EFFECT OF CALCIUM CHLORIDE INFUSION ON THE TENDERNESS OF LAMBS FED A β-ADRENERGIC AGONIST[1]

M. Koohmaraie[2] and S. D. Shackelford[3]

U.S. Department of Agriculture[4], Clay Center, NE 68933
and University of Georgia, Athens 30602

ABSTRACT

The objective of this study was to examine the effectiveness of $CaCl_2$ infusion in overcoming the toughness of meat associated with dietary administration of a β- adrenergic agonist (BAA) to lambs. Thirty-two crossbred (1/2 Finnsheep × 1/4 Dorset × 1/4 Rambouillet) wether lambs were randomly assigned to receive 0 or 4 ppm BAA ($L_{644,969}$; Merck, Sharpe and Dohme Research Laboratories) in a completely mixed, high-concentrate diet for 6 wk. Animals were slaughtered in two groups of 16. At each slaughter time half of each group (0 or 4 ppm BAA) was randomly assigned to $CaCl_2$ infusion. Feeding the BAA decreased ($P < .05$) fat thickness, kidney-pelvic fat, yield grade, and marbling and increased ($P < .05$) dressing percentage, lean firmness, leg score, and biceps femoris weight. Weight of biceps femoris was 32.8% greater in BAA-fed lambs. Treated, but not infused, lambs were significantly less tender than control lambs after 1, 7, and 14 d of postmortem storage. At 24 h postmortem, BAA-fed lambs had higher ($P < .05$) cathepsin B, calcium-dependent protease-II (CDP-II), and CDP inhibitor activities. Calcium chloride infusion increased marbling, decreased lean firmness, increased lean color score, and increased dressing percentage ($P < .05$). Infusion of carcasses with $CaCl_2$ decreased ($P < .05$) shear force at all postmortem times. Infusion of carcasses with $CaCl_2$ had no effect on cathepsins B and B + L activities, but it had a significant effect on CDP-I, CDP-II, and CDP inhibitor activities. The results of these experiments indicate that although feeding the BAA to lambs increased shear force value of longissimus muscle (32% after 14 d postmortem storage), $CaCl_2$ infusion was effective in overcoming this BAA-induced toughness.

Key Words: Lambs, Tenderness, Beta-Adrenergic Agonists, Calcium, Proteases

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Introduction

It has been demonstrated that feeding some β-adrenergic agonists (BAA) to lambs improves feed efficiency and carcass composition (Baker et al., 1984; Hamby et al., 1986; Beermann et al., 1987; Kim et al., 1987; Kretchmar et al., 1990). Also, feeding a BAA to lambs may result in a significant reduction in meat tenderness as determined by shear force (Hamby et al., 1986; Kretchmar et al., 1990). Kretchmar et al. (1989) reported that dietary administration of BAA decreased calcium-dependent protease (CDP)-I activity in lamb longissimus muscle by 10%, increased CDP-II by 34 to 42%, and increased CDP

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[2]USDA, ARS, Roman L. Hruska U.S. Meat Anim. Res. Center, P.O. Box 166, Clay Center.

[3]Present address: Dept. of Anim. Sci., Texas A&M Univ., 348 Kleberg Center, College Station, TX 77843.

[4]Mention of trade names, proprietary products or specific equipment does not constitute a guarantee or warranty of the product by the USDA and does not imply its approval to the exclusion of other products that may also be suitable.

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inhibitor activity by 59 to 75%. Wang and Beermann (1988) also reported that BAA feeding resulted in a decrease in the activity of CDP-I and an increase in CDP-II activity in lamb longissimus muscle.

We have shown that infusion of carcasses with $CaCl_2$ immediately after slaughter results in a significant reduction in shear force such that postmortem storage beyond 24 h to ensure meat tenderness is no longer necessary (Koohmaraie et al., 1988, 1989, 1990). Therefore, objectives of this study were to examine 1) the effect of dietary administration of a BAA (L644,969)[5] on the tenderness of lamb longissimus muscle and 2) the effectiveness of $CaCl_2$ infusion in overcoming the potential toughness of meat resulting from feeding a BAA.

Materials and Methods

Animals. Thirty-two crossbred wether lambs (1/2 Finnsheep × 1/4 Dorset × 1/4 Rambouillet), born within 2 wk and weighing approximately 24 kg, were randomly assigned to two treatment groups: control and BAA. Animals were given ad libitum access to a diet (Table 1) with or without 4 ppm $L_{644,969}$ 6-amino-alpha-{[(1-methyl-3-phenyl-propyl)amino]methyl}-3-pyridine methanol dichloride[5] for 6 wk. The diet was formulated to contain 18% CP. The experiment consisted of two trials, each containing 16 animals (8/treatment).

After 6 wk, animals were slaughtered. At slaughter half the animals from each treatment (control and BAA-fed) were randomly assigned to $CaCl_2$ infusion treatment. Noninfused control and BAA-fed animals were slaughtered according to normal procedures. Control and BAA-fed animals assigned to $CaCl_2$ infusion were slaughtered then infused intra-arterially with a .3 *M* solution of $CaCl_2$ (10% of live weight) according to the procedure described by Koohmaraie et al. (1989). Hot carcass weight was determined; all carcasses were stored in a holding cooler (–1.1°C, no forced-air movement) for 24 h.

At 24 h postmortem, each carcass was ribbed between the 12th and 13th rib for determining USDA quality and yield grade (USDA, 1982); dressing percentage; actual fat thickness; adjusted fat thickness; leg score; loin-eye area; percentage of kidney, pelvic, and heart fat; and marbling were recorded. Lean color and lean firmness were scored on a 1- to 8-point scale (1 = dark and soft, 8 = bleached and firm). At 24 h postmortem, biceps femoris muscle was removed, trimmed of external fat and connective tissue, and weighed.

TABLE 1. COMPOSITION OF DIET

Ingredient	%
Alfalfa	20.00
Corn	59.39
Soybean meal	15.00
Limestone	1.00
Ammonium chloride	.50
Vitamins A, D, and E	.05
Steamed bonemeal	.50
Salt	.50
Rumensin 60	.008
Liquid molasses	3.00
Aureomycin 50	.05

Determination of the Amount and Solubility of Collagen. Longissimus muscle (12th rib region) samples for determination of muscle collagen characteristics were frozen in liquid nitrogen at d 1 postmortem and stored at –70°C prior to extraction. Heat-soluble and insoluble collagen were extracted from longissimus muscle at 24 h postmortem (Hill, 1966). Hydroxyproline contents (Bergman and Loxley, 1963) of the heat-soluble and insoluble portions were multiplied by factors of 7.52 and 7.25, respectively, according to Cross et al. (1973). Values were reported per gram of wet tissue.

Sodium-Dodecyl Sulfate-Polyacrylamide Gel Electrophoresis. The effect of treatments on proteolysis of myofibrillar proteins was examined by SDS-PAGE. Myofibrils were isolated from longissimus muscle after 1 and 7 d of postmortem storage (from a chop adjacent to that used for shear force determination) at 2°C (Goll et al., 1974). Discontinuous 7.5 to 15% gradient gels were run according to the procedures described by Hames and Rickwood (1981). The ratio of acrylamide[6] to bisacrylamide[6] was 75 to 1. The acrylamide solution (30%) contained 50% glycerol.

Shear Force Determination. At 24 h postmortem, the longissimus muscle from the 5th thoracic vertebra to the 5th lumbar vertebra,

[5]Merck, Sharpe and Dohme Research Laboratories, Division of Merck and Co., Inc. Rahway, NJ.
[6]Bio-Rad Laboratories, Richmond, CA.

excluding the 12th and 13th vertebrae, was cut into 2.54-cm chops and vacuum-packaged. Chops were assigned to 1, 7, or 14 d postmortem vacuum aging by stratifying storage time along the length of the longissimus muscle. Chops were broiled[7] to an internal temperature of 40°C, turned over, broiled to an internal temperature of 70°C on electric broilers for determining Warner-Bratzler shear force at 1, 7 and 14 d postmortem such that each location occurred the same number of times for each treatment. Sample preparation followed AMSA (1978) guidelines. Internal temperature was monitored by an iron-constantan thermocouple probe attached to a Honeywell 112 potentiometer. Cooked chops were stored in ventilated polyethylene bags for 24 h at 4°C. After storage, 1.3-cm cores were removed from each chop parallel to the longitudinal orientation of the muscle fibers. Cores were sheared with an Instron 1132\Microcon II Universal Testing Instrument[8] equipped with a Warner-Bratzler type shear blade. The crosshead speed was 5 cm/min and the fail criterion was 75%.

Preparation of Cathepsins B and B + L. Longissimus muscle (at the 12th and 13th vertebrae) samples for determination of lysosomal enzyme activities were frozen in liquid nitrogen at 1 d postmortem and stored at –70°C prior to extraction. Muscle extracts were prepared from 5 g of longissimus muscle (at the 12th and 13th vertebrae) according to procedures described by Etherington et al. (1987). The homogenate was allowed to stand for 1 h at 4°C prior to centrifugation at 25,000 × g_{max} for 30 min to remove debris. The supernate was filtered through glass wool and 2 ml of the supernate was allowed to react (end-over-end mixing) for 2 h with 2 ml of *S*-carboxymethylated-papain-Sepharose[9] (Koohmaraie and Kretchmar, 1990) in a mini-column. The resin was prepared by coupling CNBr-activated Sepharose to papain[10] according to the method of Anastasi et al. (1983). The sample was eluted and the resin was washed with 8 ml of buffer. Protein concentration of the pre- and post-column supernatants was determined spectrophotometrically with bicinchoninic acid (BCA) protein assay reagent[11] according to procedures described by Smith et al. (1985). Activities of cathepsins B and B + L were determined according to the methods of Kirschke et al. (1983) as modified by Koohmaraie and Kretchmar (1990) using amidomethylcoumarin as a fluorescent tag on the substrates, Z-Arg-Arg-NMec and Z-Phe-Arg-NMec[12] (where Z = benzyloxycarbonyl and NMec = 4 methyl-7-coumarylamide) with a 15-min incubation at 37°C. Activities were expressed as nanomoles per minute per gram of muscle.

Preparation of Ca^{2+}-Dependent Proteases and Their Inhibitor. Fifty-gram samples were taken from the longissimus muscle at the 12th and 13th vertebrae for determination of CDP-I, CDP-II, and CDP inhibitor activities at 1 d postmortem. Activities were determined on fresh samples according to the method of Koohmaraie (1990) with the following modifications: 1) extraction solution consisted of 150 m*M* Tris, 50 m*M* ethylene glycol-bis(β-aminoethylether)N,N,N′,N′-tetraacetic acid and 10 m*M* 2-mercaptoethanol, ph 8.3 and 2) dialysis against elution buffer instead of addition of cold water to reduce the conductivity of muscle extract. Activities were expressed as the amount of CDP caseinolytic activity in 50 g of muscle. One unit of CDP-I and -II activity was defined as the amount of enzyme that catalyzed an increase of 1.0 absorbance unit at 278 nm in 1 h at 25°C. One unit of inhibitor activity was defined as the amount that inhibited one unit of CDP-II activity.

Determination of Water-Extractable Calcium. Water-extractable Ca content of longissimus muscle (at the 12th and 13th vertebrae) was determined at 1 d postmortem by atomic absorption according to the procedure described by Nakamura (1973a,b).

Statistical Analysis. An ANOVA (Steel and Torrie, 1980) for a 2 (dietary treatments) × 2 (Ca infusion) randomized complete block design was used to analyze data according to procedures outlined by SAS (1985). When the main effect or interaction was significant, mean separation was accomplished using least-squares *F*-test procedures (Montgomery, 1984). The predetermined level of significance of $P < .05$ was used for all comparisons and will be used for the remainder of this discussion.

[7]Farberware "Open-Hearth" broiler, Model 450N, Bronx, NY.
[8]Instron Corp., Canton, MA.
[9]Pharmacia LKB, Piscataway, NJ.
[10]Sigma Chemical Co., St. Louis, MO.
[11]Pierce, Rockford, IL.
[12]Bachem Fine Chemicals, Torrance, CA.

Results and Discussion

The effect of BAA on weight gain and carcass characteristics is reported in Tables 2 and 3. There were no differences between initial and final weight; consequently, BAA feeding had no effect on weight gain during the 6-wk feeding period. The BAA-fed animals tended to have heavier carcasses (1.2 kg); however, this difference was not statistically significant ($P > .05$). The dressing percentage was significantly ($P < .05$) greater in both BAA-fed and $CaCl_2$-infused animals. The biceps femoris (expressed as percentage of hot carcass weight) was affected by BAA feeding ($P < .05$) but not by $CaCl_2$ infusion. Weight of biceps femoris was 32.8% greater in BAA-fed lambs (269.2 vs 202.7 g). Beermann et al. (1987) and Forsberg et al. (1989) found the same effect on biceps femoris when cimaterol was fed to lambs and rabbits, respectively. The BAA-fed animals had significantly ($P < .05$) lower actual and adjusted fat thicknesses, lower kidney-pelvic fat (expressed as percentage of hot carcass weight), higher leg scores, and lower yield grades and marbling scores. The $CaCl_2$ infusion significantly ($P < .05$) increased marbling and decreased ($P < .05$) lean firmness scores in both control and BAA-fed animals.

Treatment effects on longissimus muscle postmortem proteolysis of the myofibrillar proteins at d 1 and 7 were determined by SDS-PAGE (Figure 1). In myofibrils extracted from control, noninfused samples by d 7 the following changes were observed: 1) the disappearance of a high molecular weight protein (probably titin), 2) the disappearance of a 55 kDa protein (probably desmin), 3) the disappearance of troponin-T, and 4) the appearance of polypeptides with molecular weights of 28 and 32 kDa. However, none of these changes was observed in the longissimus muscle samples obtained from the BAA-fed, noninfused animals. Similar findings have been reported by Kretchmar et al. (1990) and Fiems et al. (1990). These results indicate that the ability of the muscle to undergo postmortem proteolysis was significantly reduced when BAA was fed to lambs. Moreover, the reduced myofibrillar protein degradation in BAA-fed animals corresponds with the decreased antemortem protein degradation (for review, see Yang and McElligott, 1989). Infusion of carcasses with $CaCl_2$ accelerated the occurrence of these changes in the control carcasses such that these changes were evident after 1 d of postmortem storage, as opposed to 7 d in control, noninfused carcasses. However, $CaCl_2$ infusion seems to be less effective in degradation of 55-kDa polypeptide. Infusion of carcasses with $CaCl_2$ also induced these changes in the BAA-fed animals such that the differences between control and BAA-fed animals were eliminated. In fact, these results indicate that meat from BAA-fed animals, after 1 d of postmortem storage, was in a more advanced stage of proteolysis than meat from control, noninfused animals at the same time postmortem time.

Neither BAA feeding nor $CaCl_2$ infusion affected total collagen content or percentage of heat-soluble collagen of longissimus muscle

TABLE 2. EFFECT OF TREATMENTS ON GROWTH AND CARCASS CHARACTERISTICS OF WETHER LAMBS

Treatment	$CaCl_2$ infusion	Starting wt, kg	Slaughter wt, kg	Hot carcass wt, kg	Dressing percentage	Biceps femoris wt, % of hot carcass wt
Control	–	24.9	35.1	18.6	52.8	1.09
Control	+	24.0	35.0	19.6	55.9	1.09
$L_{644,969}$	–	24.4	35.4	19.8	55.9	1.36
$L_{644,969}$	+	24.3	35.4	20.9	59.0	1.23
Pooled SEM		.8	1.0	.7	.8	.04
Significance						
Treatment		NS[a]	NS	NS	*	*
$CaCl_2$		NS	NS	NS	*	NS
Interaction		NS	NS	NS	NS	NS

[a]NS = not statistically significant ($P > .05$).

*$P < .05$.

TABLE 3. EFFECT OF TREATMENTS ON CARCASS CHARACTERISTICS OF WETHER LAMBS

Treatment	$CaCl_2$ infusion	Actual fat thickness, mm	Adjusted fat thickness, mm	Lion-eye area, cm^2	Kidney-pelvic fat, %	Leg score	Yield grade	Marbling score[a]	Lean color[b]	Lean firmness[b]
Control	–	4.3	4.5	10.5	4.8	9.1	3.6	187.5	4.5	5.6
Control	+	3.9	4.3	11.7	4.4	9.5	3.4	242.5	5.9	3.9
$L_{644,969}$	–	2.5	2.7	11.8	3.3	10.9	2.6	136.3	4.4	7.1
$L_{644,969}$	+	3.3	3.4	11.4	3.6	11.0	2.9	195.0	6.4	4.9
Pooled SEM		.4	.4	.5	.5	.4	.2	15.5	.3	.4
Significance										
Treatment		*	*	NS	*	*	*	*	NS	*
$CaCl_2$ infusion		NS[c]	NS	NS	NS	NS	NS	*	*	*
Interaction		NS	NS	NS	NS	NS	NS	NS	NS	NS

[a]Marbling scores were 100–199 = slight, 200–299 = small, and 300–399 = modest.
[b]Lean color and lean firmness were scored on an 8- point scale: 1 = dark and soft and 8 = bleached and firm.
[c]NS = not statistically significant ($P > .05$).
*$P < .05$.

TABLE 4. EFFECT OF TREATMENTS ON LONGISSIMUS MUSCLE COLLAGEN CHARACTERISTICS IN WETHER LAMBS

Treatment	$CaCl_2$ infusion	Total collagen, mg/g tissue	Heat-soluble collagen, %
Control	–	3.41	22.0
Control	+	3.29	19.5
$L_{644,969}$	–	2.96	23.6
$L_{644,969}$	+	2.69	20.4
Pooled SEM		.27	2.0
Significance			
Treatment		NS[a]	NS
$CaCl_2$ infusion		NS	NS
Interaction		NS	NS

[a]NS = not statistically significant ($P > .05$).

(Table 4). These results are in agreement with those of Morgan et al. (1989), who reported that feeding cimaterol to broiler chickens had no effect on similar collagen characteristics.

The longissimus muscle tenderness at 1, 7, and 14 d postmortem as determined by shear force is reported in Table 5. Results indicate that regardless of $CaCl_2$ infusion, BAA-fed animals had higher ($P < .05$) shear force (i.e., were tougher) at all postmortem times. Results also indicate that $CaCl_2$ infusion lowered ($P < .05$) shear force values (i.e., more tender) of both BAA-fed and control animals at all postmortem times. The interaction between $CaCl_2$ infusion and BAA feeding was not significant at any postmortem time, indicating that the magnitude of the decrease in shear

TABLE 5. EFFECT OF TREATMENTS ON LONGISSIMUS TISSUE TENDERNESS AT DIFFERENT POSTMORTEM TIMES IN WETHER LAMBS

Treatment	$CaCl_2$ infusion	Shear force, kg		
		d 1	d 7	d 14
Control	–	10.0	7.7	6.9
Control	+	3.0	3.1	2.7
$L_{644,969}$	–	11.4	9.6	9.1
$L_{644,969}$	+	6.0	5.2	5.2
Pooled SEM		.7	.7	.9
Significance				
Treatment		*	*	*
$CaCl_2$		*	*	*
Interaction		NS[a]	NS	NS

[a]NS = not statistically significant ($P > .05$).
*$P < .05$.

force due to $CaCl_2$ infusion was the same on control and BAA-fed carcasses. Although the difference in the magnitude of the decrease in shear force (i.e., tenderization) was not statistically different in BAA-fed and control animals, the shear force at all postmortem times was lower in control/$CaCl_2$-infused than in BAA-fed/$CaCl_2$-infused carcasses. When the data were analyzed using Ca content after infusion as a covariate, the interaction still was not significant, indicating that the differences in the shear force values between control/$CaCl_2$-infused and BAA-fed/$CaCl_2$-infused carcasses were probably due to factors other than Ca content of the muscle. This conclusion is supported by the CDP-I activities (Table 6); CDP-I was activated to the same degree with $CaCl_2$ infusion of control and BAA-fed animals. In addition, SDS-PAGE results indicated that $CaCl_2$ infusion induced similar changes in both groups of animals. The question at this point is why chops obtained from BAA-fed $CaCl_2$-infused animals were less tender than control/$CaCl_2$-infused chops (Table 5) when other results indicate that infusion was just as effective in control carcasses (Table 6 and Figure 1). It has been demonstrated that feeding a different BAA, cimaterol, did not alter fiber type composition of longissimus muscle but did significantly (50%) increase the cross-sectional area of both type I and II fibers (Kim et al., 1987). It has

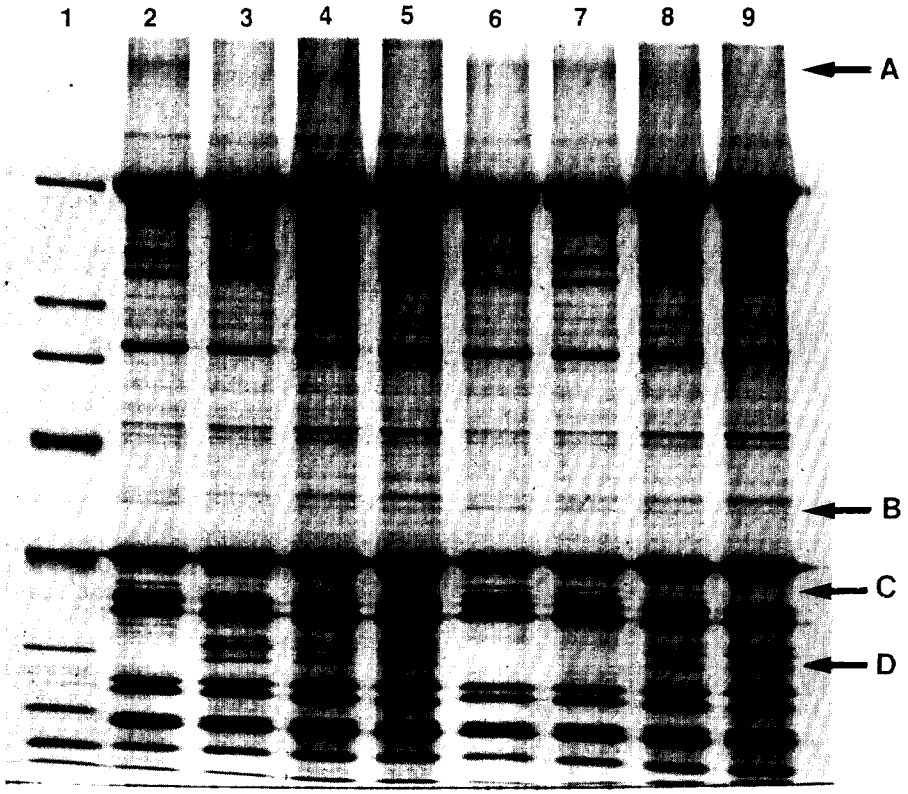

Figure 1. SDS-PAGE of myofibrils isolated from longissimus muscle of control (Lanes 2 and 3), control-infused with $CaCl_2$ (Lanes 4 and 5), β-agonist-fed (Lanes 6 and 7), and β-agonist-fed $CaCl_2$-infused (Lanes 8 and 9) carcasses after 1 and 7 d of postmortem storage at 2°C. Lane 1 is molecular weight standards corresponding to 200 kDa (myosin), 116.2 kDa (*E. coli* β-galactosidase), 97.4 kDa (rabbit muscle phosphorylase b), 66.2 kDa (bovine serum albumin), 42.7 kDa (hen egg white ovalbumin), 31 kDa (bovine carbonic anhydrase), 21.5 kDa (soybean trypsin inhibitor), and 14.4 kDa (hen egg white lysozyme) from top to bottom, respectively. Arrows A, B, C, and D correspond to the high molecular weight polypeptide (probably titin), 55 kDa polypeptide (probably desmin), troponin-T, and 28 to 32 kDa polypeptides, respectively. Samples (60 μg of purified myofibrillar proteins) were separated by electrophoresis on a 7.5 to 15% gradient polyacrylamide gel and stained with coomassie blue R-250.

TABLE 6. EFFECT OF TREATMENTS ON THE CALCIUM CONTENT AND ACTIVITIES OF CALCIUM-DEPENDENT PROTEASES AND THEIR INHIBITOR OF LONGISSIMUS MUSCLE IN WETHER LAMBS

Treatment	$CaCl_2$ infusion	Calcium[a]	CDP-I[b]	CDP-II[c]	CDP inhibitor[d]
Control	–	9.2[g]	60.9	62.9	72.8[f]
Control	+	835.7[e]	2.5	10.7	11.2[g]
$L_{644,969}$	–	9.1[g]	57.3	89.8	183.1[e]
$L_{644,969}$	+	372.6[f]	9.0	22.9	46.2[f]
Pooled SEM		92.7	5.0	7.1	12.1
Significance					
Treatment		*	NS[h]	*	*
$CaCl_2$ infusion		*	*	*	*
Interaction		*	NS	NS	*

[a]Water-extractable calcium, μg/g muscle.

[b]Low Ca^{2+}-requiring Ca^{2+}- dependent protease total activity/50 g muscle (caseinolytic activity).

[c]High Ca^{2+}-requiring Ca^{2+}-dependent protease total activity/50 g muscle (caseinolytic activity).

[d]Inhibitor of CDP-I and CDP-II, A_{278}/50 g muscle (inhibition of casein hydrolysis by CDP-II).

[e,f,g]Means within the same column, within an independent variable, with different superscripts differ ($P < .05$).

[h]NS = not statistically significant ($P > .05$).

*$P < .05$.

been found that there is a significant positive correlation between fiber diameter and shear force in longissimus muscle (Tuma et al., 1962; Crouse et al., 1990). Because high shear force is associated with larger fiber diameter and feeding a BAA increases fiber diameter, it is possible that the differences between shear force values of control- and BAA-fed/$CaCl_2$-infused carcasses are due to the differences in fiber diameter. Further support for this speculation was indicated when the data were analyzed by using Ca content as covariate.

The results of lysosomal enzymes and their inhibitor activities determined at 24 h postmortem are reported in Table 7. Of the determinations made, the only statistically significant effect ($P < .05$), was that BAA-fed animals had higher (41%) cathepsin B activity. In contrast to this study, using the same BAA compound and the same species, Kretchmar et al. (1989) reported that BAA feeding reduced the activity of cathepsin B by 30%. The reason for this discrepancy is not apparent. However, it is worth mentioning that different methods

TABLE 7. EFFECT OF TREATMENTS ON THE ACTIVITIES OF CATHEPSIN B, CATHEPSIN B + L, AND CYSTATIN(S) OF LONGISSIMUS MUSCLE IN WETHER LAMBS

Treatment	$CaCl_2$ infusion	B[a]	B + L[a]	Cystatin(s)[b]
Control	–	28.4	135.3	1.8
Control	+	25.6	143.9	1.8
$L_{644,969}$	–	38.7	156.9	1.8
$L_{644,969}$	+	37.5	146.0	1.7
Pooled SEM		4.9	20.6	.1
Significance				
Treatment		*	NS	NS
$CaCl_2$ infusion		NS[c]	NS	NS
Interaction		NS	NS	NS

[a]Nanomoles of NMec (amido-methylcoumarin) released per minute per gram of muscle.

[b]Cathepsin B + L activity after affinity chromatography/cathepsins B + L activity before affinity chromatography.

[c]NS = not statistically significant ($P > .05$).

*$P < .05$.

were used in these two studies to quantify cathepsin B activity. We believe that the method used in this study is more appropriate, because we (Koohmaraie and Kretchmar, 1990) have compared the methods used in these two studies and found that the method used in the present study was more appropriate for quantification of cathepsins for comparative purposes. Kretchmar et al. (1989) assayed catheptic enzymes before removal of their endogenous inhibitor (cystatins) and at substrate concentrations far below K_m (see Koohmaraie and Kretchmar, 1990).

The results of Ca content and the activities of the components of the CDP system of longissimus muscle, determined at 24 h postmortem, are reported in Table 6. As expected (Koohmaraie et al., 1989, 1990), $CaCl_2$ infusion significantly ($P < .05$) increased the water-extractable Ca content of longissimus muscle. However, the increase in Ca content was not the same for control and BAA-fed carcasses ($P < .05$). The Ca content of the longissimus muscle for control- and BAA-infused carcasses was 835.7 and 372.6 μg/g muscle, respectively. It is not clear at this point why, in spite of all the precautions taken (i.e., all $CaCl_2$ solutions prepared and infused by the same person, and complete randomization of treatment with regard to order of infusion), the uptake of Ca was so much lower in BAA-infused than in control-infused longissimus muscle. Results also indicate that BAA feeding had no effect ($P < .05$) on extractable CDP-I activity and increased the extractable CDP-II and CDP inhibitor activities ($P < .05$). As expected (Koohmaraie et al., 1989), $CaCl_2$ infusion significantly ($P < .05$) decreased the extractable CDP-I, -II and CDP inhibitor activities. The interaction between the effect of $CaCl_2$ infusion and BAA-feeding was significant with regard to CDP inhibitor activity, indicating that the percentage of decline in the CDP inhibitor activity was not the same for longissimus muscle from control and BAA-fed animals, after $CaCl_2$ infusion. At 24 h postmortem the CDP inhibitor activity was highest in muscle from BAA-fed and lowest in control $CaCl_2$-infused animals. Muscle from control and BAA-fed/$CaCl_2$-infused was intermediate in 24-h CDP inhibitor activity. When the CDP inhibitor data were analyzed by using Ca content at 24 h postmortem as a covariate, the interaction between $CaCl_2$ infusion and BAA feeding was still significant. This analysis indicated that the differences in the 24-h CDP inhibitor activities were not due to the differences observed in the Ca content after infusion and thus resulted from the BAA feeding.

Implications

Results of several studies have indicated that feeding some β-adrenergic agonist (BAA) compounds to lambs results in improvement in feed efficiency and carcass composition. One of the major disadvantages of feeding BAA is the significant reduction in meat tenderness. We have previously shown that infusion of lamb carcasses with calcium chloride immediately after slaughter results in significant improvement in meat tenderness. This study was undertaken to determine the effectiveness of calcium chloride infusion in overcoming the BAA-induced meat toughness. Results indicate that calcium chloride infusion is an effective method to overcome BAA-induced meat toughness.

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