough	Extremely difficult	Extremely bland	Abundant

of 48 h at 4 C. The sample was then placed in 20 ml of fresh formalin and mixed for one minute in a Waring blender equipped with reversed blades to separate the individual muscle fibers. Two subsamples of 25 fibers were measured by a light microscope equipped with an ocular micrometer.

Data were analyzed by a split plot analysis of variance (table IV). Days-fed tests of significance (F-tests) for each variable were computed utilizing the mean square for days-fed within steer as the appropriate error term. Orthogonal polynomials were used to determine trends for individual traits across days-fed for each treatment (n=48), as well as for the pooled data (n=96). Means were separated by Tukey's w procedure (Steel and Torrie, 1980). Dummy variable regression was used to compare rates of decline across days-fed for both longissimus muscle temperature and pH (Weisberg, 1980). Appropriate days-fed based regression equations and simple correlations were determined for carcass and postmortem traits. Path coefficients (standard partial regression coefficients) were computed to allow direct comparisons of traits that interrelate to influence tenderness (Wright, 1934).

TABLE IV

EXPERIMENTAL MODEL

Source	Degrees of freedom
Days-fed (D)	7
b_1 (days-fed)	1
b_2 (days-fed)^2	1
Steer (days-fed)	40
Treatment (T)	1
T X D	7
Error	40

CHAPTER IV

RESULTS AND DISCUSSION

Production Traits

The production traits are presented in table V. Slaughter weight and dressing percentage increased linearly ($P<.01$) across days-fed. Except for the 28-d slaughter group, growth rate (ADG) did not ($P>.05$) differ between the slaughter groups. The steers in the 28-d group may have experienced a compensatory response as a result of being placed on the grain-based diet.

Carcass Characteristics

Extending the time cattle receive a high concentrate diet increases subcutaneous fat thickness (Harrison et al., 1978; Tatum et al., 1980; Dolezal et al., 1982a), carcass weight (Zinn et al., 1970a; Dolezal et al., 1982a), yield grade (Schroeder et al., 1980; Tatum et al., 1980) and marbling score (Campion et al., 1975; Dolezal et al., 1982a). In this study carcass weight, as well as most weight related traits (fat thickness, longissimus muscle area, and yield grade) increased linearly ($P<.01$) over the 196-d finishing period (table VI). Maturity score also increased linearly ($P<.01$) with increased days-fed;

TABLE V

MEAN VALUES FOR PRODUCTION TRAITS

Days-fed	Slaughter weight, kg	Dressing percentage, %	Average daily gain, kg
0	345.9^{g}	56.8^{c}	-
28	430.6^{f}	57.3^{c}	2.33^{a}
56	449.8^{ef}	61.1^{b}	1.52^{b}
84	501.2^{de}	61.6^{b}	1.59^{b}
112	527.7^{cd}	64.6^{a}	1.46^{b}
140	567.0^{bc}	64.8^{a}	1.40^{b}
168	587.4^{b}	64.6^{a}	1.27^{b}
196	648.6^{a}	67.0^{a}	1.41^{b}
Standard error	2.3	.1	.2

^{a,b,c,d,e,f,g}Means in the same column bearing a common superscript do not differ ($P>.05$).

TABLE VI

MEAN SQUARES FOR CARCASS GRADE TRAITS

Source	df	Overall maturity	Marbling score	Fat thickness, mm	Ribeye area, cm^2	Carcass weight, kg	KPH, %	Yield grade
Days-fed	7	736.9**	43092**	2.655**	539.1**	31864**	1.642**	5.53**
b_1(Days-fed)	1	4547.5**	262224**	18.271**	3446.4**	220549**	10.241**	37.91**
b_2(Days-fed)^2	1	25.8	18462*	.005	52.6	153	.856**	0.17
Error	40	75.5	2746	.058	47.1	491	.081	0.19

*P <.05
**P <.01

however, the maturity scores for the individual slaughter periods remained well within "A" maturity (table VII). Marbling score and kidney, pelvic, and heart fat showed quadratic trends ($P<.05$) across days-fed and means for these traits showed no ($P>.05$) increase after intensive feeding for 112-d. The carcasses from steers fed 112-d were the first to attain the necessary mean marbling score (Small) required for "U.S. Choice" quality.

Palatability Attributes

Feeding cattle grain based diets improves tenderness over cattle fed forage diets (Bowling et al., 1977; Dolezal et al., 1982a). This study revealed that feeding a high concentrate diet for 0 through 84-d improved taste panel tenderness scores. However, beyond 84-d additional feeding did little ($P>.05$) to enhance the tenderness scores (table VIII). Shear force and ease of fragmentation showed little ($P>.05$) improvement after 56-d. Dolezal et al., (1982a) suggested that taste panel tenderness improves with increased time-on-feed up to 100-d. Additionally, studies have concluded that extending the feeding period beyond 100-d will not substantially improve sensory tenderness (Tatum et al., 1980; Dolezal et al., 1982a). However, it is important to note that these studies utilized a variety of breed-types which may partially explain the extended time. McKeith et al. (1985) found that longissimus muscle

TABLE VII

MEAN VALUES FOR CARCASS CHARACTERISTICS ACROSS DAYS-FED

Days-fed	Maturity score[a]	Marbling score[b]	Fat thickness, mm	Longissimus muscle area, cm^2	Carcass weight, kg	KPH,%	Yield grade
0	137.2^{d}	254.2^{g}	3.05^{f}	63.3^{f}	196.6^{h}	1.0^{f}	1.4^{g}
28	133.0^{d}	299.0^{fg}	4.11^{f}	69.8^{ef}	236.7^{gh}	1.3^{ef}	1.7^{fg}
56	139.0^{d}	336.0^{efg}	6.82^{ef}	78.6^{de}	263.7^{fg}	1.5^{e}	1.7^{fg}
84	147.0^{cd}	372.8^{def}	9.78^{e}	76.3^{de}	295.8^{ef}	1.8^{de}	2.4^{ef}
112	156.7^{c}	472.2^{c}	14.60^{d}	82.8^{cd}	327.2^{de}	2.1^{cd}	2.9^{e}
140	158.0^{c}	428.3^{cde}	15.03^{d}	85.7^{cd}	353.0^{d}	2.4^{c}	3.2^{de}
168	156.5^{c}	471.7^{c}	18.20^{cd}	84.5^{cd}	364.7^{d}	2.3^{c}	3.7^{cd}
196	161.8^{c}	464.2^{cd}	21.08^{c}	93.2^{c}	417.4^{c}	2.2^{cd}	4.0^{c}
Standard error	3.6	21.4	.10	2.8	9.1	.1	.2

[a]Maturity score: 100-199 = A.

[b]Marbling score: 200-299 = traces; 300-399 = slight; 400-499 = small.

[c,d,e,f,g,h]Means in the same column bearing a common superscript do not differ ($P > .05$).

TABLE VIII

MEAN VALUES FOR PALATABILITY ATTRIBUTES BY DAYS-FED AND TREATMENT

Item	Juiciness[a]	Ease of fragmentation[a]	Connective tissue[a]	Flavor intensity[a]	Tenderness[a]	Shear force, kg
Days-fed						
0	4.74	3.66^{g}	5.02^{f}	4.61	3.52^{e}	8.23^{f}
28	4.95	4.46^{fg}	5.51^{ef}	4.93	4.20^{e}	6.68^{e}
56	4.96	5.59^{cde}	6.12^{cde}	4.83	5.34^{d}	5.06^{cd}
84	5.13	6.11^{cde}	6.43^{cd}	4.81	5.88^{cd}	4.37^{cd}
112	5.49	6.41^{c}	6.66^{c}	5.04	6.36^{c}	3.81^{c}
140	4.86	5.48^{de}	6.02^{cde}	4.94	5.53^{cd}	4.64^{cd}
168	5.46	6.39^{cd}	6.34^{cd}	5.03	6.36^{c}	4.26^{cd}
196	4.81	5.27^{ef}	5.84^{de}	4.98	5.33^{d}	5.38^{de}
Treatment						
Control	5.09^{c}	5.65^{c}	6.14^{c}	4.94^{c}	5.59^{c}	5.16^{c}
Trimmed	5.02^{c}	5.19^{d}	5.84^{d}	4.85^{c}	5.04^{d}	5.44^{c}
Residual SD[b]	.65	.71	.53	.34	.73	1.15

[a]Juiciness: 1 = extremely dry to 8 = extremely juicy; ease of fragmentation: 1 = extremely difficult to 8 = extremely easy; flavor intensity: 1 = extremely bland to 8 = extremely intense; amount of connective tissue: 1 = abundant to 8 = none; tenderness: 1 = extremely tough to 8 = extremely tender.

[b]Standard errors can be calculated as $1/\sqrt{n}$ X standard deviation for a trait; n = 12 for days-fed means and n = 48 for treatment means.

^{c,d,e,f,g}Means in the same column and within the same item bearing a common superscript do not differ ($P>.05$).

steaks from Angus steers were acceptable in sensory tenderness between 56 and 112 days of feeding.

Taste panel tenderness, amount of perceived connective tissue, and shear force values were less desirable ($P<.05$) for the 196-d slaughter period than the 112-d slaughter period. This decrease in tenderness value may be maturity related. Zinn et al. (1970b) utilizing Hereford cattle indicated that maturity may influence tenderness in cattle fed longer than 180-d. Conversely, others have shown no apparent detrimental effects in extending the feeding period longer than 200-d (Bidner et al., 1981; Dolezal et al.,1982a). However, important cattle age/weight differences at the onset of feeding must be considered. Bidner et al. (1981) fed steers a forage diet supplemented with grain for up to 300-d but, these steers had considerably lighter ontest weights than the slaughter weights of the 0-d steers utilized in the present study. In the study conducted by Dolezal et al.(1982a), calves were used for the extended feeding groups as compared to yearling steers in the present study.

Juiciness and flavor intensity were not significantly influenced by extending the feeding of high concentrates. Other studies have indicated similar results. Bowling et al. (1977) and Bidner et al. (1981) indicated that the feeding of grain diets did not affect juiciness or flavor intensity. Tatum et al. (1980) also noted that juiciness

did not significantly increase by extending the feeding period (100-160 d).

Postmortem Muscle Characteristics

Marsh et al. (1981) stated that early postmortem pH (3 h) influenced tenderness. In this study the monitoring of pH decline by the use of portable meters equipped with puncture-tip electrodes produced unsatisfactory results. The meters were standardized at 15 C and pH 6.0, and were left inserted for the entire 24 h chilling period in an attempt to reduce the excitatory response which may be generated by probe reinsertion (Dutson, 1983a). The lower than normal readings obtained may have resulted due to the effect of the cooler temperature and single standardization of the pH meters or the clogging of the pH electrode with debris. Accordingly, only 24 h (post-rigor) laboratory pH readings were used for analysis.

The 24 h pH tended to be higher for the steers within the early slaughter groups (table IX). Carcasses from the 0-d steers had higher ($P<.05$) 24 h pH values than carcasses from steers fed the high energy diet for at least 112-d. Bowling et al. (1977) indicated that grass-fed steers had higher ultimate pH values than grain-fed steers and suggested that grass-fed cattle tend to be more susceptible to pre-slaughter stress which could result in higher pH values.

TABLE IX

MEANS VALUES FOR POSTMORTEM MUSCLE CHARACTERISTICS

Item	Temperature at 2.5 h, C	24 h pH	Sarcomere length, μm	Fiber diameter, μm
Days-fed				
0	25.8^{g}	5.78^{b}	1.73^{d}	62.4^{e}
28	28.2^{f}	5.71^{bc}	1.89^{b}	61.8^{e}
56	30.2^{de}	5.75^{bc}	1.87^{bc}	63.0^{de}
84	31.9^{de}	5.69^{cd}	1.91^{b}	62.4^{e}
112	34.3^{c}	5.61^{d}	1.80^{cd}	67.4^{cd}
140	33.7^{cd}	5.52^{e}	1.84^{bc}	67.6^{c}
168	33.8^{cd}	5.53^{e}	1.85^{bc}	79.7^{b}
196	36.8^{b}	5.53^{e}	1.91^{b}	76.3^{b}
Treatment				
Control	33.0^{b}	5.61^{c}	1.87^{b}	67.9^{b}
Trimmed	30.6^{c}	5.67^{b}	1.83^{c}	67.2^{b}
Residual SD[a]	1.5	.06	.06	.34

[a]Standard errors can be calculated as $1/\sqrt{n}$ X standard deviation for a trait; n = 12 for days-fed means and n = 48 for treatment means.

[b,c,d,e,f,g]Means in the same column and within the same item bearing a common superscript do not differ (P>.05).

The rate of temperature decline among time-based slaughter groups for days-fed are illustrated in figure 1. The mean longissimus muscle temperature at .5 h postmortem (the initial measurement) did not differ (P>.05) among days-fed groups. Steers in the early slaughter periods (0-56) chilled at similar rates (P>.05). In addition, the 112-d and 140-d slaughter periods showed similar (P>.05) rates of decline. The overall trend reflected that carcasses from steers fed for longer periods of time tended to chill more slowly than carcasses from steers in the earlier slaughter periods.

These results imply that carcass fatness and mass altered the chilling rate between slaughter groups. Smith et al. (1976) demonstrated with lamb carcasses which varied in the degree of finish that carcass fatness acted as an insulatory agent and slowed the rate of temperature decline. Similarly, Bowling et al. (1977) indicated that heavier, fatter beef carcasses chilled more slowly and produced more tender steaks than lighter weight carcasses.

Simple correlation coefficients (table X) indicated a high positive correlation between 2.5 h postmortem longissimus muscle temperature and carcass weight, fat thickness and days-fed. The 2.5 h temperature was the trait most highly correlated with tenderness. This is in agreement with Lochner et al. (1980). The authors concluded that muscle temperature was most highly correlated with tenderness early postmortem (2-4 h). Taste panel tenderness and

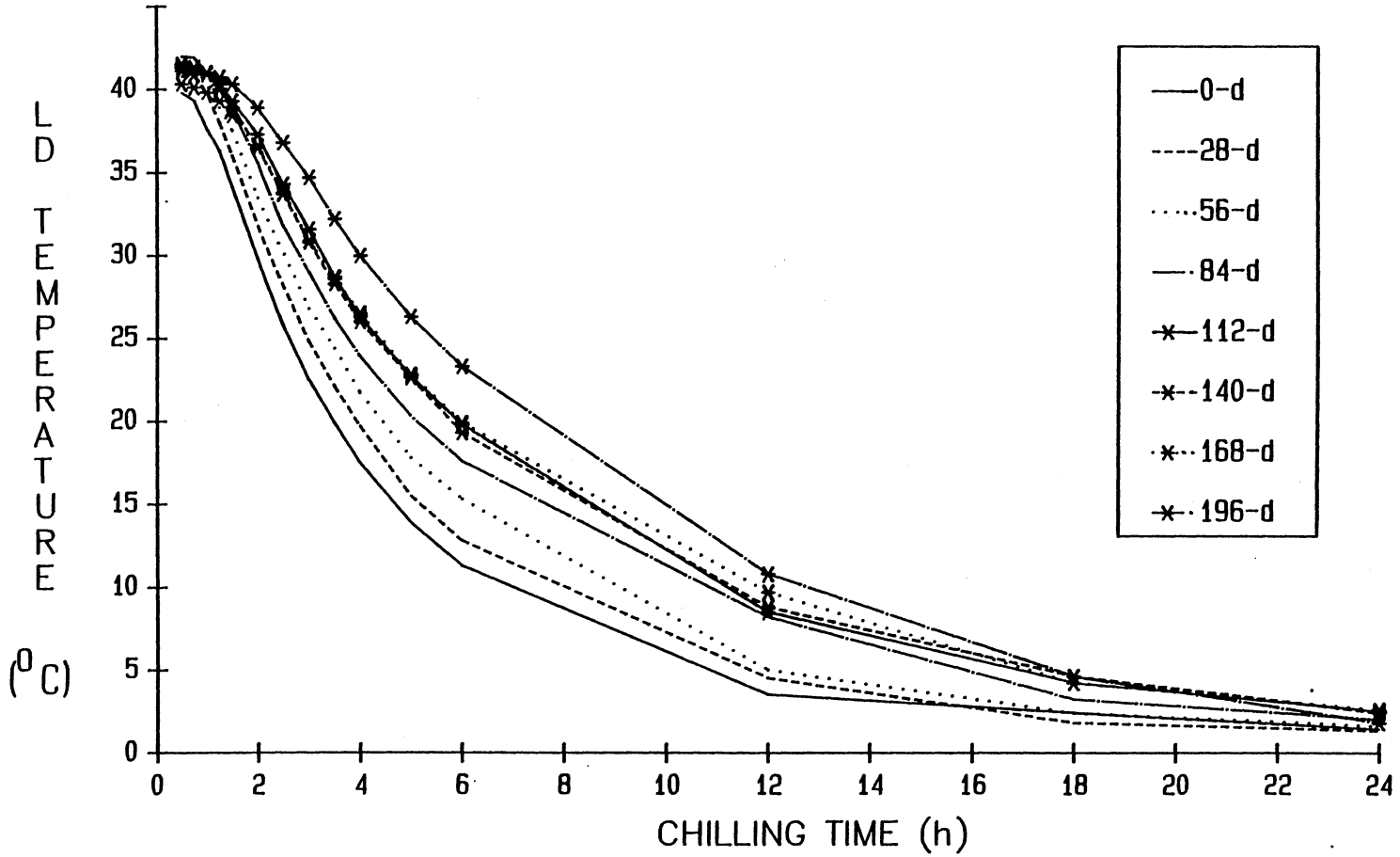

Figure 1. Longissimus Muscle Temperature for Pooled Treatment Groups Versus Chilling Time Across Days-fed

TABLE X

SIMPLE CORRELATION COEFFICIENTS FOR CONTROL SIDES[a]

Item	Shear force	Tender-ness	Flavor	Connective tissue	Fragmen-tation	Juici-ness	24 h pH	Temp. 2.5 h	Fiber dia.	Sarco-mere length	Ave daily gain	Marb-ling score	LD area	Fat thick-ness	Car-cass weight	Days-Fed
Days-fed	-.56**	.48**	.29*	.23	.45**	.13	-.76**	.86**	.74**	.31*	-.63**	.80**	.78**	.94**	.95**	-
Carcass weight, kg	-.53**	.46**	.26	.22	.42**	.10	-.75**	.86**	.73**	.31*	-.56**	.79**	.84**	.90**	-	
Fat thick-ness, mm	-.55**	.45**	.30*	.20	.42**	.15	-.73**	.80**	.70**	.21	-.55**	.81**	.70**	-		
LD area, cm^2	-.48**	.37*	.20	.22	.36*	.14	-.68**	.75**	.66**	.27	-.56**	.59**	-			
Marbling score	-.61**	.51**	.34*	.28	.48**	.31*	-.60**	.77**	.60**	.18	-.49**	-				
Average daily gain, kg	.55**	-.39*	-.07	-.22	-.35*	-.09	-.44**	-.58**	-.41**	.11	-					
Sarcomere length, µm	-.34*	.25	.26	.09	.29*	-.08	-.12**	.28	.15	-						
Fiber dia-meter, m	-.36*	.21	.20	.04	.20	.15	-.55**	.64**	-							
Temperature 2.5 h, C	-.63**	.54**	.25	.37**	.52**	.22	-.68**	-								
24 h pH	.49**	-.42**	-.09	-.18	-.37**	.04	-									
Juiciness	-.14	.20	.12	.20	.20	-										
Ease of frag-mentation	-.82**	.96**	.11	.76**	-											
Connective tissue	-.67**	.73**	.13	-												
Flavor intensity	-.25	.09	-													
Tenderness	-.82**	-														
Shear force, kg	-															

[a] n = 48 (except for average daily gain; n = 42)
*P<.05
**P<.01

2.5 h longissimus muscle temperature are shown in figure 2. Taste panel tenderness and 2.5 h longissimus muscle temperature follow similar trends through the 168-d slaughter period.

Several studies have investigated the effect of altering carcass chilling rate and its subsequent relationship with tenderness (Moellar et al., 1976; Smith et al., 1976; Bowling et al., 1977; Lochner et al., 1980). These studies have attributed the changes in tenderness to either cold-induced toughening or endogenous proteolytic enzyme activity.

Few differences existed between slaughter periods for sarcomere length. However, sarcomeres measured for carcasses from the 0-d steers were shorter ($P<.05$) than all other slaughter groups, except for the 112-d group (table IX). The lack of finish and light carcass weight may have contributed to the shortening of the sarcomeres in the 0-d cattle. Lee and Ashmore (1985) suggested that cold induced toughening is primarily a factor only in rapid chilled, light weight carcasses and has little effect in well finished beef carcasses. Sarcomere length was not significantly related to taste panel tenderness and possessed a low correlation coefficient with shear force (table X).

Herring et al. (1965) indicated that fiber diameter was highly correlated ($r=.73$) to shear force. In this study fiber diameter tended to increase with advanced intensive feeding and increased weights, and was highly

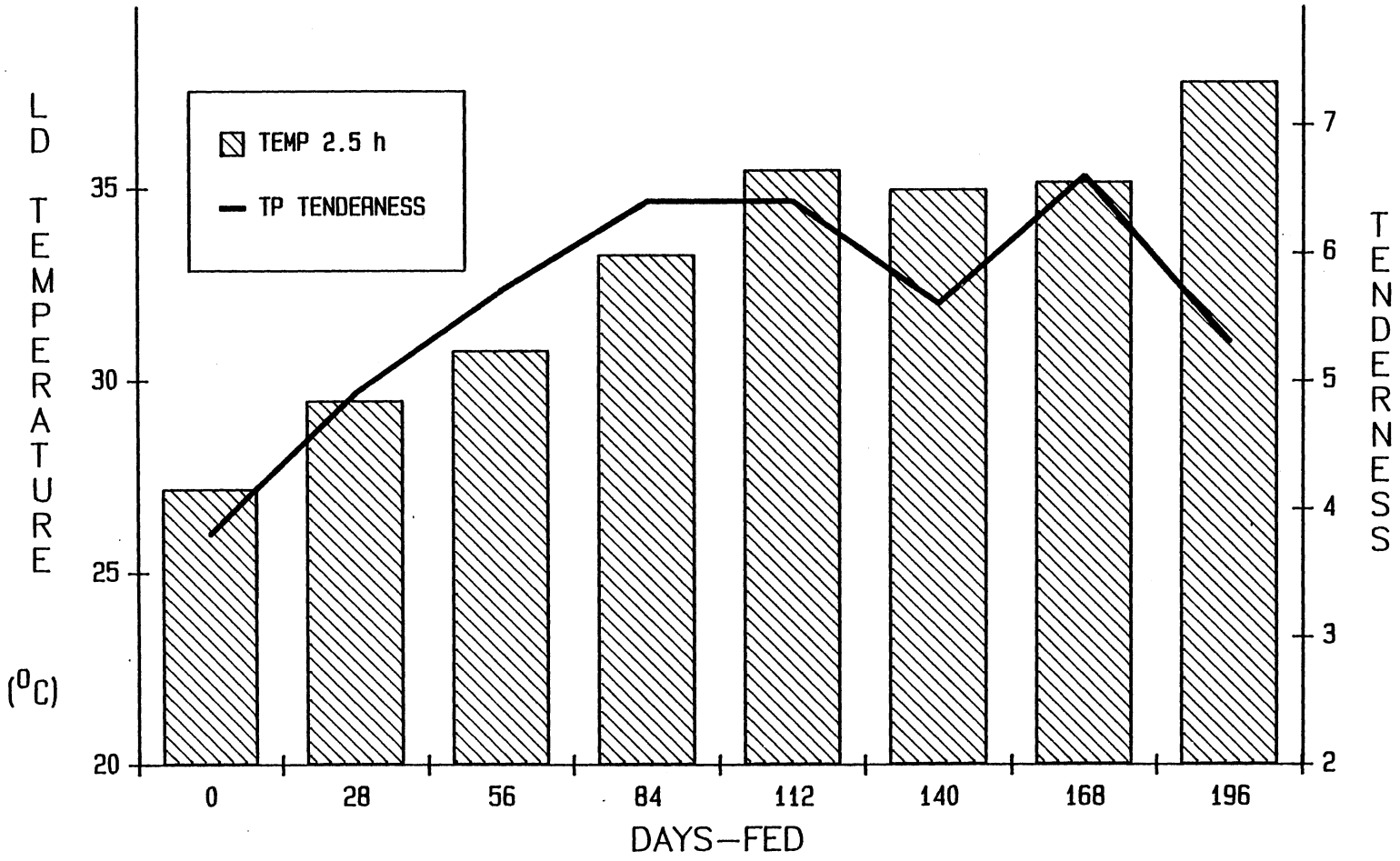

Figure 2. Longissimus Muscle Temperature and Taste Panel Tenderness Values Across Days-fed

correlated with both traits. However, fiber diameter was lowly related to shear force (r=-.36) and was not significantly related to taste panel tenderness. Tuma et al. (1962) concluded that within a narrow age group the ability of fiber diameter to measure tenderness is questionable.

Treatment Effects

Trimming of subcutaneous fat over the wholesale rib section was conducted to examine the effect of fat thickness, independent of production and carcass characteristics, on postmortem muscle traits and palatability attributes. While marbling score was not significantly different, control (untrimmed) sides had larger ($P<.05$) longissimus muscle areas than trimmed sides (table XI). Possibly, natural physical restraints on the longissimus muscle may have been severed due to the removal of the subcutaneous fat on the trimmed sides.

Studies have indicated that cattle reared under different feeding regimens slaughtered at a constant weight (Bidner et al., 1981; Bidner et al., 1986) or a constant fat thickness of .96 cm (Crouse et al., 1984) produced steaks with no significant difference in tenderness rating. The possibility exists that these carcass traits are influencing the rate of temperature decline and subsequently the tenderness of the steaks. In this study, there was a treatment effect for the rate of temperature decline

TABLE XI

MEAN VALUES FOR MARBLING SCORE AND LONGISSIMUS MUSCLE AREA BY DAYS-FED AND TREATMENT

Item	Marbling score[a]	Longissimus muscle area, cm^2
Days-fed		
0	248.6^{h}	62.6^{h}
28	298.1^{g}	69.4^{g}
56	340.8^{f}	76.8^{ef}
84	373.3^{e}	75.0^{f}
112	472.8^{c}	80.5^{de}
140	442.5^{d}	84.0^{d}
168	482.1^{c}	83.4^{d}
196	467.1^{c}	93.5^{c}
Treatment		
Control	387.3^{c}	79.3^{c}
Trimmed	394.0^{c}	77.0^{d}
Residual SD[b]	17.8	3.1

[a]Marbling score: 200-299 = traces; 300-399 = slight; 400-499 = small.

[b]Standard errors can be calculated as $1/\sqrt{n}$ X standard deviation for a trait; n = 12 for days-fed means and n = 48 for treatment means.

[c,d,e,f,g,h]Means in the same column and within the same item bearing a common superscript do not differ ($P>.05$).

(figure 3). Trimmed sides chilled at a faster rate ($P<.05$) than control sides, exemplifing the insulatory effect of subcutaneous fat. Temperature at 2.5 h for control sides was higher ($P<.05$) than for trimmed sides.

Sensory evaluation revealed that juiciness and flavor intensity were not ($P>.05$) affected by the trimming of subcutaneous fat. However, steaks from the trimmed sides were less tender ($P<.05$) and more difficult to fragment ($P<.05$) than the steaks from the control sides. The latter indicates muscle temperature was playing a role in tenderness determination.

Histological examinations revealed that control sides had longer ($P<.05$) sarcomeres than the trimmed sides, suggesting the possibility of cold-induced toughening. Lochner et al., (1980) indicated that in well finished beef that sarcomere length did not account for tenderness variations. Similarly, in the present study it appears cold-induced toughening does not account for much of the variation in taste panel tenderness as indicated by the lack of significance between taste panel tenderness and sarcomere length. With a moderate relationship between tenderness and 2.5 h temperature, apparently the enhancement of early postmortem temperature is stimulating other intrinsic means of tenderization.

The longissimus muscle from the control sides had lower ($P<.05$) 24 h pH values than trimmed sides (table IX).

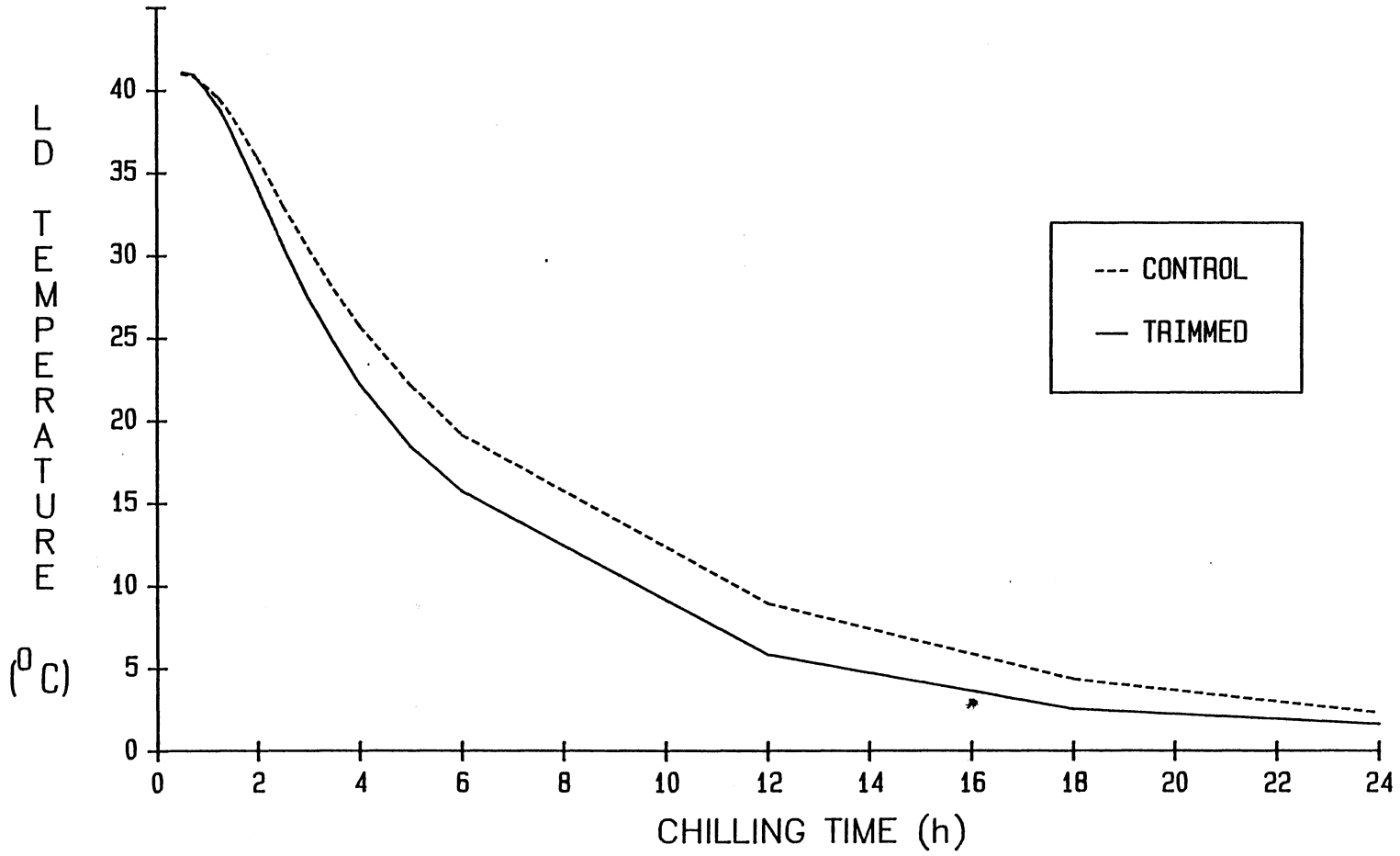

Figure 3. Longissimus Muscle Temperature Versus Chilling Time for the Treatment Groups

However, the difference was low in magnitude so the practical importance is questionable.

The trimming of subcutaneous fat also caused adverse effects on lean characteristics (not shown in tabular form). The longissimus muscle in the trimmed sides was darker in color ($P<.05$) and coarser in texture ($P<.05$) than control sides. These results are similar to data for light weight, forage fed carcasses that have little external fat covering (Bowling et al., 1977).

The only significant days-fed X treatment interaction in this study occurred for longissimus muscle heat ring (figure 4). Heat ring occurs most often in carcass with little external fat covering (Savell et al., 1978). Aside from the carcasses for 0-d steers, control sides showed little evidence of heat ring and did not ($P>.05$) differ in severity of heat ring over the 196-d feeding period. Conversely, trimmed sides were more variable and tended to be more susceptible to heat ring among steers fed 28-140 days. It is of interest to note that the interaction involved the 0-d steers where control sides showed greater severity of heat ring than trimmed sides. It is possible that the trimming of the subcutaneous fat enhanced glycolytic activity and caused more rapid rigor onset in the trimmed sides resulting in less severe heat ring.

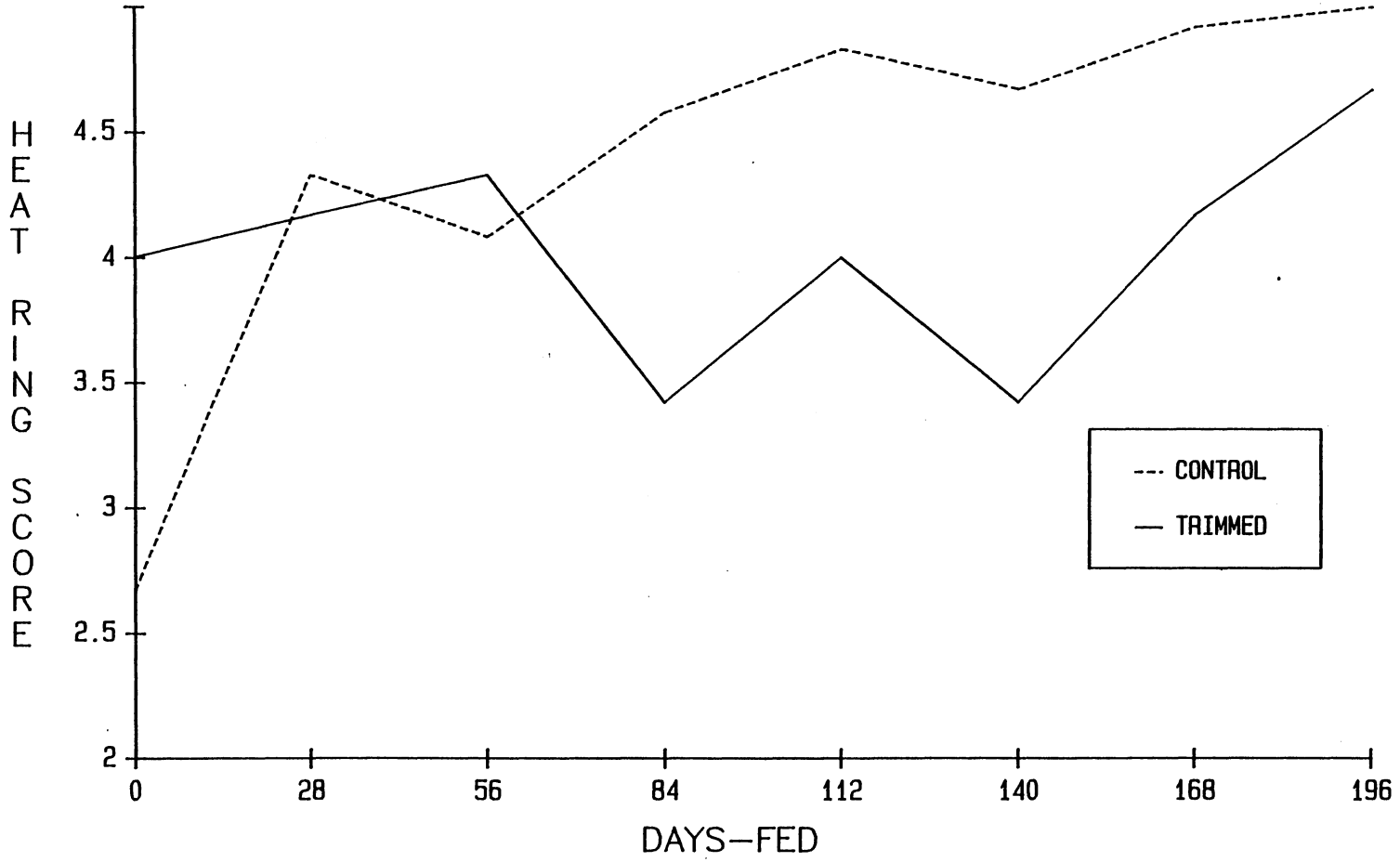

Figure 4. Days-fed X Treatment Interaction for the Severity of Heat Ring

Palatability Predictions

Marbling score currently has the most influence when determining the USDA quality grades of youthful (less than 42 months at slaughter) beef carcasses. Crouse et al., (1978) concluded that marbling only accounted for three percent of the variation in taste panel tenderness. Many studies have found a positive correlation with marbling and tenderness, however; the correlation was low to moderate (Parrish, 1974; Campion et al., 1975; Tatum et al., 1980). In this study with Angus X Hereford steers, marbling was moderately related to taste panel tenderness and shear force (table X). In addition, marbling was the carcass grade trait most highly correlated with the palatability attributes. In fact, juiciness and flavor intensity were only associated ($P<.05$) with carcass traits related to fattening.

Dolezal et al. (1982b) and Riley et al. (1983) found a close association between subcutaneous fat thickness and palatability. The researchers noted little improvement in palatability once cattle had reached at least 7.6 mm of subcutaneous fat at the 12th rib. Similar results were obtained in the present study where the steers attained 7.6 mm between the 56 and 84-d slaughter periods.

In an attempt to clarify the relationship of selected carcass and postmortem muscle traits with tenderness, multiple regression was used to map a path analysis for

shear force (figure 5). Control sides were used to eliminate the treatment effects (removal of subcutaneous fat). The direct effects of the selected traits on shear force are depicted by the standard partial regression coefficients shown parenthetically on the single-headed paths. The remaining coefficients are simple correlations between the various traits and are used to determine the indirect effects of the trait on shear force through a third variable. All simple correlations in the path analysis were highly ($P<.001$) significant. The simple correlations account for both the direct and indirect paths. Thus, the sum of the values for the direct and indirect paths equal the simple correlation.

The determination of direct and indirect paths will be illustrated by the use of the simple correlation between marbling and shear force (-.61). The direct effect of marbling score on shear force is -.37. The indirect path of marbling on shear force through days-fed is -.2 which is the product of the direct path of days-fed (-.25) and the simple correlation between marbling score and days-fed (.8). The other indirect paths for marbling score through 2.5 h temperature, fat thickness, and carcass weight are -.39, -.03, and .36, respectively.

The selected traits in the path analysis accounted for 46 percent of the variation in shear force. Temperature at 2.5 h had the greatest ($P<.05$) direct effect on shear force. Consequently, indirect paths for other variables

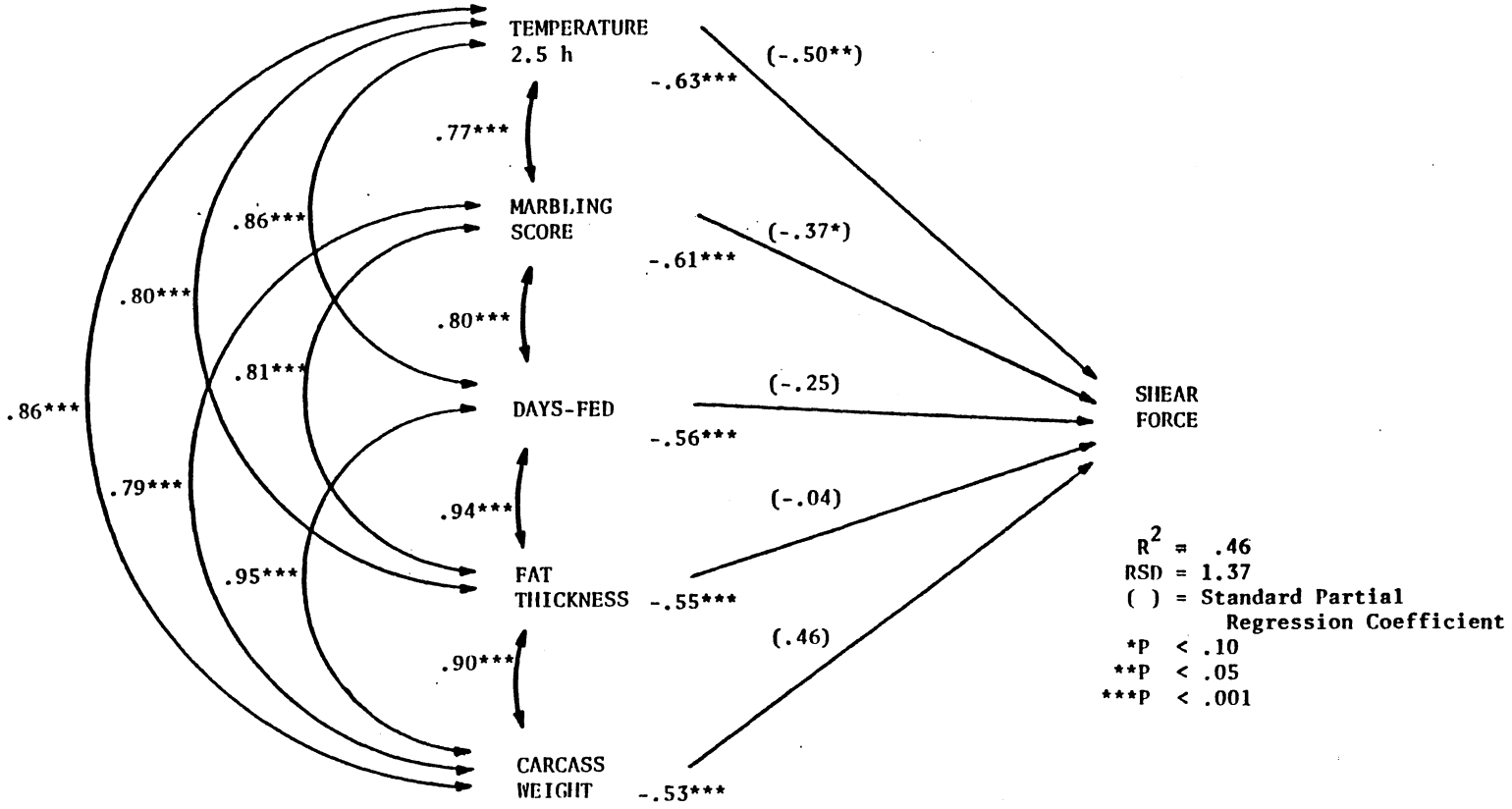

Figure 5. Path Coefficient Diagram for Several Constituents of Shear Force

had the greatest impact on shear force when routed through 2.5 h temperature. Magnitudinal order of secondary paths (indirect) involved carcass weight (2nd), marbling score (3rd), and fat thickness (4th).

Figure 6 illustrates the path analysis for longissimus muscle temperature at 2.5 h. The four carcass traits selected for the analysis accounted for 77 percent of the variation in the early postmortem temperature (2.5 h). Days-fed, followed by carcass weight had the most effect (direct) on temperature at 2.5 h. Apparently these carcass traits bring about changes in tenderness largely through the enhancement of early postmortem temperature.

Through the use of appropriate days-based regression equations, the singular effect for each of the various traits necessary for a slightly tender (5.0 on an 8.0 point scale) sensory tenderness rating was calculated for this group of Angus X Hereford steers. Slightly tender steaks were attained once steers achieved the following singular conditions: 1) 84-d of high concentrate feeding, 2) subcutaneous fat thickness of 1.03 cm, 3) hot carcass weight of 293 kg, 4) marbling score of "Slight^{93}", or 5) longissimus muscle temperature at 2.5 h of 33 C.

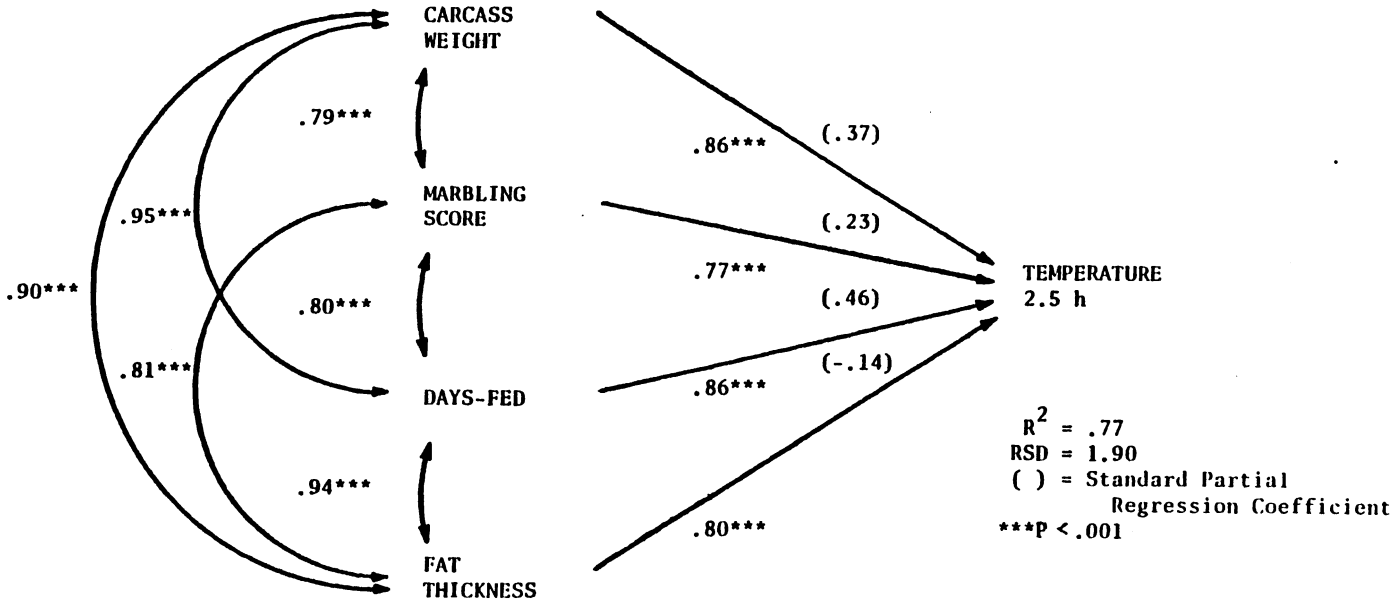

Figure 6. Path Coefficient Diagram for Several Constituents of Temperature at 2.5 h Postmortem

CHAPTER V

SUMMARY AND CONCLUSIONS

The objective of this study was to examine the effects of time-on-feed and carcass grade traits (fat thickness, carcass weight, and marbling score) on postmortem muscle characteristics and beef palatability.

The results of the study indicated that with increased days on a high concentrate diet, steaks from the Angus X Hereford steers markedly improved in tenderness (through 84-d). In addition, early postmortem temperature, fat thickness, carcass weight, and marbling score were associated with improved tenderness values. Among the carcass grade traits, marbling was most highly related to tenderness. The relationship between marbling score and tenderness is undoubtedly represented well in this study through the use of Angus X Hereford steers, a crossbreed known for their ability to marble.

Time-on-feed and the carcass grade traits appear to affect tenderness by delaying carcass chilling rate and enhancing early postmortem muscle temperature. Of the traits regressed on tenderness, longissimus muscle temperature at 2.5 h had the greatest direct and indirect impact.

Through days-based regression equations criteria for "acceptable" tenderness were determined. It appears that with the relationships among the various traits, utilizing a combination of traits in conjunction with the criteria currently used in quality grade determination would strengthen the prediction of beef palatability. Such an incorporation is practical since carcass weight and fat thickness are currently used for yield grade determination, and early postmortem temperature can be easily obtained. However, it is important to note that these findings and conclusions were derived through the utilization of Angus X Hereford steers. These interrelationships should be further examined over a wide range of breed-types.

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TABLE XII

EXPERIMENTAL DESIGN

Days-fed	Treatment of side		Number of observations
	Control	Trimmed	
0	6	6	12
28	6	6	12
56	6	6	12
84	6	6	12
112	6	6	12
140	6	6	12
168	6	6	12
196	6	6	12
Number of Observations	48	48	96

TABLE XIII

MEAN SQUARES FOR PRODUCTION TRAITS

Source	df	Slaughter weight, kg	Dressing percent	Average daily gain, kg
Days-fed	7	56277**	82.32**	0.74**
b_1(Days-fed)	1	384555**	532.98**	2.55**
b_2(Days-fed)^2	1	1656	14.07	1.08**
Error	40	1037	2.24	0.06

**P<.01

TABLE XIV

MEAN SQUARES FOR POOLED PALATABILITY ATTRIBUTES

Source	df	Juiciness	Fragmentation	Connective tissue	Flavor intensity	Tenderness	Shear force, kg
Days-fed (D)	7	.984	11.07**	3.38**	.248*	12.01**	26.01**
b_1(Days-fed)	1	.665	31.11**	6.82**	.945**	42.88**	82.04**
b_2(Days-fed)^2	1	2.036*	36.03**	14.03**	.159	32.33**	93.78**
Steer (Days-fed)	40	.452	.64	.42	.086	.83	1.58
Treatment (T)	1	.128	4.95**	2.23**	.183	7.38**	1.92
T x D	7	.147	.52	.29	.098	.74	.65
Error	40	.424	.50	.28	.113	.53	1.32

*P<.05
**P<.01

TABLE XV

MEAN SQUARES FOR LONGISSIMUS MUSCLE (12-13TH RIB) LEAN AND MARBLING ATTRIBUTES

Source	df	Lean			Marbling		Heat ring
		Color	Texture	Firmness	Distribution	Texture	
Days-fed (D)	7	.60	1.29*	5.03**	1.64	1.61	2.37**
b_1 (Days-fed)	1	.39	2.90**	32.38**	6.91**	.45	10.07**
b_2 (Days-fed)^2	1	.39	.10	1.17	.24	5.47**	.06
Steer (Days-fed)	40	.36*	.59	.57	1.30	.99	.43
Treatment (T)	1	5.04**	11.00**	.32	.04	5.04**	3.19**
T X D	7	.19	1.14	.43	.57	.38	2.18**
Error	40	.19	.33	.29	.41	.42	.18

*P<.05
**P<.01

TABLE XVI

MEAN VALUES FOR LONGISSIMUS MUSCLE (12-13 RIB) LEAN AND MARBLING ATTRIBUTES BY DAYS-FED AND TREATMENT

	Lean			Marbling	
Item	Color	Texture	Firmness	Distribution	Texture
Days-fed					
0	5.21^{d}	4.54^{d}	4.08^{f}	5.04^{cd}	5.13^{cd}
28	5.75^{cd}	5.46^{c}	4.50^{ef}	4.54^{d}	5.46^{c}
56	5.58^{cd}	4.92^{cd}	5.17^{de}	5.00^{cd}	4.92^{cd}
84	5.88^{c}	5.13^{cd}	5.17^{de}	4.75^{cd}	5.00^{cd}
112	5.67^{cd}	5.00^{cd}	5.33^{cd}	5.25^{cd}	4.42^{d}
140	5.46^{cd}	5.00^{cd}	5.50^{cd}	5.50^{c}	5.13^{cd}
168	5.46^{cd}	5.25^{cd}	5.96^{c}	5.58^{c}	5.25^{cd}
196	5.83^{c}	5.58^{c}	5.92^{c}	5.42^{c}	5.63^{c}
Treatment					
Control	5.83^{c}	5.45^{c}	5.26^{c}	5.12^{c}	5.34^{c}
Trimmed	5.38^{d}	4.77^{d}	5.15^{c}	5.16^{c}	4.89^{d}
Residual SD[b]	.43	.57	.54	.64	.65

[a]Lean color: 1 = black to 8 = light grayish-red or pink; lean texture: 1 = very coarse to 8 = very fine; lean firmness: 1 = very soft to 8 = very firm; marbling distribution: 1 = very uneven to 8 = very uniform; marbling texture: 1 = very coarse to 8 = very fine.

[b]Standard errors can be calculated as $1/\sqrt{n}$ X standard deviation for a trait; n = 12 for days-fed means and n = 48 for treatment means.

[c,d,e,f]Means in the same column and within the same item bearing a common superscript do not differ (P>.05).

TABLE XVII

MEAN SQUARES FOR LONGISSIMUS MUSCLE AREA AND MARBLING SCORES FOR TRIMMED AND CONTROL SIDES

Source	df	Marbling score	Longissimus muscle area, cm^2
Days-fed (D)	7	94590**	1085.6**
b_1(Days-fed)	1	581808**	7022.3**
b_2(Days-fed)^2	1	94691*	14.6
Steer (Days-fed)	40	6135	79.9
Treatment (T)	1	1093	122.4**
T X D	7	484	8.2
Error	40	317	9.6

*P<.05
**P<.01

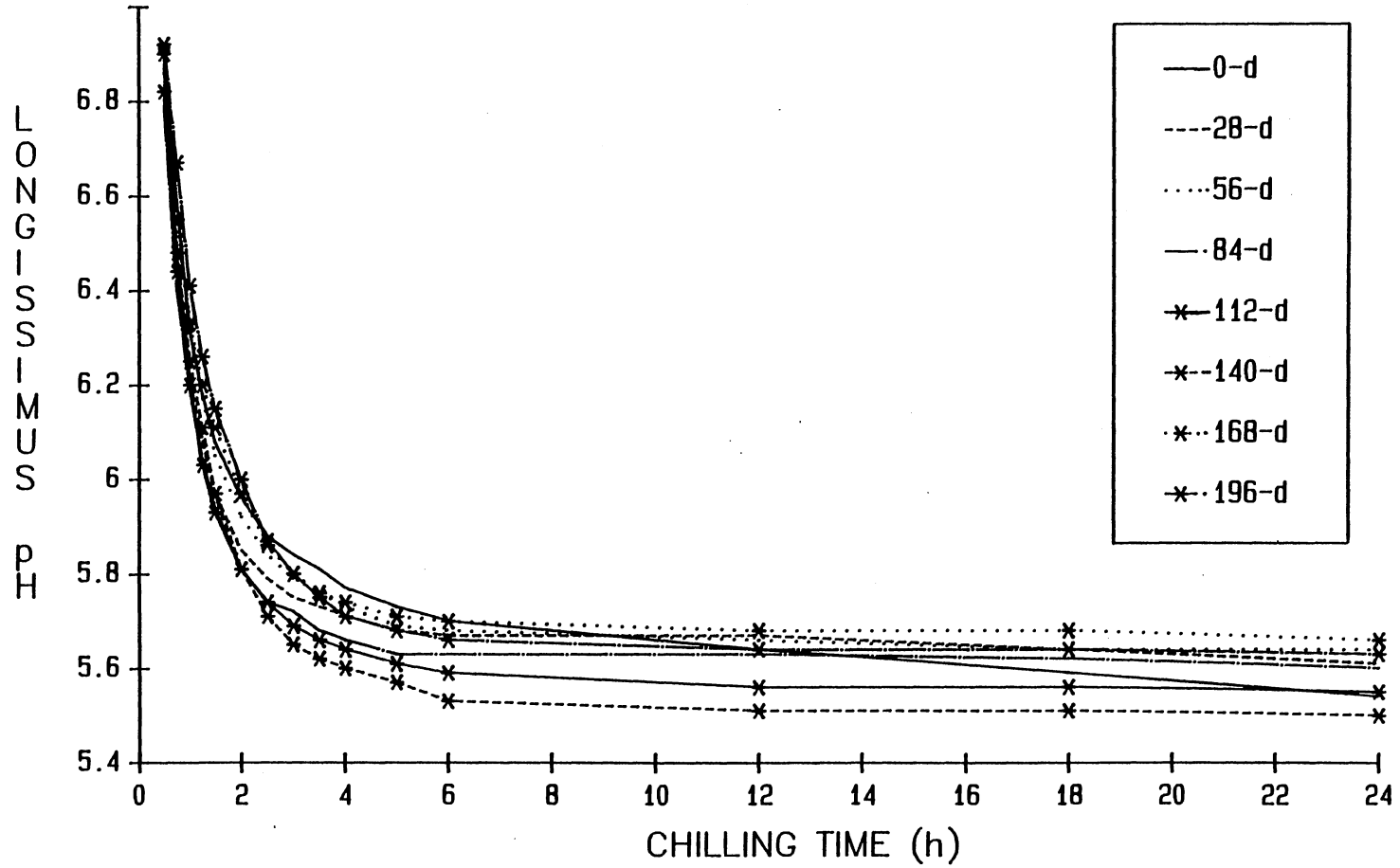

Figure 7. Longissimus Muscle pH for Pooled Treatment Groups Versus Chilling Time Across Days-fed

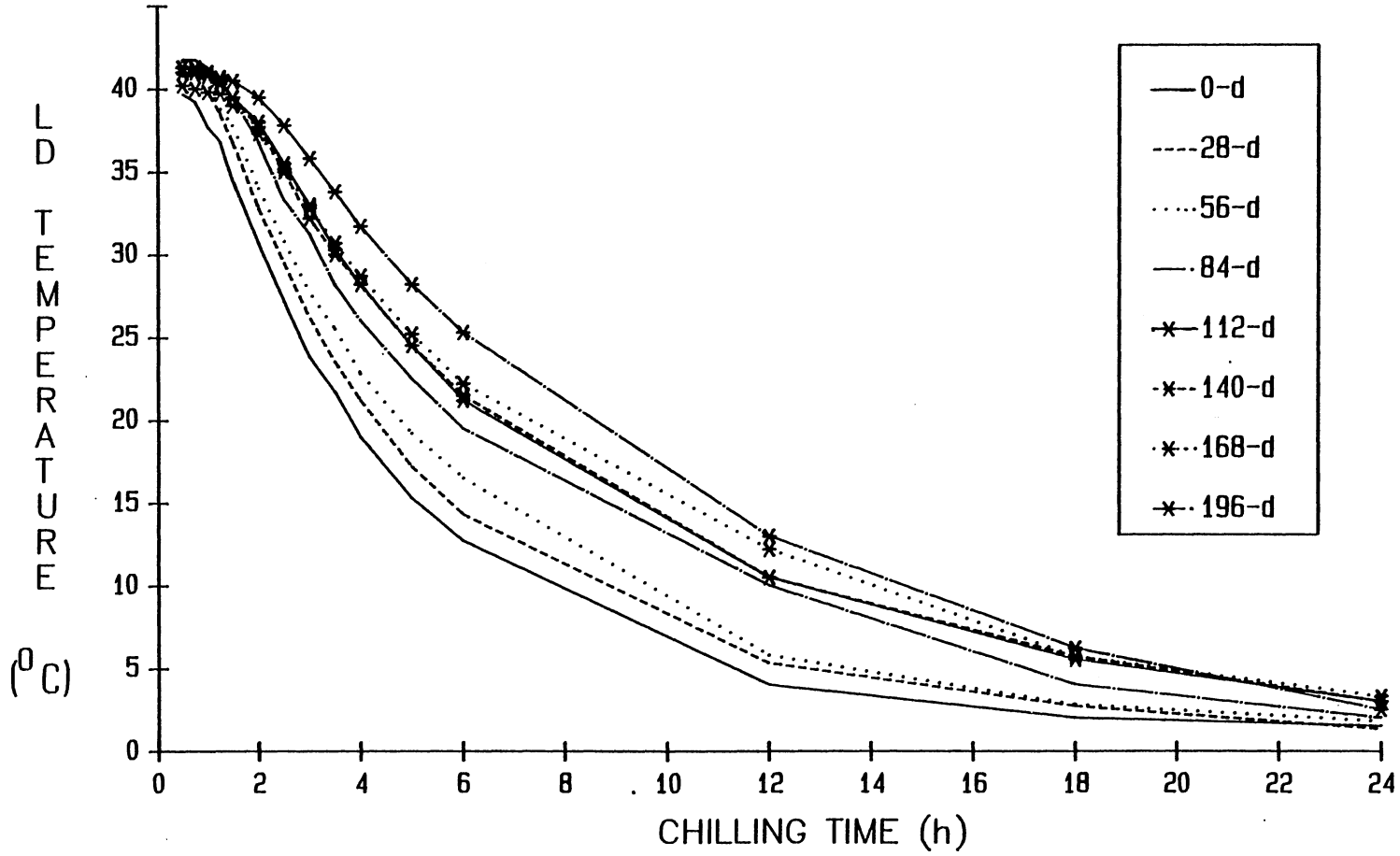

Figure 8. Longissimus Muscle Temperature for Control Sides Versus Chilling Time Across Days-fed

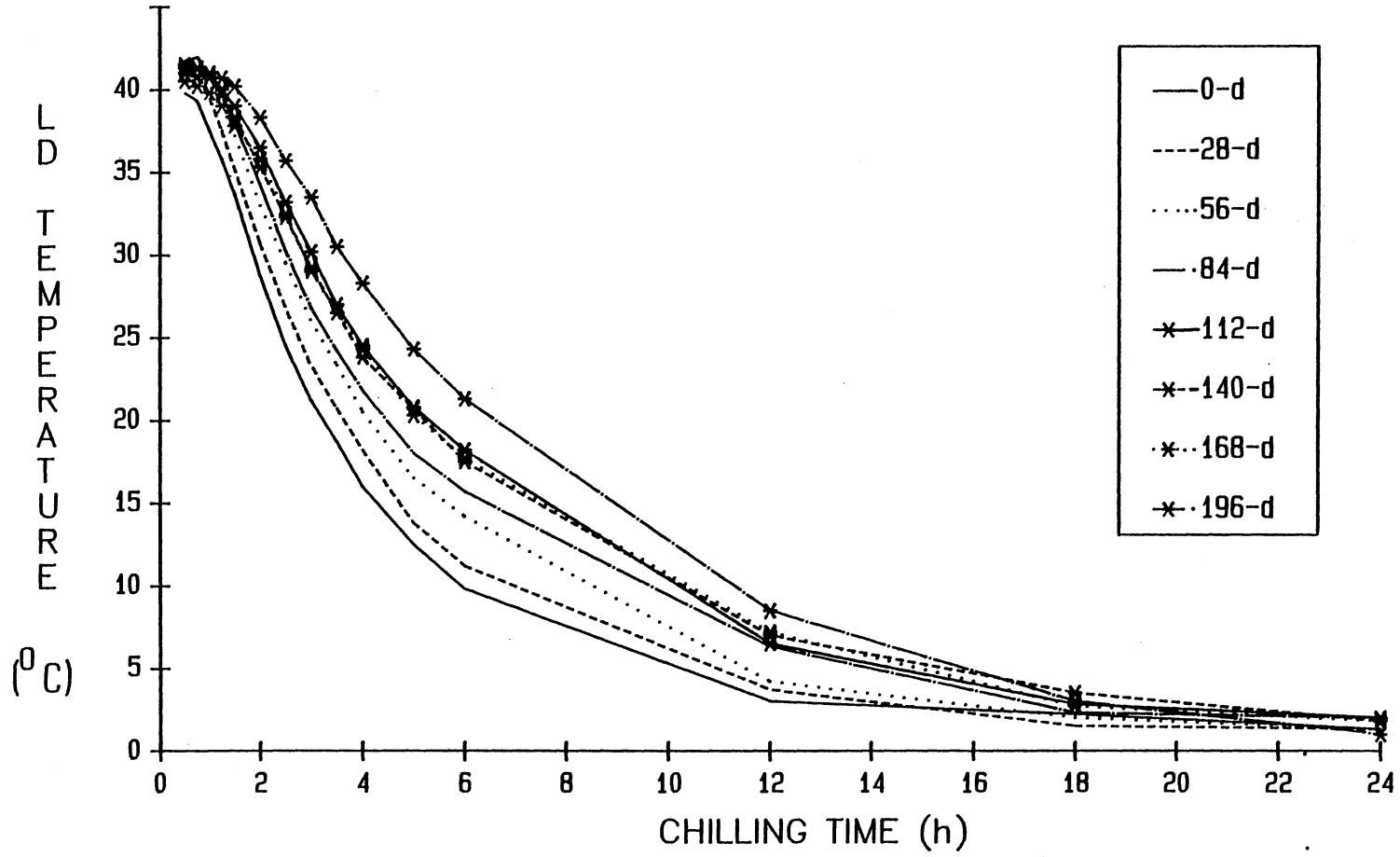

Figure 9. Longissimus Muscle Temperature for Trimmed Sides Versus Chilling Time Across Days-fed

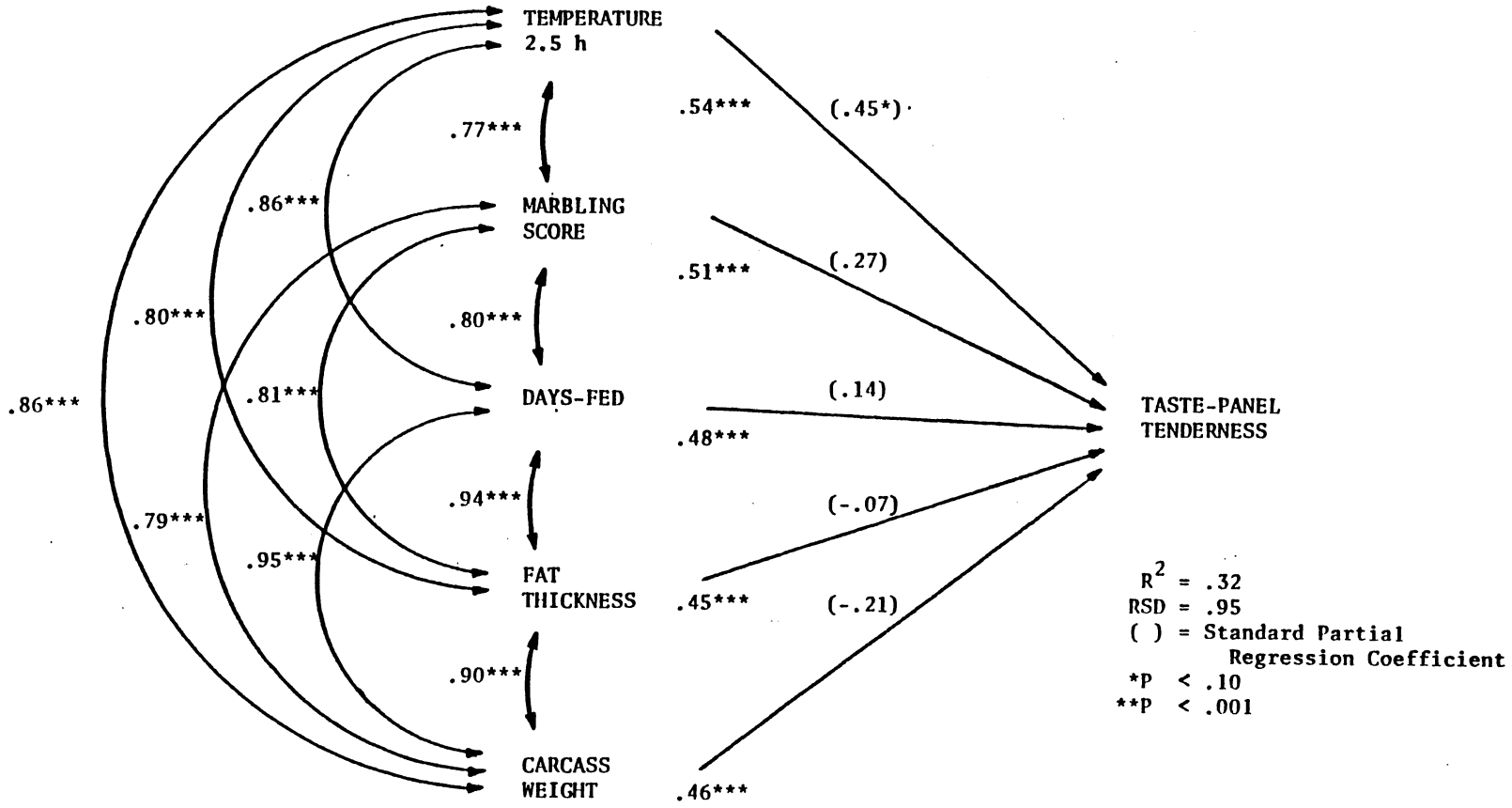

Figure 10. Path Coefficient Diagram for Several Constituents of Taste-panel Tenderness

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