Growth, Composition and Palatability of Market Lambs
Expressing Extreme Muscle Hypertrophy

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INTRODUCTION

Consumer demands are forcing all segments of the meat industry to decrease fat and increase leanness in products. "The National Survey of Lamb Carcass Cutability Traits" (Tatum et al., 1989) reported that a large proportion of lamb carcasses were excessively fat. In that survey, the average fat thickness at the 12th/13th rib was 7.4 mm, and over 39% of the sample were USDA yield grade 4 and 5. This survey illustrated that the U.S. lamb industry has been moving backwards, as the average fat thickness for lamb was 4.8 mm in 1969 (Southam and Field, 1969). Individuals interviewed across industry segments cited overfinished lambs as the major marketing/merchandising problem (Williams, 1991). The second most important problem in marketing lamb was seen as high retail prices. These high prices are attributed to the relatively small serving sizes. To improve consumer acceptance of lamb products, the lamb industry must take action to produce a leaner product.

Recently, a genetic mutation that causes extreme muscling in sheep has been identified (Cockett et al., 1993). Market lambs that display this extreme muscle hypertrophy phenotype, referred to as *Callipyge*, are very lean and muscular in appearance. While this phenotype seems desirable to the producer, there remain questions about the use of these extremely muscular animals in the meat industry. With the possible benefits from the inclusion of this phenotype into the commercial lamb population from a producer standpoint, the objective of this study was to determine the effect of extreme muscle hypertrophy on animal growth, carcass composition, and meat palatability characteristics.

LITERATURE REVIEW

Recently a genetic mutation which causes extreme muscle hypertrophy, thought to originate in a flock of Dorset lambs, has been identified. The preliminary results indicate that an autosomal dominant gene could be responsible for the production of extremely lean and muscular lambs. Using bovine DNA markers, researchers have mapped the *Callipyge* locus to ovine chromosome 18 (Cockett et al., 1994). This knowledge of the *Callipyge* locus may lead to cloning of the corresponding gene, which could have a profound effect on production potential of the lamb industry.

Recent research has found *Callipyge* lambs to have superior carcass characteristics. Jackson et al. (1993) found dressing percent to be higher for *Callipyge* ram lambs. In the same study, dissection data concluded that *Callipyge* lamb carcasses had less fat and a higher proportion of muscle mass in the more valuable pelvic limb and dorsal muscles. When studying the influence of the *Callipyg*e gene on carcass characteristics of 58 white faced and black faced lambs, Snowder et al. (1994) found that dressing percent improved in the *Callipyge* lambs by 5-8% over normal counterparts. Backfat thickness was 35-32% lower in the *Callipyge* lambs of both Dorset X Rambouillet and Dorset X Columbia genotypes. Yield grade improved significantly and Longissimus dorsi area of *Callipyge* lambs increased 22-24%. Leg, sirloin, and loin retail cut weights were found to be greater in *Callipyge* individuals. Other researchers have also seen increases in dressing percentages, ribeye area, and leg conformation scores, along with less fat, higher retail yields and improved muscle to bone ratios (Busboom et al., 1994; Jackson et al., 1994a)

In addition to improved carcass characteristics, *Callipyge* lambs have been found to be superior in feed efficiency. Growth and feed efficiency of 158 lambs was observed in a recent study. Average daily gain was not affected but feed efficiency was higher for lambs heterozygous for the *Callipyg*e gene (Snowder et al., 1994).

Current research indicates that palatability of meat from *Callipyge* lambs may be

affected by this gene. Results of the evaluation of *Longissimus* dorsi samples by a trained sensory panel suggest that meat from normal phenotype lambs was more juicy, tender, flavorful, and more palatable (Jackson et al., 1994b). Shear force values tended to be lower for normal muscled ram lambs as well. In another study, tenderness scores were recorded by 35 panelists for 10 pure Dorset and 16 Dorset X Suffolk carcasses (Rawlings et al., 1994). Mean tenderness scores of loins from the *Callipyge* Dorset carcasses were significantly lower than their normal half-siblings. Tenderness scores of the leg samples were not significantly different. However, differences were found in flavor, juiciness, and overall acceptability of both leg and loin samples in favor of normal muscled lambs.

There are many factors responsible for meat tenderness. Extensive research has been conducted examining postmortem factors that affect tenderness. The contractile state of muscle fibers, connective tissue content, and the degree of protein degradation within a muscle have significant effects on tenderness. Largely dependent on chilling rate and pH decline, the contractile state of muscle has been associated with tenderness differences (Marsh et al., 1968; Locker and Hagyard, 1966). Rate of temperature and pH decline within muscle is affected by ambient temperature, humidity and air velocity, size of the carcass, and the amount of fat covering the muscle which provides insulation. The effect of temperature and pH on meat tendernes was evaluated by Dutson (1983). Higher temperature activates the enzymes systems involved in degradation of myofibrillar proteins. In general, elevated temperature in postmortem muscle increases the rate of pH decline. Lowered pH of muscle causes a release of enzymes from the lysosome in muscle tissue, thus relating to tenderness Researchers have found that fatter and larger carcasses will produce more tender meat as they chill more slowly and are less susceptible to cold-induced shortening (Smith et al., 1976; Tatum et al., 1981). Ultimate contractile length as measured by sarcomere length has been determined as an indicator of tenderness (Marsh et al., 1968). Sarcomeres are the

structural units that make up the myofibrillar structure of muscle. A sarcomere has a banded structure, with the A-band consisting of thick (myosin) filaments and the I-band consisting of thin (actin) filaments. Z-disks show the ends of sarcomeres, and the measure between z-disks is the measure of the contractile state of the muscle, or the sarcomere length. Studies show that muscles with shorter sarcomeres are tougher than those with longer sarcomeres.

Toughness of meat may also be influenced by amount and solubility of collagen (Goll et al., 1963; Hill, 1966; Herring et al., 1967; Cross et al., 1973). Collagen is the basic structural element of soft tissue that provides mechanical integrity and strength to the tissue. An increase in collagen content is related to less tender meat (Herring et al., 1967). Solubility of collagen has been related to the fibrillar structure and type of crosslinking within the collagen molecule. Loss of heat solubility of collagen is a result of heat-stable crosslink formation within the collagen molecule (Hill, 1966).

Meat tenderness is highly associated with postmortem proteolysis. The proteolytic breakdown of structural proteins of muscle has been extensively researched in recent years (Goll et al., 1983, 1992; Koohmaraie, 1988, 1992a, 1994). Research indicates level and activity of the calcium-dependent proteolytic enzyme calpain, and the inhibitor of this enzyme, calpastatin, are primarily responsible for postmortem proteolysis (Koohmaraie 1988, 1992b). This system dramatically improves tenderness in the presence of increased concentrations of intracellular calcium (Koohmaraie and Shackelford, 1991; Wheeler et al., 1991). The level of calpastatin at 24 h postmortem has shown to be a good indicator of ultimate meat tenderness (Shackelford et al., 1991).

Examination of muscle fiber tenderness throughpostmortem temperature and pH decline and sarcomere length, connective tissue content through collagen amount and percent solubility, and postmortem proteolysisthrough calpastatin enzyme activity, may determine if there are differences in chemical muscle characteristics between lambs with normal muscle phenotype and lambs with extreme muscle hypertrophy.

MATERIALS AND METHODS

Animal Selection and Feeding Regime

Twenty young crossbred wether lambs were selected from a flock containing partial expression of extreme muscle hypertrophy phenotype (*Callipyge*). After selection of ten normal phenotype and ten *Callipyge* whethers, lambs were transported to the Texas A&M University Sheep Center. Each lamb was ear tagged, drenched for worms with Ivomectin®, and given an overeating shot. A pelleted 15% crude protein diet consisting of corn, alfalfa, soybean meal, dried molasses, limestone, ammonium chloride, steamed bone meal, salt, vitamins A, D, and E, Aureomycin 50, and Rumensin 60 was fed throughout the study. During an extensive adjustment period due to very unfavorable weather patterns, lambs were mass fed in a single pen before individual feed data were collected for each lamb. Following this three-week period, lambs were fed in feeding crates with individual stalls so that feed consumption could be measured for each lamb. Lambs were allowed access to a controlled amount of feed twice a day (0.91 kg during morning and evening feedings). Live weights were collected on each lamb every seven days throughout the feeding period.

Slaughter and Sample Collection

All lambs were slaughtered at the Rosenthal Meat Science and Technology Center at Texas A&M University following all appropriate humane slaughter methods as set forth in the Humane Methods of Slaughter Act. Kidney and pelvic fat (KP), usually removed during slaughter, was not removed and was left intact until fabrication.

Warm carcass weight was measured at the time lambs were put into the chill cooler. Carcasses were chilled for 24 h (-2°C), during which time temperature decline in the *Biceps femoris* (BF), *Semitendinosus* (ST), *Semimembranosus* (SM), *Longissimus dorsi*

(LD), and *Triceps brachii* (TB) (at the approximate geometric center of each muscle) was monitored on the left side of the carcass. Temperature was recorded at 1, 2, 3, 4, 5, 6, 8, 10, 12, and 24 h postmortem on an Omega Model OM-272 Multipoint recorder and data logger (Omega Engineering, Inc., Stamford, CT). Also at these times, muscle pH was monitored with a hand-held UniFET Microprocessor pH/mV/ C with ISFET sensor (UniFET Inc., San Diego, CA).

At 24 h postmortem, samples of approximately 20 g were removed from the BF, ST, SM, LD, and TB for quantification of post-rigor calpastatin activity and determination of sarcomere length. Samples were removed from the right side of the carcass from the posterior end of the BF, ST, and SM, between the 8th and 9th ribs for the LD, and from the anterior end of the TB. All carcasses were evaluated for ribeye area at the 12th/13th rib interface, fat thickness opposite the ribeye, and percent kidney and pelvic fat before fabrication and dissection.

Determination of Carcass Composition

Carcasses were split for fabrication of both sides and dissection of the left side. Each side was fabricated into a rough leg, rough loin, rough rack, rough shoulder, neck, breast, plate, flank, and shank. The kidney and KP were removed from the rough leg and rough loin following breaking. Weights were recorded for each cut on the left side and total KP was weighed.

The foresaddle was removed from the hindsaddle between the 12th and 13th ribs. The shoulder was removed from the rack as a square-cut shoulder by making a cut originating between the 4th and 5th ribs. The breast was removed from the shoulder by a straight cut perpendicular to the blade end through the cartilaginous juncture of the first rib and the anterior extremity of the sternum, and the shank was removed from the breast following the natural seam. The neck was removed from the foresaddle in a straight cut perpendicular to the vertebral column, leaving no more than 2.54 cm of

neck on the shoulder. The plate was removed from the rack by making a cut 10.16 cm from the LD on both the anterior and posterior ends.

The hindsaddle was fabricated by separating the leg from the loin by making a straight cut through the center of the last lumbar vertebra and perpendicular to the length of the loin. The flank then was removed from the loin by a cut 7.62 cm from the distal edge of the LD on both the anterior and posterior ends.

The BF and LD from the right side of each carcass then were fabricated into chops for palatability trait evaluation. Chops from the BF, ST, SM, LD, and TB also were removed for collagen amount and solubility and fat and moisture percentage determination. The left side of each carcass then was separated by physical dissection into lean tissue, subcutaneous fat, intermuscular fat, bone, and heavy connective tissue. Individual muscle weights were taken for the BF, ST, SM, LD, and TB and individual weights were taken for the femur, humerus, and scapula.

Sarcomere Length

To determine sarcomere length, the laser diffraction method was used (Cross et al., 1981). Approximately 10 g of tissue was placed in 50 g of sucrose solution (0.25 M sucrose, .002 M KCl and .005 M iodoacetate) and blended for 10-15 sec at low speed (30 to 40 rpm) in a Virtishear homogenizer (Virtes Company, Gardiner, NY). The homogenate then was placed on a glass slide and covered with a cover slip. Using a Spectro-Physics Model 155 helium-neon laser (Spectra Physics, Eugene, OR), sarcomere length measurements were taken by measuring the distance between the origin of the first order diffraction band. An average of twenty-five sarcomere measurements was calculated for each muscle sample and sarcomere length was determined as follows:

$$\text{sarcomere length, } \mu m = \frac{.6328 \times D \times ((T/D) + 1)1/2}{T}$$

where D = distance in mm from the sample to the diffraction screen (100 mm); T =

distance in mm from the origin to the first order diffraction band (distance was the average of the twenty-five measurements taken); and 0.6328 = wavelength of the Helium-Neon laser light.

Collagen

Total collagen content and solubility were analyzed and calculated utilizing the hydroxyproline procedure of Hill (1966) as modified by AOAC (1990) and then converting hydroxyproline to collagen content as defined by Cross et al. (1973). Samples were run in duplicates. Two 4 g samples of each homogenized muscle were weighted into two labeled 50 ml centrifuge tubes. Added to each tube was 12 mL of 1/4 strength Ringer's solution (0.03 M sodium chloride, 0.06 mM calcium chloride, and 0.001 M potassium chloride). Each tube was stirred 20 revolutions with a glass stirring rod before being placed into a water bath preheated to 78°C for 60 min and stirred 10 revolutions every 5 min. The centrifuge tubes then were removed from the water bath and allowed to cool for 15 min in a refrigerator (2°C).

After cooling, the tubes were centrifuged at 3.200 rpm for 10 min in a centrifuge cooled to 2°C running temperature. The supernatants were decanted into cooking jars and the residues were suspended in 8 mL of the Ringer's solution and centrifuged again under the same conditions for 10 min. These supernatants were decanted into their respective cooking jars. To each residue, 10 mL of water (double distilled, deionized) was added and the resulting solution was poured into a cooking jar. To each supernatant jar, 20 mL of 7N sulfuric acid was added and 30 mL of 7N sulfuric acid was added to each residue jar.

All cooking jars were capped tightly and heated for 16-18 h at 105°C. After heating, the jars were uncapped and allowed to cool to room temperature. Hot hydrolysates from the supernatants and residues were transformed into 200 and 500 mL flasks, respectively, and diluted to volume with distilled water. Approximately 50 mL

of each diluted solution then was filtered through a Whatman #2 filter paper into collection flasks. Each sample then was covered and stored in a refrigerator (2°C) until subsequent color analysis could be performed.

The samples were allowed to cool to room temperature before beginning the color reaction. Two mL of each final filtrate was pipetted into test tubes. Five standard solutions were prepared from a stock hydroxyproline solution to contain 2, 4, 6, and 8 mg/mL-1 hydroxyproline, respectively. Two mL of each standard solution were pipetted into test tubes and 2 ml of water were pipetted into each of two "blank" tubes. Each final filtrate and each standard solution were prepared in duplicate. An oxidant solution was prepared (1.41 g chloramine T in 100 mL buffer solution made of 30 g citric acid, 15 g NaOH, 90 g sodium acetate trihydrate, 290 mL of isopropanol, with pH of 6.0). To each tube (including standards and blanks) 1 mL of the oxidant solution was added and mixed thoroughly with a vortex for 5 sec. Twenty min after the addition of the oxidant solution, 2 mL of color reagent (10 g 4-dimethylamino benzaldehyde, 35 mL 60% perchloric acid, 65 mL isopropanol) were added to each tube. The tubes were again vortexed for 5 sec and placed in a water bath pre-heated to 60°C for exactly 15 min.

Tubes were allowed to cool to room temperature. Absorbance was read at 558 nm using a Beckman DU-7 Spectrophotometer (Beckman Institutes, Inc., Fullerton, CA). The "blanks" and the standards were used to generate a standard curve from which to calculate the hydroxyproline content of each sample. For the supernatants, hydroxyproline concentration was converted to collagen by multiplying by a factor of 7.52. The hydroxyproline concentration of the residues was converted to collagen by multiplying by 7.25. Total collagen was calculated by combining the collagen content of the supernatants and residues, and percent solubility was calculated by the following:

Percent solubility = (supernatant collagen/total collagen) x 100.

Shear Force

Chops from the biceps femoris and longissimus dorsi muscles were removed from the carcass, vacuum packaged, and allowed to age 14 d before being frozen at -20°C until Warner-Bratzler shear force determinations could be performed. Chops then were thawed in a refrigerator (2°C) before being broiled.

The chops were broiled on a Farberware Open Hearth electric broiler until an internal temperature of 65°C was reached. Internal temperature was monitored using copper-constantan thermocouples inserted into the geometric center of each chop. Temperature was recorded on an Omega hand-held microcomputer thermometer model HH-72T (Omega Engineering, Inc. Stamford, CT). After cooking, chops were cooled to room temperature. Four 1.27 cm diameter cores were removed from each chop parallel to the muscle fiber orientation. Each core was sheared once using a Warner-Bratzler shear force machine (John Chatillon and Sons, New York, NY). A shear force value (kg) was obtained from each core. All of the measurements from each chop were averaged to obtain a single value that was reported as the mean shear force for each sample.

Sensory

Warm (approximately 65°C) 1 cm x 1 cm x 1 cm cubes of cooked chops were served in duplicate to a seven-member sensory panel trained according to the methods of Cross et al. (1978). The panelists were served in a sensory panel laboratory equipped with partitioned booths and controlled levels of incandescent light. The panel evaluated each sample, using eight-point scales, for connective tissue amount (8 = none; 1 = abundant), juiciness (8 = extremely juicy; 1 = extremely dry), muscle fiber tenderness and overall tenderness (8 = extremely tender; 1 = extremely tough), and flavor intensity (8 = extremely intense; 1 = extremely bland).

Fat and Moisture

Samples were taken from the BF, ST, SM, LD, and TB, trimmed of subcutaneous fat, ground and frozen until AOAC (1990) procedures to determine the percentage of ether extractable fat could be performed. Approximately 2 g of each muscle sample was placed in oven-dried filter paper, weighed, and heated to 100°C for approximately 24 h. Samples then were weighed again for determination of moisture loss. The percentage of fat was determined by placing the samples in a soxhlet fat extraction unit with diethyl ether for 12 h. Samples were air-dried and placed in a drying oven for 12 h. When the ether had evaporated, the samples were weighed to determine the amount of fat extracted. Analyses were run in duplicate.

Calpastatin Activity

Calpastatin activity was quantified using the heated procedures of Shackelford et al. (1994). Muscle samples of the BF, ST, SM, LD, and TB were obtained 24 h postmorten. Ten g of finely minced muscle tissue (free of visible fat and connective tissue) were homogenized in 30 ml of extraction buffer consisting of 50 mM Tris base, 10 mM EDTA, and 10 mM 2-mercaptoethanol (MCE), adjusted to a final pH of 8.3 with HCl. Samples were homogenized in a Waring blendor at high speed with three 30 s extraction cycles with a 30 s cooling period in between homogenizations. The homogenate was centrifuged at 16,500 rpm for 60 min. The resulting supernate was filtered through glass wool and cheesecloth. The supernatant was transferred to 5 13X100-mm borosilicate test tubes and heated for 15 min in a 95° C water bath. Samples then were chilled in an ice bath for 15 min. During chilling, the coagulated protein was scrambled with a glass rod. Samples again were centrifuged at 16,500 rpm for 30 min. Following centrifugation, the volume of the supernatant was measured and filtered through glass wool and cheesecloth before storing in conical tubes for subsequent assay

analysis.

Calpastatin assay was run utilizing 50, 100, 200, 300, 400, 500, 600, and 700 µL of the sample. The appropriate volume of sample was added to each of three test tubes and 1 mL was added to three tubes labeled "EDTA" tubes. An elution buffer (40 mM Tris base, .5 mM EDTA, and 10 mM MCE, pH of 7.35 using 6N HCl) was added to bring all tubes up to a total volume of 1 mL, including 3 calcium-positive and 3 blank tubes. 1 mL of assay media (100 mM Tris, 1 mM NaN_3, and 5 mg/g Casein, pH of 7.35 using 1.0 N acetic acid) was added to every tube. 30 µL of purified m-calpain was added also 100 µLof 100 mM $CaCl_2$ was added to each tube, except the blank tubes and the EDTA tubes for each sample. 100 µL of 100 mM EDTA were added to each EDTA tube. The tubes were vortexed and incubated in a 25°C water bath for 1 h. 5% TCA was added to every tube in a 2mL volume. Tubes then were vortexed and placed in the centrifuge at 3,000 rpm for 30 min. Each tube was read utilizing a micro-sipper cell on a DU-7 Spectrophotometer (Beckman Institutes, Inc., Fullerton, CA) against the blank at 278 nm (UV).

Statistical Analysis

The total number of lambs analyzed was nineteern, due to the death of one lamb expressing muscle hypertrophy at the beginning of the study. Data were analyzed using GLM pricedure of SAS (1990) with a significance level of $P < .05$. Unadjusted means were reported for live andimal and carcass characteristics, and means were separated using Tukey's Studentized Range Test ($P < .05$). Least-squares means were generated for chemical, pH, temperature, sensory and shear attributes. These means were tested for significance ($P < .05$) using Bonferoni's procedure (Lenter and Bishop, 1993).

RESULTS AND DISCUSSION

Growth Data

Lambs from the two treatment groups performed differently with respect to feed conversion (Table 1). There were no significant differences in ADG, but control lambs demonstrated more gain as evidenced by a heavier live weight. DFI data showed a trend for control lambs to consume more feed. Control lambs had a lower FC ratio ($P < .05$) combined with higher feed consumption, indicating they were less efficient from a production standpoint. *Callipyge* lambs were more efficient at depositing lean with minimal fat (Table 2) while requiring less feed energy (Table 1). This trend in growth and feed efficiency agrees with results found in Snowder et al., (1994).

Table 1. Mean growth data ± SE of control and *Callipyge* lambs.

Trait[a]	Control	*Callipyge*
ADG	.11 ± .01	.10 ± .01
FC	1.77[c] ± .02	1.94[b] ± .03
DFI	1.59 ± .03	1.54 ± .03
Live weight, kg	56.7[b] ± .6	52.3[c] ± .9

[a]Traits: ADG = Average Daily Gain (kg/d), FC = Feed Conversion (kg of feed per kg of gain) and DFI = Daily Feed Intake (kg/d).
[b, c] Means within a row lacking a common superscript letter differ ($P < .05$).

Carcass Traits

Carcass data (Table 2) indicated that hot carcass weight did not differ ($P > .05$), but fat thickness was lower ($P < .05$). Even though they were not significantly different, *Callipyge* carcasses tended to a lower percent of kidney and pelvic fat. Ribeye area was greater ($P < .05$) for the *Callipyge* group, and USDA yield grade was improved ($P < .05$) for lambs expressing extreme muscle hypertrophy. With significantly lower live weights (Table 1), hypertrophy lamb carcasses had a higher cutability value. The

current study follows previous research conclusions regarding carcass data (Snowder et al., 1994; Jackson et al., 1994a; Busboom et al., 1994).

Table 2: Mean characteristics ± SE of control (n = 10) and *Callipyge* (n = 9) lambs.

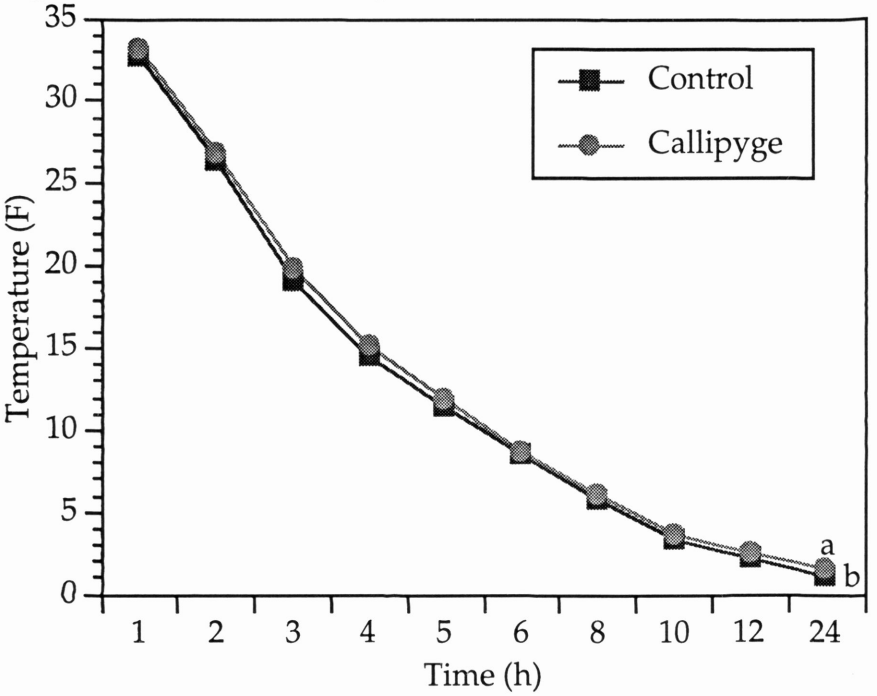
Trait	Control	*Callipyge*
Hot carcass weight, kg	32.3 ± .7	32.2 ± .7
Fat thickness, cm	$.56^{a}$ ± .05	$.30^{b}$ ± .05
Ribeye area, cm^2	16.6^{b} ± .9	24.4^{a} ± .6
Kidney/pelvic fat, %	1.7 ± .2	1.1 ± .2
USDA yield grade	2.6^{a} ± .2	1.6^{b} ± .2

^{a,b} Means within a row lacking a common superscript letter differ ($P < .05$).

Temperature decline for the two treatment groups showed that there were no significant differences before reaching 24 h postmortem (Figure 1). *Callipyge* muscles had consistently higher temperature values at each measurement, though not statistically significant. However, *Callipyge* muscle on average had a higher ($P < .05$) temperature at 24 h postmortem, attibutable to greater muscle volume.

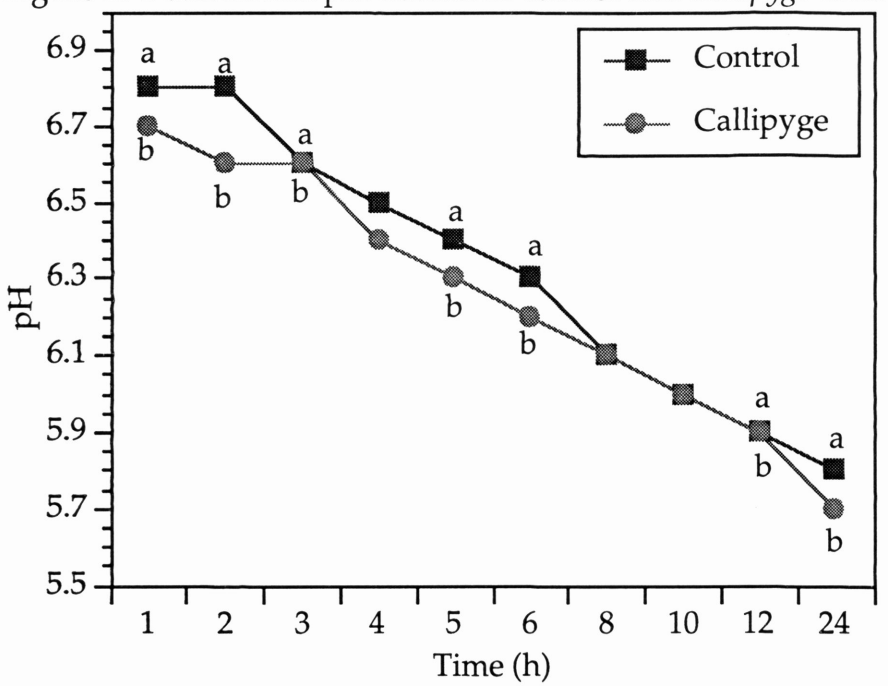
Decline of pH in muscles of both treatment groups showed significant differences at 1, 2, 3, 4, 5, 6, 12, and 24 h as seen in Figure 2. The pH value at 24 h postmortem was lower for *Callipype*, which is consistent with current knowledge of the relationship of elevated temperature and lower pH. Even though there were significant differences statistically for early and late readings but not for two intermediate times (8 h and 10 h), ultimate pH means for both treatment groups were within normal pH values (Dutson 1983).

Figure 1: Postmortem temperature decline in control and *Callipyge* lamb carcasses.



a,b Means within a row lacking a common superscript letter differ ($P < .05$).

Figure 2: Postmortem pH decline in control and *Callipyge* lamb carcasses.



a,b Means within a row lacking a common superscript letter differ ($P < .05$).

Carcass Component Data

Another objetive of the study was to determine the effect of muscle phenotype on composition of the carcass. Data collected indicated that there were few significant differences in the percentage of cold side weight for each primal and subprimal (Table 3). The only primal with a significant treatment effect was the leg. *Callipyge* lambs had a higher ($P < .05$) percentage of cold side weight expessed as leg than control lambs.

Table 3. Mean primal and subprimal yield (percent of side weight) ± SE for control and *Callipyge* lamb carcasses.

Primal or subprimal cut	Control	*Callipyge*
Shoulder	20.9 ± .6	19.7 ± .6
Rack	10.4 ± .4	10.3 ± .1
Loin	11.7 ± .3	11.5 ± .34
Leg	32.3^{b} ± .8	35.6^{a} ± .5
Neck	2.9 ± .4	3.0 ± .2
Breast	4.2 ± .3	3.5 ± .2
Shank	5.8 ± .3	6.1 ± .3
Plate	5.9 ± .3	5.9 ± .2
Flank	3.1 ± .3	2.5 ± .2

^{a,b} Means within a row lacking a common superscript letter differ ($P < .05$).

Fat, lean, and bone relationships are reported in Table 4. *Callipyge* carcasses had less fat and more lean as a percentage of total side weight ($P < .05$). Percentage of bone did not differ between treatment groups ($P > .05$). Thus, *Callipyge* demonstrated higher cutability carcasses and a more desirable muscle to bone ratio.

Individual muscle weights were taken for the BF, ST, SM, LD, and BF as

percentage of cold side weight (Table 5). Means for each muscle differed ($P < .05$). *Callipyge* carcasses had more mass for each muscle, particularly in the BF and LD. When comparing data from Tables 3, 4, and 5, it should be noted that *Callipyge* were superior to the control carcasses. For example, while the rack and loin primals were approximately of equal percent of the total side weight for each carcass, Table 4 shows that the *Callipyge* carcass side was composed of significantly more lean and significantly less fat. Furthermore, the major muscle in both of these primals, the LD, accounted for a significantly greater proportion of side weight in *Callipyge* than in control carcass. Thus, *Callipyge* deposited lean tissue whereas the control lambs deposited fat to equal the same percent of side weight.

Table 4. Mean dissectible components (percent of side weight) ± SE for control and *Callipyge* lamb carcasses.

Component	Control	*Callipyge*
Fat	$29.0^{b} \pm 1.7$	$19.7^{a} \pm 1.9$
Lean	$48.5^{b} \pm 1.5$	$60.0^{a} \pm 1.6$
Bone	$16.6 \pm .6$	$15.2 \pm .5$

^{a,b} Means within a row lacking a common superscript letter differ ($P < .05$).

Table 5. Mean individual muscle weights (percenr of side weight)± SE for control and *Callipyge* lamb carcasses.

Muscle	Control	*Callipyge*
Biceps femoris	$2.7^{b} \pm .1$	$3.5^{a} \pm .2$
Semitendinosus	$1.0^{b} \pm .1$	$1.3^{a} \pm 0$
Semimembranosus	$3.0^{b} \pm .2$	$3.9^{a} \pm .2$
Longissimus dorsi	$5.8^{b} \pm .2$	$8.1^{a} \pm .3$
Triceps brachii	$2.0^{b} \pm .1$	$2.4^{a} \pm .1$

^{a,b} Means within a row lacking a common superscript letter differ ($P < .05$).

Biochemical Data

Collagen amount did not differ (both were 2.4), however there were differences in percent solubility as affected by muscle (Table 6). This is indicative of a study completed by Hill (1966), in which results indicated that degree of solubility of the collagen, not just total amount, should be considered when biochemical explanations of toughness of meat are considered. The LD had the highest percent solubility while the BF had the lowest.

Table 6. Mean percentage solubility of collagen as affected by muscle.

Muscle	Solubility (%)
Biceps femoris	15.6^{b}
Semitendinosus	16.7^{ab}
Semimembranosus	15.7^{b}
Longissimus dorsi	18.0^{a}
Triceps brachii	15.9^{b}

^{a,b} Means within a row lacking a common superscript letter differ ($P < .05$).

There was no ($P > .05$) treatment by muscle interaction for calpastatin activity;

however, there was a significant treatment effect. *Callipyge* muscles had higher ($P < .05$) calpastatin activity levels than control muscles (3.11 versus 2.47). Across muscles, those from the leg had similar ($P > .05$) calpastatin activity levels than contol muscles. The LD muscle had the lowest calpastatin activity (2.43), but did not differ in calpastatin activity from the BF and SM. *Callipyge* muscles exhibited a higher ($P < .05$) percentage of moisture than the control group (74.71 versus 73.74). versus *Callipyge* muscles.

Sarcomeres from *Callipyge* BF were the longest while other muscles were similar (Table 7). Between muscles, BF and ST had longer ($P < .05$) sarcomere lengths than SM, LD, and TB. Shear force values did not differ between control and *Callipyge* BF. Shear force values for control LD were lowest, but did not differ from BF. *Callipyge* LD had the highest numerical shear values, but did not differ from either the control or *Callipyge* BF. Control muscles contained a higher percentage of fat than the *Callipyge* muscles, which logically follows the rest of the fat data collected in this study. SM had a proportionately greater amount of fat in the control muscle than the *Callipyge* SM.

Table 7. Least-squared means for treatment x muscle effect on sarcomere length (μm), fat (%), and Warner-Bratzler shear force (kg).

Muscle	Control	*Callipyge*
Sarcomere length (μm)		
Biceps femoris	1.85^{b}	1.96^{a}
Semitendinosus	1.87^{b}	1.82^{bc}
Semimembranosus	1.75^{d}	1.74^{d}
Longissimus dorsi	1.77^{cd}	1.72^{d}
Triceps brachii	1.73^{d}	1.70^{d}
Fat (%)		
Biceps femoris	.22^{e}	.12^{e}
Semitendinosus	6.36^{a}	2.71^{cd}
Semimembranosus	3.46^{bc}	1.88^{d}
Longissimus dorsi	4.07^{b}	1.92^{d}
Triceps brachii	3.60^{bc}	2.37^{d}
Shear force (kg)		
Biceps femoris	2.91^{ab}	3.14^{ab}
Longissimus dorsi	1.96^{b}	3.62^{a}

^{a,b,c,d,e} Means within a subheading lacking a common superscript letter differ ($P < .05$).

There was a treatment by muscle interaction for sensory panel tenderness and connective tissue amount ratings (Table 8). The BF did not differ between control or *Callipyge* in myofibrillar or overall tenderness or for connective tissue amount. However, *Callipyge* LD received the lowest tenderness ratings and the control LD received the highest. This interaction followed that observed for shear force values (Table 7).

Table 8. Least-squared means for treatment x muscle effect on sensory attributes.

Sensory attribute[a] / muscle	Control	*Callipyge*
Myofibrillar tenderness		
Biceps femoris	6.2[c]	5.9[c]
Longissimus dorsi	7.0[b]	5.0[d]
Connective tissue		
Biceps femoris	6.0[c]	6.3[c]
Longissimus dorsi	7.1[b]	6.1[c]
Overall tenderness		
Biceps femoris	6.0[c]	6.0[c]
Longissimus dorsi	6.9[b]	4.9[d]

[a] Sensory attributes were rated on an eight point scale where 1 = extremely tough, abundant connective tissue; 8 = extremely tender, no connective tissue.

[b,c,d] Means within a sensory attribute lacking a common superscript letter differ ($P < .05$).

CONCLUSION

Growth traits, such as feed efficiency, and carcass characteristics, such as cutability and USDA yield grade, favored lambs expressing extreme muscle hypertrophy. *Callipyge* lambs produced leaner, trimmer carcasses and required less feed energy to produce the same carcass and primal weight beginning with lighter live weights. However, data suggest that muscle from lambs with normal muscle phenotype was more tender and palatable. Muscle from the control lambs had lower calpastatin activity levels and lower shear force values for LD. Sensory data indicate advantages in myofibrillar and overall tenderness, and connective tissue amount for control LD. Presence or absence of the *Callipyge* gene had a significant effect on LD, while BF was not affected. Carcass data are consistent with current research on lambs expressing the *Callipyge* gene (Koohmaraie et al., 1994; Jackson et al., 1994a), and meat quality data follow trends as seen in Jackson et al. (1994b). Therefore, quality and palatability of meat may be decreased in lambs expressing extreme muscle hypertrophy.

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