Effect of the administration program of 2 β-adrenergic agonists on growth performance and carcass and meat characteristics of feedlot ram lambs

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ABSTRACT: The aim of the study was to determine the effects of 3 feeding dose programs of the β-adrenergic agonists (β-AA) ractopamine hydrochloride (RH) or zilpaterol hydrochloride (ZH) for the final 30 d before slaughter on growth performance and carcass and meat characteristics of feedlot ram lambs. Eighty-four Dorper × Katahdin ram lambs (30.0 ± 1.6 kg) were blocked by BW and randomly assigned to pens (4 lambs per pen and 3 pens per treatment). Pens within a block were assigned randomly to 1 of 7 dietary treatments: 1) control (CTL) = diet without β-AA; 2) RH constant (RHC) = 20.0 mg/kg of RH, d 1 to 30; 3) RH increasing (RHI) = 10.0 mg/kg, d 1 to 10; 20.0 mg/kg, d 11 to 20; and 30.0 mg/kg, d 21 to 30; 4) RH decreasing (RHD) = 30.0 mg/kg, d 1 to 10; 20.0 mg/kg, d 11 to 20; and 10.0 mg/kg, d 21 to 30; 5) ZH constant (ZHC) = 6.0 mg/kg of ZH, d 1 to 30; 6) ZH increasing (ZHI) = 3.0 mg/kg, d 1 to 10; 6.0 mg/kg, d 11 to 20; and 9.0 mg/kg d 21 to 30; and 7) ZH decreasing (ZHD) = 9.0 mg/kg, d 1 to 10; 6.0 mg/kg, d 11 to 20; and 3.0 mg/kg, d 21 to 30. Overall, β-AA supplementation reduced DMI ($P < 0.001$) compared with CTL lambs, but lambs fed RHI and ZHI programs had greater ($P < 0.05$) total BW gain, ADG, and G:F. Carcass weight was improved ($P < 0.05$) by RHI and ZHI programs, but dressing percentage was enhanced ($P < 0.05$) by only ZHC or ZHI treatments. Fat thickness and yield grade were reduced ($P < 0.05$) by ZH or RH regardless of feeding program. Most LM characteristics (pH, moisture loss, and chemical composition) were not different among treatments ($P > 0.05$), with the exception of fat content that was reduced ($P < 0.001$) in lambs fed β-AA, and diameter of muscle fibers that was increased ($P < 0.05$) by ZHI treatment. Constant and increasing doses of ZH reduced ($P < 0.05$) the a* value of LM and semitendinosus muscles, with no effects on L* or b* values. The mass of liver was reduced ($P < 0.05$) in ZHI-treated lambs compared with CTL lambs, and plasma urea concentration was reduced ($P < 0.05$) by RH or ZH administration regardless of feeding program, although there were no other differences in organ mass weight ($P \geq 0.35$) or blood metabolites ($P \geq 0.16$). Increasing doses of RH or ZH augmented the growth performance response without negative effects on organ mass weight or blood metabolites. Although a ZHI program improved carcass characteristics, the increased LM fiber diameter of lambs fed ZHI program could be unfavorable because of the potential negative effect on tenderness.

Keywords: carcass characteristic, feeding program, growth performance, ractopamine hydrochloride, ram lamb, zilpaterol hydrochloride

J. Anim. Sci. 2012.90:1521–1531
doi:10.2527/jas2010-3513

INTRODUCTION

The livestock and meat industries are constantly seeking alternatives to promote growth performance and improve carcass characteristics (Beermann, 2009). The β-adrenergic agonists (β-AA) improve growth performance, disruption of adipose accretion, and increase muscle mass in food animals (Johnson and Chung, 2007). Currently, ractopamine hydrochloride (**RH**) and zilpaterol hydrochloride (**ZH**) are the only β-AA available for use in cattle and swine feed in México, Canada, the United States, and South Africa.

[1]This study was conducted while the first author was a graduate student with financial support of the National Council of Science and Technology and the Autonomous University of Zacatecas, México.

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Received September 14, 2010.
Accepted November 18, 2011.

Neither RH nor ZH are approved for feeding sheep in México or other countries, but improvements in growth performance or carcass characteristics have been previously reported by oral administration of both β-AA in finishing lambs (Aguilera-Soto et al., 2008; Estrada-Angulo et al., 2008; López-Carlos et al., 2010), demonstrating their potential use as growth promoters in sheep. Although, most research studies in sheep have focused on the feeding of a constant dietary concentration of β-AA for a fixed period of time, it seems that β-AA administration has its greatest effect during the first 2 wk of treatment with a subsequent gradual decrease in the response for the next weeks (Kim et al., 1989; Pringle et al., 1993; Aguilera-Soto et al., 2008). This effect may be attributed to a temporal desensitization or downregulation of β-adrenergic receptors, leading to a decrease in the expecting response by chronic administration of β-AA (Mills, 2002).

Previous research demonstrated that modifying the dose of β-AA throughout the feeding period may be useful to compensate for the decline response in rats (McElligott et al., 1989; Kim et al. 1995) and pigs (See et al., 2004; Canchi et al., 2010). However, the possibility to improve the response to β-AA with this approach has not been investigated in finishing ram lambs. Therefore, our hypothesis was that increasing or decreasing the dose concentration of RH or ZH in the diet of feedlot ram lambs during the last 30 d on feed will improve their growth performance and carcass and meat characteristics compared with a constant dose concentration in the diet. The objective of this study was to evaluate the effect of a RH or ZH feeding program on growth performance and carcass and meat characteristics of feedlot ram lambs.

MATERIALS AND METHODS

Research protocols, animal care, and management procedures were made in accordance with approved local official techniques of animal care (NOM-051-ZOO-1995: Humanitarian care of animals during mobilization of animals; NOM-024-ZOO-1995: Animal health stipulations and characteristics during transportation of animals; NOM-033-ZOO-1995: Humanitarian sacrifice of domestic and wild animals; NOM-EM-015-ZOO-2002: Technical stipulations for the control use of β agonists in animals). In addition, the techniques and procedures employed were in agreement with the provisions of the Guide for the Care and Use of Agricultural Animals in Research and Teaching (FASS, 2010). After taking measurements and samples required for this study, the resulting meat and organs were destroyed by incineration because currently neither RH nor ZH are approved for feeding sheep in México.

Animals, Housing, and Management

The experiment was conducted in the Small Ruminant Experimental Center of the Veterinary Medicine and Animal Science College of the University of Zacatecas. One hundred fifteen crossbred (Dorper × Katahdin) ram lambs born in June and July of 2009 in Zacatecas, México (north-central México), were acquired from a local flock. Ram lambs received supplementation with a standard lamb creep-feed 7 d postpartum until weaning. At weaning, lambs were fed with concentrates and the available forage (alfalfa, oat hay, corn stover, or a mixture of the 3).

Ram lambs were received after weaning (9 to 10 wk of age), weighed, and randomly assigned to groups of 10 lambs per pen. Lambs were dewormed (Cydectin, Fort Dodge Animal Health, México City, México) and vaccinated against *Clostridium* spp. and *Pasteurella* spp. (Bobact 8, Intervet, México City, México). Forty days before the feeding trial, ram lambs were allowed ad libitum access to a diet formulated for early-weaned lambs of moderate growth potential (NRC, 2007) containing alfalfa hay, corn grain, soybean meal, and a commercial mix of vitamins and trace elements. Upon conclusion of the 40-d postweaning growth period, 84 ram lambs were selected out of the original 115 lambs based on size conformity and BW. Lambs were ranked by BW and divided into 3 blocks (block 1 = 28.3 ± 0.6, block 2 = 30.1 ± 0.5, block 3 = 31.8 ± 0.5 kg), with 28 lambs in each block. From each block, 4 lambs were randomly assigned to 1 of 7 treatments, for a total of 21 pens (4 lambs per pen). Pens were roofed (2.5 × 3 m) and equipped with a 1.5-m metallic fence-line feed bunk and automatic waterers. After a 10-d adaptation period, lambs consumed a diet, ad libitum twice daily (at 0700 and 1800 h), containing 18.7% CP and 3.53 Mcal/kg of DE on a DM basis (Table 1).

Treatments

Dietary treatments were administered for the final 30 d before slaughter, and diet changes occurred at 10-d intervals over the 30-d experimental period. The treatments were intended to evaluate the effects of constant, increasing (step-up), and decreasing (step-down) dietary doses of 2 β-AA compounds, RH (Optaflexx, Elanco Animal Health, Guadalajara, Jalisco, México) and ZH (Zilmax, Intervet/Schering-Plough Animal Health, México City, México), and a control.

Dietary treatments (as-fed basis) were 1) control (**CTL**) = basal diet without β-AA; 2) RH at a constant dose (**RHC**) = 20.0 mg/kg of RH for 30 d; 3) RH at a stepwise increasing dose (**RHI**) = 10.0 mg/kg of RH from d 1 to 10, 20.0 mg/kg of RH from d 11 to 20, and 30.0 mg/kg of RH from d 21 to 30; 4) RH at

Table 1. Ingredient and nutrient composition of the basal diet (as-fed basis)[1] fed to ram lambs

Item	Value
Ingredient, %	
Ground yellow corn	47.65
Alfalfa hay	28.06
Cottonseed meal	12.40
Soybean meal	5.09
Molasses	2.25
Liquid fat	2.17
Limestone	0.95
Sodium bicarbonate	0.95
Sodium phosphate	0.48
Chemical composition[2,3]	
DM, %	90.6
CP, %	18.7
TDN, %	79.7
DE, Mcal/kg of DM	3.5
ME, Mcal/kg of DM	3.0
NDF, %	51.8
ADF, %	32.5
Ca, %	1.2
P, %	0.6
Fat, %	5.3

[1]Ractopamine hydrochloride (Optaflexx, Elanco Animal Health Guadalajara, Jalisco, México) or zilpaterol hydrochloride (Zilmax, Intervet/Schering-Plough Animal Health, México City, México) were added to the basal diet at the expense of ground corn to achieve final dietary ractopamine concentrations (as fed) of 10.0, 20.0, and 30.0 mg/kg, or final dietary zilpaterol concentrations of 3.0, 6.0, and 9.0 mg/kg.

[2]Values except DM are expressed on a DM basis.

[3]Analyzed values, except for TDN, DE, and ME, which were calculated from NRC (2007) feed composition tables.

a stepwise decreasing dose (**RHD**) = 30.0 mg/kg of RH from d 1 to 10, 20.0 mg/kg of RH from d 11 to 20, and 10.0 mg/kg of RH from d 21 to 30; 5) ZH at a constant dose (**ZHC**) = 6.0 mg/kg of ZH for 30 d; 6) ZH at a stepwise increasing dose (**ZHI**) = 3.0 mg/kg of ZH from d 1 to 10, 6.0 mg/kg of ZH from d 10 to 20, and 9.0 mg/kg of ZH from d 21 to 30; and 7) ZH at a stepwise decreasing dose (**ZHD**) = 9.0 mg/kg of ZH from d 1 to 10, 6.0 mg/kg of ZH from d 11 to 20, and 3.0 mg/kg of ZH from d 21 to 30.

Growth Performance

All lambs were individually weighed at d 0, 10, 20, and 30 of the experimental period (before the morning feeding) using an electronic scale (EziWeigh1, Tru-test Ltd. Auckland, New Zealand). Feed offered and rejected was weighed and registered daily and adjusted for minimal accumulation (<5%). A sample of orts was collected daily and dried in a forced-air oven at 100°C for 24 h to determine DM content and used to estimate the corrected DMI (as-fed intake of feed multiplied by percentage DM). The corrected DMI by pen was divided by the number of animals in the pen to determine the average DMI/lamb. The feed efficiency ratio [(kg of BW gain/kg of feed intake) × 100] was calculated for every feeding period.

Lamb Slaughter and Carcass Measurements

At the end of the 30-d trial period, 2 ram lambs per pen (6 ram lambs per treatment, n = 42) were randomly chosen for slaughter. Before slaughter, lambs experienced a 72-h withdrawal period from RH or ZH. Lambs were loaded at 0700 h and hauled less than 0.5 km to the abattoir of the Faculty of Veterinary Medicine and Animal Science of the Autonomous University of Zacatecas for slaughter. Upon arrival at the abattoir and immediately before slaughter, the lambs were weighed (preslaughter BW) for further calculations.

The slaughter procedures were according to humane methods (Mexican Official Standard NOM-033-ZOO-1995: Humanitarian harvest of domestic and wild animals). The lambs were eviscerated, and the head, testicles, liver, pluck, mesentery fat, and full and digesta-free components of the gastrointestinal tract were weighed. The gastrointestinal content was weighed and subtracted from preslaughter BW to obtain empty BW (**EBW**). Mass of body components was expressed in kilograms and grams per kilogram of EBW. Individual carcasses were weighed to obtain HCW. Carcasses were refrigerated for 24 h at 4°C and weighed to obtain cold carcass weight (**CCW**) and carcass dressing percentage (**DP**). The difference between HCW and CCW was used to calculate cooling loss (**CL**).

Carcasses were split in half, and the right sides of each carcass were used for further analyses. Right sides were separated between the 12th and 13th ribs, and LM area was measured with a planimeter. Fat thickness (**FT**) was measured at approximately 5.0 cm lateral to the middle line, over the center of the LM with calipers, and used to calculate USDA yield grade {[(10 × fat thickness, in.) + 0.4]; USDA, 1992}.

Lean Surface Color, pH, Moisture Loss, Chemical Composition, and Fiber Diameter of LM

The lean surface color (L*, a*, and b*) was measured (in triplicate each time and averaged) using a Minolta CR-400 spectrometer (Konica Minolta Sensing Inc., Osaka, Japan) on the surface of the semitendinosus muscle (**STN**) and in the posterior LM exposure resulting from the 12th/13th-rib cut, after 24 h postmortem and at 4°C. The pH measurements were obtained at 45 min and 24 h postmortem in the LM between 1st and 2nd lumbar vertebrae, using a pH meter equipped with a penetrating electrode and thermometer (Hanna Instruments, HI–9025, Woonsocket, RI).

At 24 h postmortem, the LM located between 12th rib and 2nd lumbar vertebrae was removed from the right side of each carcass and fabricated into 2-cm-thick steaks. Steaks were weighed and placed individually in sealed plastic bags under vacuum. Steaks were refrigerated at 4°C for 3 d, and then frozen and stored at −20°C until subsequent measurements were performed.

Purge loss and cook loss were determined at 14 d postmortem. After storage, frozen steaks were tempered for 24 h at 4°C, blotted dry, and weighed. Purge loss was calculated using the weights taken before and after opening the vacuum packages after 14 d of storage. Cook loss was determined by weight loss after cooking steak samples of approximately 2 cm^3 and between 15 to 20 g. Samples were individually placed in sealed plastic bags and heated in a water bath at 75°C until reaching an internal temperature of 70°C. Temperature was monitored with thermocouples introduced in the core. After cooking, samples were cooled for 15 min under running tap water, removed from packaging, blotted to remove excess surface moisture, and weighed. Purge loss and cook loss were expressed as the percentage of loss related to the initial weight [(initial weight − final weight)/initial weight] × 100.

Chemical analyses on the LM were carried out according to AOAC procedures in sections 950.46, 992.15, 960.39, and 920.153 (AOAC, 2006). The total water content was determined using an oven drying method at 110°C for 24 h. The CP content (N × 6.25) was carried out with a Leco protein analyzer (model FP628, Leco Corp., St. Joseph, MI). The total lipid content was measured using the Soxhlet method. The total ash content was determined using a gravimetric method by heating the sample at 550°C in a muffle furnace for 24 h.

Samples of the LM were dissected from the right side of the carcass, and 1-cm^3 samples were taken from the area adjacent to the last rib at a constant depth of 1 cm. Muscle samples were collected within 45 min after slaughter and placed in neutral buffered 10% formalin. Samples were subsequently processed by routine paraffin embedding techniques, and transverse serial sections were cut in 4-µm sections. Slides were stained with hematoxylin-eosin, and then 1 drop of glycerol gelatin was placed on the section and covered with a coverslip.

Muscle fiber measurements were obtained by capturing photomicrograph pictures with a Moticam 1000 High-Resolution live imaging camera (Motic China Group, Co. Ltd., Xiamen, China) mounted on a light microscope (Zeiss, Germany). Several fields on each serial section were photographed at 25×, and photos of different areas of each muscle sample were used to evaluate the fiber diameter. For each carcass sample, a minimum of 300 fibers was measured with the help of the software Motic Images plus 2.0 (Motic China Group Co. Ltd., Xiamen, China). The minimum fiber diameter was measured to avoid possible errors because of tilted sections. Muscle fiber area was calculated from the fiber diameters: $A = \pi(\text{diameter}/2)^2$ (Kirchofer et al., 2002).

Blood Metabolites

Six lambs from each treatment (2 ram lambs per block) were randomly selected for collection of blood samples to evaluate blood metabolites. Blood samples (15 mL) were collected into vacuum tubes (BD Vacutainer, Becton Dickinson, Franklin Lakes, NJ) on d 0, 10, 20, and 30 by jugular venipuncture 2 h after the morning meal. Blood serum was harvested by centrifugation (2,000 × *g* for 15 min; 4°C) and stored in aliquots (1 mL) at –20°C for later analysis of urea N, total proteins, creatinine, triacylglycerols, and cholesterol. Plasma metabolites were quantified by spectrophotometry procedures (Jenway 6320D, Bibby Scientific Limited, Staffordshire, UK) using kits of Diagnostic Chemicals Ltd. (Charlottetown, Prince Edward Island, Canada).

Statistical Analyses

Assumptions of normality were tested using the UNIVARIATE procedure (SAS Inst. Inc., Cary, NC). Growth performance and blood metabolites data were analyzed as a randomized complete block design and repeated measurements using the MIXED procedure of SAS. Blocking criteria was initial BW. Pen was the experimental unit, and block was a random effect. Fixed effects included duration (10-d periods), treatment (CTL, RH, and ZH feeding programs), and the duration × treatment interaction. Analyses were conducted using multiple covariance structures to determine the most appropriate structure by the smallest Akaike and Schwarz's Bayesian criteria. For growth performance, an autoregressive structure was used for GDP and BW, and a variance component structure was used for DMI and G:F. Moreover, for blood metabolites, an unstructured covariance was used for total proteins, triglycerides, and cholesterol, and the variance component structure was adjusted for creatinine and urea.

Data for carcass and meat characteristics and body component mass were analyzed as a randomized complete block design using the MIXED procedure of SAS. Pen served as the experimental unit. Means were separated using the Tukey method at a significance level of $P < 0.05$.

RESULTS AND DISCUSSION

Growth Performance

There were treatment × period interactions ($P < 0.001$) for all growth and performance variables (Table 2). During d 1 through 10, there were not differences ($P \geq 0.19$) in BW, ADG, and G:F among lambs fed CTL, RH, or ZH diets, but there was a reduction ($P < 0.004$) in DMI for lambs receiving β-AA independent of the feeding program. During d 11 to 20, there were not differences among treatments for BW ($P = 0.75$) and DMI ($P = 0.26$), but ADG and G:F were improved ($P < 0.05$) in lambs on ZHD and ZHC programs compared with CTL lambs. During d 21 to 30, lambs receiving either β-AA showed greater BW ($P = 0.031$) in comparison with CTL lambs. Furthermore, greater ($P < 0.05$) ADG and G:F were observed in lambs fed RHI or ZHI programs, followed by lambs fed ZHC programs, but lambs fed RHC, RHD, or ZHD programs were not different ($P > 0.05$) from CTL lambs. In this period, DMI did not differ ($P = 0.40$) among treatments.

For the overall 30-d trial (Table 2), lambs that received the RHI or ZHI programs showed greater ($P < 0.05$) total BW gain and ADG than CTL lambs, but lambs that received constant (RHC and ZHC) or stepwise decreasing programs (RHD and ZHD) were similar ($P < 0.05$) to lambs fed CTL diet. In addition, DMI was reduced ($P < 0.001$) by β-AA administration at any dietary regimen. Furthermore, G:F was improved ($P = 0.016$) in lambs on RHI, ZHI, ZHC, or ZHD feeding programs.

In concurrence with results observed in the present study, increases in ADG, G:F, total BW gain, and final BW have been consistently reported in experiments carried out in beef cattle fed RH (Abney et al., 2007; Winterholler et al., 2008) and ZH (Plascencia et al., 2008; Montgomery et al., 2009), and in sheep fed ZH (Salinas-Chavira et al., 2004; Estrada-Angulo et al., 2008). Moreover, Robles-Estrada et al. (2009) reported improvements on final BW, ADG, and G:F for ZH-treated compared with RH-treated feedlot lambs. However, in this study, growth performance was similar between lambs fed RH and ZH at a constant dose (RHC and ZHC), in agreement with López-Carlos et al. (2010), who reported similar growth in finishing lambs fed RH or ZH.

Table 2. Effect of constant, step-up, or step-down feeding program of the β-adrenergic agonists ractopamine hydrochloride (RH) or zilpaterol hydrochloride (ZH) during the last 30 d on feed on growth performance of feedlot ram lambs[1]

		RH program[3]			ZH program[4]				
Item	CTL[2]	RHI	RHC	RHD	ZHI	ZHC	ZHD	SEM	*P*-value
BW at d 0, kg	30.0	30.2	30.7	29.2	29.9	29.4	30.5	0.81	0.81
d 1 to 10									
BW at 10 d, kg	32.1	31.9	31.7	32.4	31.4	31.6	31.2	0.45	0.44
ADG, kg/d	0.204	0.205	0.179	0.238	0.138	0.163	0.126	0.0342	0.19
DMI, kg/d	1.27[a]	1.15[b]	1.10[b]	1.11[b]	1.10[b]	1.08[b]	1.10[b]	0.037	0.004
G:F	0.169	0.166	0.162	0.215	0.120	0.145	0.126	0.0327	0.43
d 11 to 20									
BW at 20 d, kg	34.4	34.5	34.6	35.0	34.1	35.0	35.1	0.48	0.75
ADG, kg/d	0.253[c]	0.283[bc]	0.319[bc]	0.292[bc]	0.301[bc]	0.370[ab]	0.426[a]	0.0285	0.002
DMI, kg/d	1.42	1.33	1.31	1.30	1.32	1.37	1.32	0.040	0.26
G:F	0.178[c]	0.219[bc]	0.240[bc]	0.227[bc]	0.225[bc]	0.268[ab]	0.314[a]	0.0232	0.005
d 21 to 30									
BW at 30 d, kg	36.7[b]	38.2[a]	37.3[a]	37.5[a]	38.3[a]	38.2[a]	37.8[a]	0.50	0.031
ADG, kg/d	0.258[c]	0.428[a]	0.296[bc]	0.269[c]	0.472[a]	0.352[b]	0.310[bc]	0.0218	<0.001
DMI, kg/d	1.48	1.42	1.37	1.36	1.45	1.43	1.43	0.044	0.40
G:F	0.179[d]	0.303[ab]	0.223[cd]	0.210[cd]	0.353[a]	0.251[bc]	0.220[cd]	0.0246	<0.001
Overall									
Total BW gain, kg	6.61[b]	8.45[a]	7.33[ab]	7.42[ab]	8.33[a]	8.13[ab]	7.88[ab]	0.485	0.014
ADG, kg/d	0.235[b]	0.302[a]	0.262[ab]	0.254[ab]	0.298[a]	0.290[ab]	0.281[ab]	0.0179	0.020
DMI, kg/d	1.39[a]	1.31[b]	1.26[c]	1.25[c]	1.29[bc]	1.29[bc]	1.28[bc]	0.023	<0.001
G:F	0.175[b]	0.229[a]	0.208[ab]	0.217[ab]	0.233[a]	0.221[a]	0.220[a]	0.0152	0.016

[a–d]Within a row, means without a common superscript differ ($P < 0.05$).

[1]The experimental unit was pen. There were 3 pens per treatment, with 4 lambs in each pen (12 lambs per treatment).

[2]CTL = control diet, 0 mg/kg of RH or ZH, d 1 to 30.

[3]Ractopamine hydrochloride (Optaflexx, Elanco Animal Health, Guadalajara, Jalisco, México) was added to the diet according to feeding program. RHI = 10 mg/kg, d 1 to 10; 20 mg/kg, d 11 to 20; 30 mg/kg, d 21 to 30. RHC = 20 mg/kg, d 1 to 30. RHD = 30 mg/kg, d 1 to 10; 20 mg/kg, d 11 to 20; 10 mg/kg, d 21 to 30.

[4]Zilpaterol hydrochloride (Zilmax, Intervet/Schering-Plough Animal Health, México City, México) was added to the diet according to feeding program. ZHI = 3 mg/kg, d 1 to 10; 6 mg/kg, d 11 to 20; 9 mg/kg, d 21 to 30. ZHC = 6 mg/kg, d 1 to 30. ZHD = 9 mg/kg, d 1 to 10; 6 mg/kg, d 11 to 20; 3 mg/kg, d 21 to 30.

In this study, ADG and G:F response was modified across the periods by a stepwise increasing dose of both β-AA (treatment × duration interaction; $P < 0.001$) mainly because greater ($P < 0.05$) ADG and G:F were observed for lambs fed RHI or ZHI programs on d 21 to 30 of the feeding period. The changes observed through periods suggest a modification of the response over time with the use of stepwise increasing-dose programs. Similar effects have been described in finishing pigs with the use of RH by Trapp et al. (2002), who indicated that an increasing or step-up feeding regimen produced improved growth performance over a constant dose administration.

According to Mills (2002), desensitization is defined as the attenuation of a response despite continued presence of the stimulus, whereas downregulation is defined as a decline in the total number of β-adrenergic receptors and contributes to desensitization from chronic exposure to β-AA. Our data suggest that a stepwise increasing dose of both β-AA in finishing lambs could be an effective way to diminish the desensitization effect from chronic exposure to β-AA and could contribute to increase the growth response to β-AA over time.

Carcass Characteristics

The HCW and CCW were increased ($P < 0.05$) by RHI and ZHI treatments, but not ($P > 0.05$) for RHC, RHD, ZHC, and ZHD treatments compared with CTL lambs. The β-AA feeding programs did not alter CL ($P = 0.26$), but DP was increased ($P < 0.05$) in carcasses of lambs fed ZHI and ZHC programs compared with carcasses of lambs fed the CTL diet. However, lambs fed RH programs and ZHD treatment were intermediate and showed no differences ($P > 0.05$) from lambs on the CTL diet (Table 3).

The LM was increased ($P < 0.05$) 23.6% by administration of a ZHI program when compared with the CTL group. Both FT and the USDA yield grade were reduced ($P = 0.003$) by β-AA administration independent of the feeding program. Both traits showed similar results, likely because the calculated yield grade is derived from measured external fat depth.

The enhancement of carcass weight and dressing percentage is an expected response to β-AA supplementation because these compounds have the potential to stimulate muscle hypertrophy through both an increase in protein synthesis and a decrease in protein degradation (Moody et al., 2000; Dikeman, 2007). In this regard, Scramlin et al. (2010) in beef cattle, and Robles-Estrada et al. (2009) and López-Carlos et al. (2010) in sheep, reported consistent improvements in carcass characteristics with the use of ZH compared with RH, which is in concurrence with results reported in this trial.

Although in this study all RH programs stimulated improvements of some carcass characteristics, other reports in the literature are contradictory. Strydom et al. (2008) in beef cattle and Robles-Estrada et al. (2009) in sheep reported that the administration of RH did not improve carcass characteristics. Meanwhile, in beef cattle Scramlin et al. (2010) reported an increase ($P < 0.01$) in HCW, and no change in DP. Moreover, Abney et al. (2007) reported a linear improvement for HCW ($P = 0.02$) and a lineal tendency to increase LM area ($P < 0.09$) as dose of RH augmented. In addition, López-Carlos et al. (2010) reported an increment ($P < 0.001$) for CCW and DP, and a reduction ($P < 0.001$) for CL, FT, and USDA yield grade in feedlot ram lambs fed RH.

Table 3. Effect of constant, step-up, or step-down feeding program of the β-adrenergic agonists ractopamine hydrochloride (RH) or zilpaterol hydrochloride (ZH) during the last 30 d on feed on carcass characteristics of feedlot ram lambs[1]

		RH program[3]			ZH program[4]				
Item	CTL[2]	RHI	RHC	RHD	ZHI	ZHC	ZHD	SEM	*P*-value
HCW, kg	20.6[b]	23.3[a]	22.5[ab]	21.6[ab]	23.0[a]	22.5[ab]	21.6[ab]	0.60	0.023
Cold carcass weight, kg	20.1[b]	22.7[a]	21.9[ab]	21.0[ab]	22.5[a]	22.1[ab]	21.2[ab]	0.60	0.035
Cooling loss, %	2.49	2.56	2.56	2.51	2.44	2.64	2.09	0.149	0.26
Dressing, %	53.9[b]	55.3[ab]	56.5[ab]	55.0[ab]	57.1[a]	57.3[a]	55.2[ab]	0.68	0.023
LM area, cm^2	14.4[b]	16.9[ab]	14.9[ab]	14.1[b]	17.8[a]	16.9[ab]	15.8[ab]	0.79	0.035
12th-rib fat thickness, mm	4.16[a]	3.35[b]	3.36[b]	3.22[b]	3.20[b]	3.24[b]	3.39[b]	0.135	0.003
USDA yield grade[5]	2.05[a]	1.71[b]	1.72[b]	1.68[b]	1.65[b]	1.67[b]	1.74[b]	0.055	0.003

[a,b]Within a row, means without a common superscript differ ($P < 0.05$).

[1]The experimental unit was pen. There were 3 pens per treatment. At the end of the 30-d trial period, 2 ram lambs per pen were randomly chosen for slaughter and data collection (6 lambs per treatment).

[2]CTL = control diet, 0 mg/kg of RH or ZH, d 1 to 30.

[3]Ractopamine hydrochloride (Optaflexx, Elanco Animal Health, México) was added to the diet according to feeding program. RHI = 10 mg/kg, d 1 to 10; 20 mg/kg, d 11 to 20; 30 mg/kg, d 21 to 30. RHC = 20 mg/kg, d 1 to 30. RHD = 30 mg/kg, d 1 to 10; 20 mg/kg, d 11 to 20; 10 mg/kg, d 21 to 30.

[4]Zilpaterol hydrochloride (Zilmax, Intervet/Schering-Plough Animal Health, México) was added to the diet according to feeding program. ZHI = 3 mg/kg, d 1 to 10; 6 mg/kg, d 11 to 20; 9 mg/kg, d 21 to 30. ZHC = 6 mg/kg, d 1 to 30. ZHD = 9 mg/kg, d 1 to 10; 6 mg/kg, d 11 to 20; 3 mg/kg, d 21 to 30.

[5]Yield grade = (10 × fat thickness, in.) + 0.4 (USDA, 1992).

Baxa et al. (2010) and Holland et al. (2010) reported favorable effects on carcass characteristics with the use of ZH in beef cattle. Nevertheless, in feedlot lambs the results have been less consistent. Felix et al. (2005) reported that CCW, DP, LM, and FT of Pelibuey lambs were unaffected by ZH supplementation at doses of 4.5 or 6.7 mg/kg of DM during 56 d, whereas Aguilera-Soto et al. (2008) administered ZH to Rambouillet lambs and observed increases for cooling loss, but not for other carcass traits. The experiments of Felix et al. (2005) and Aguilera-Soto et al. (2008) lasted 8 wk, and the prolonged exposition to β-AA might be the cause of the null effects observed on carcass traits in their trials, due to the expected desensitization or downregulation of β-adrenergic receptors produced with chronic β-AA administration (Mills, 2002).

In addition, Estrada-Angulo et al. (2008) reported no effects for HCW, CCW, FT, or LM, but a linear increase in DP was reported as ZH was supplemented within the diet. The effect of the addition of other β2-selective compounds to the diet with a consequent increase in muscularity and reduced fat content in sheep carcasses has been also reported for clenbuterol (Baker et al., 1984), cimaterol (Rikhardsson et al., 1991), L644–969 (Li et al., 2000), and metaproterenol (Nourozi et al., 2008).

Moisture Loss, pH, Chemical Composition, and Fiber Diameter of LM

There were no differences ($P \geq 0.18$) in purge loss, cook loss, pH at 45 min or 24 h postmortem, moisture, CP, or ash content in LM of lambs fed with ZH or RH feeding programs (Table 4). Fat content of the LM was reduced ($P < 0.001$) in lambs fed RH or ZH compared with CTL lambs, independent of the feeding program applied. Previous reports of the chemical analysis of muscle of lambs supplemented with β-AA are inconsistent. Koohmaraie et al. (1996) reported no effects in any chemical value of meat, but Baker et al. (1984) and Boler et al. (2009) reported increases in moisture and protein percentages, accompanied by reductions in percentages of fat, in lambs and in dairy steers, respectively.

Muscle hypertrophy has been a consistent result of supplementing animals with a repartitioning agent (Beermann, 2002). In the present study, fiber diameter (17.3%) and fiber area (36.6%) was increased ($P < 0.05$) in muscle samples from lambs on ZHI compared with CTL. Muscle fiber area increases have been reported previously in sheep fed cimaterol (Kim et al., 1987) and L-644,969 (Koohmaraie et al., 1996), and in beef cattle fed RH and ZH (Strydom et al., 2008).

Surface Lean Color

The L* (lightness) and b* (yellowness) values of STN and LM were unaffected ($P \geq 0.44$) by β-AA supplementation, but the a* (redness) value was reduced ($P < 0.05$) in both the STN and LM of lambs fed ZHI and ZHC programs (Table 5). There are limited data reported regarding the color of muscles of lambs fed β-AA. In this regard, Kim et al. (1987) and Shackelford et al. (1992) did not find changes in lean color (estimated on a visual scale) of lambs supplemented with L644,969 or cimaterol, respectively.

Table 4. Effect of constant, step-up, or step-down feeding program of the β-adrenergic agonists ractopamine hydrochloride (RH) or zilpaterol hydrochloride (ZH) during the last 30 d on feed on LM characteristics of feedlot ram lambs[1]

		RH program[3]			ZH program[4]				
Item	CTL[2]	RHI	RHC	RHD	ZHI	ZHC	ZHD	SEM	*P*-value
Purge loss, %	2.33	2.39	2.40	2.33	2.29	2.75	1.95	0.321	0.57
Cook loss, %	21.8	22.0	22.3	20.9	20.7	21.2	22.4	0.73	0.21
45 min postmortem pH	6.05	6.02	6.10	6.07	6.08	6.04	6.01	0.058	0.97
24 h postmortem pH	5.74	5.65	5.78	5.65	5.72	5.77	5.74	0.081	0.44
Moisture, %	72.7	73.1	74.2	72.8	74.3	73.7	73.7	0.74	0.21
CP, %	19.6	20.2	20.0	19.7	20.1	20.2	19.5	0.54	0.36
Fat, %	6.14[a]	4.34[b]	4.31[b]	4.44[b]	4.25[b]	4.30[b]	4.66[b]	0.546	<0.001
Ash, %	0.90	1.18	0.92	0.86	1.19	1.13	0.97	0.097	0.18
Fiber diameter, μm	24.3[b]	26.2[ab]	23.5[b]	24.3[b]	28.5[a]	25.8[ab]	24.4[b]	0.86	<0.001
Fiber area, μm^2	484[b]	552[ab]	457[b]	476[b]	661[a]	540[ab]	485[b]	29.8	<0.001

[a,b]Within a row, means without a common superscript differ ($P < 0.05$).

[1]The experimental unit was pen. There were 3 pens per treatment. At the end of the 30-d trial period, 2 ram lambs per pen were randomly chosen for slaughter and data collection (6 lambs per treatment).

[2]CTL = control diet, 0 mg/kg of RH or ZH, d 1 to 30.

[3]Ractopamine hydrochloride (Optaflexx, Elanco Animal Health, Guadalajara, Jalisco, México) was added to the diet according to feeding program. RHI = 10 mg/kg, d 1 to 10; 20 mg/kg, d 11 to 20; 30 mg/kg, d 21 to 30. RHC = 20 mg/kg, d 1 to 30. RHD = 30 mg/kg, d 1 to 10; 20 mg/kg, d 11 to 20; 10 mg/kg, d 21 to 30.

[4]Zilpaterol hydrochloride (Zilmax, Intervet/Schering-Plough Animal Health, México City, México) was added to the diet according to feeding program. ZHI = 3 mg/kg, d 1 to 10; 6 mg/kg, d 11 to 20; 9 mg/kg, d 21 to 30. ZHC = 6 mg/kg, d 1 to 30. ZHD = 9 mg/kg, d 1 to 10; 6 mg/kg, d 11 to 20; 3 mg/kg, d 21 to 30.

In agreement with results from the present study, previous research documented a trend for paler meat when beef steers were supplemented with ZH (Hilton et al., 2009) and pigs were supplemented with RH (Carr et al., 2005a). As suggested by Carr et al. (2005b), reduction ($P < 0.05$) in muscle color (a* and b* values) of pigs fed RH could be a dilution effect in the muscle oxymyoglobin caused by hypertrophy of the muscle fiber. Therefore, a possible explanation for the decrease in a* value observed for both STN and LM muscles in this study was a decrease in the amount of oxymyoglobin in muscles from lambs fed the ZHI and ZHC programs.

Moreover, Geesink et al. (1993) reported that clenbuterol treatment in veal calves caused a reduction of the heme iron concentration of LM and STN. The authors argued that this reduction may be the result of a "dilution" effect by an increase in myofiber hypertrophy. However, reduced heme iron concentration did not result in clear differences in a* or b* values. In the present study, an increase in the LM area (Table 3) and LM fiber diameter (Table 4) was more evident in meat from lambs fed the ZHI program, suggesting the mentioned "dilution" effect in the amount of oxymyoglobin was caused by muscle hypertrophy.

Organ Mass

The relative mass (g/kg of EBW) of liver from ZHI-treated lambs was reduced ($P < 0.05$) by 20.7% compared with CTL lambs (Figure 1); however, weight of the liver was unaffected ($P > 0.05$) in lambs fed the other β-AA programs. There were no other effects in mass of body components (head, testicles, pluck, mesentery fat, rumen, large intestine, or small intestine), expressed in kilograms ($P \geq 0.36$) or as a fraction of empty BW ($P \geq 0.57$).

Mersmann (2002) stated that β-AA are present on almost every cell type and control an exceptionally large number of physiological and metabolic functions (e.g., regulation of heart rate and contractile force, blood pressure, bronchial muscle tension, uterine contraction, and glycogen and lipid degradation). Therefore, some effect on organ mass could be expected in animals fed β-AA. However, previous reports in beef steers agreed that the weight of visceral organs was not altered or was reduced by β-AA administration (Gonzalez et al., 2010; Holland et al., 2010).

Moloney et al. (1990) reported a linear reduction in organ weights (heart, lungs, liver, kidneys), and a linear increase in carcass weight and dressing percentage as dose of the β-AA L-644,969 increased in the diet of finishing Friesian steers. Moloney et al. (1990) concluded that the remarkable increment of protein deposition in finishing steers fed β-AA was almost exclusive of skeletal muscle and not necessarily due to an enhancement of organ mass. In addition, other researchers (Kim et al., 1989; Koohmaraie et al., 1996) have reported effects of β-AA on the mass of the organs of feedlot lambs. In these studies, the weight is generally reduced in those organs of greater metabolic activity such as liver (Kim et al., 1989) and heart alone (Koohmaraie et al., 1996).

Williams et al. (1987) reported increased N retention in the carcasses of calves treated with 2 μg of clenbuterol/kg, compensated by a reduction in the N content from the noncarcass components and major organs. The authors suggested that because organs have considerably

Table 5. Effect of constant, step-up, or step-down feeding program of the β-adrenergic agonists ractopamine hydrochloride (RH) or zilpaterol hydrochloride (ZH) during the last 30 d on feed on surface lean color (L*, a*, b*)[1] of the semitendinosus muscle and LM of feedlot ram lambs[2]

		RH program[4]			ZH program[5]				
Item	CTL[3]	RHI	RHC	RHD	ZHI	ZHC	ZHD	SEM	*P*-value
Semitendinosus muscle									
L*	33.5	38.1	37.6	34.4	37.7	37.6	36.4	1.59	0.44
a*	7.2[a]	6.0[ab]	6.0[ab]	6.5[ab]	5.4[b]	5.3[b]	5.9[ab]	0.48	0.047
b*	1.7	1.9	2.2	2.3	2.0	2.3	2.3	0.39	0.85
LM									
L*	31.6	33.1	33.3	32.6	32.7	31.9	32.4	1.27	0.88
a*	10.6[a]	9.0[abc]	9.4[abc]	10.0[ab]	6.6[c]	7.0[bc]	8.5[abc]	0.51	0.013
b*	3.4	3.3	2.6	2.7	2.6	2.7	3.6	0.67	0.56

[a–c]Within a row, means without a common superscript differ ($P < 0.05$).

[1]Color scale: L* = lightness (0 = black, 100 = white); a* = red to green (positive values = red, negative values = green); b* = yellow to blue (positive values = yellow, negative values = blue).

[2]The experimental unit was pen. There were 3 pens per treatment. At the end of the 30-d trial period, 2 ram lambs per pen were randomly chosen for slaughter and data collection (6 lambs per treatment).

[3]CTL = control diet, 0 mg/kg of RH or ZH, d 1 to 30.

[4]Ractopamine hydrochloride (Optaflexx, Elanco Animal Health, Guadalajara, Jalisco, México) was added to the diet according to feeding program. RHI = 10 mg/kg, d 1 to 10; 20 mg/kg, d 11 to 20; 30 mg/kg, d 21 to 30. RHC = 20 mg/kg, d 1 to 30. RHD = 30 mg/kg, d 1 to 10; 20 mg/kg, d 11 to 20; 10 mg/kg, d 21 to 30.

[5]Zilpaterol hydrochloride (Zilmax, Intervet/Schering-Plough Animal Health, MéxicoCity, México) was added to the diet according to feeding program. ZHI = 3 mg/kg, d 1 to 10; 6 mg/kg, d 11 to 20; 9 mg/kg, d 21 to 30. ZHC = 6 mg/kg, d 1 to 30. ZHD = 9 mg/kg, d 1 to 10; 6 mg/kg, d 11 to 20; 3 mg/kg, d 21 to 30.

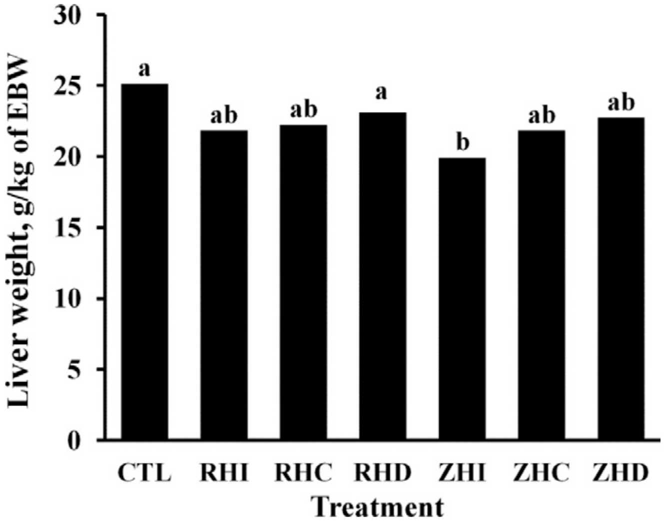

Figure 1. Effect of constant, step-up, or step-down feeding program of the β-adrenergic agonists ractopamine hydrochloride (RH; Optaflexx, Elanco Animal Health, Guadalajara, Jalisco, México) or zilpaterol hydrochloride (ZH; Zilmax, Intervet/Schering-Plough Animal Health, México City, México) during the last 30 d on feed on liver weight (g/kg of empty BW, EBW) of feedlot ram lambs. Treatments consisted of the following: CTL = control diet, 0 mg/kg of RH or ZH, d 1 to 30. RHI = RH at doses of 10 mg/kg, d 1 to 10; 20 mg/kg, d 11 to 20; 30 mg/kg, d 21 to 30. RHC = RH at doses of 20 mg/kg, d 1 to 30. RHD = RH at doses of 30 mg/kg, d 1 to 10; 20 mg/kg, d 11 to 20; 10 mg/kg, d 21 to 30. ZHI = ZH at doses of 3 mg/kg, d 1 to 10; 6 mg/kg, d 11 to 20; 9 mg/kg, d 21 to 30. ZHC = ZH at doses of 6 mg/kg, d 1 to 30. ZHD = ZH at doses of 9 mg/kg, d 1 to 10; 6 mg/kg, d 11 to 20; 3 mg/kg, d 21 to 30. Bars without a common letter (a,b) differ ($P < 0.05$). SEM = 0.89.

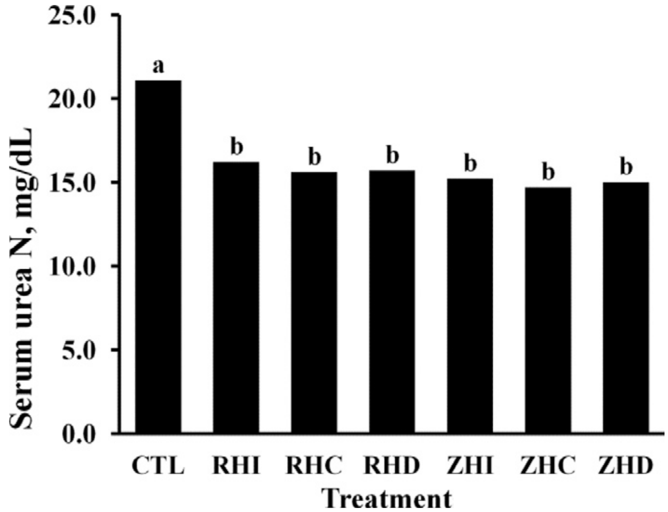

Figure 2. Effect of constant, step-up, or step-down feeding program of the β-adrenergic agonists ractopamine hydrochloride (RH; Optaflexx, Elanco Animal Health, Guadalajara, Jalisco, México) or zilpaterol hydrochloride (ZH; Zilmax, Intervet/Schering-Plough Animal Health, México City, México) during the last 30 d on feed on serum urea N (mg/dL) of feedlot ram lambs. Treatments consisted of the following: CTL = control diet, 0 mg/kg of RH or ZH, d 1 to 30. RHI = RH at doses of 10 mg/kg, d 1 to 10; 20 mg/kg, d 11 to 20; 30 mg/kg, d 21 to 30. RHC = RH at doses of 20 mg/kg, d 1 to 30. RHD = RH at doses of 30 mg/kg, d 1 to 10; 20 mg/kg, d 11 to 20; 10 mg/kg, d 21 to 30. ZHI = ZH at doses of 3 mg/kg, d 1 to 10; 6 mg/kg, d 11 to 20; 9 mg/kg, d 21 to 30. ZHC = ZH at doses of 6 mg/kg, d 1 to 30. ZHD = ZH at doses of 9 mg/kg, d 1 to 10; 6 mg/kg, d 11 to 20; 3 mg/kg, d 21 to 30. Bars without a common letter (a,b) differ ($P < 0.05$). SEM = 1.73.

greater metabolic activity than skeletal muscle, small reductions in mass may yield considerable savings in the N requirement for organ homeostasis. In addition, Mader et al. (2009) evaluated the relationships between measures of growth performance and feed efficiency with carcass characteristics and visceral organ mass in feedlot cattle. Mader et al. (2009) reported that G:F was negatively correlated ($P < 0.001$) with total visceral weight (g/kg of BW; r = −0.44) and visceral fat weight (g/kg of BW; r = −0.41), but was positively correlated ($P = 0.02$) with lean weight (g/kg of rib; r = 0.30). Mader et al. (2009) suggest that in ruminants, an increase in feed efficiency could be accompanied by a decrease in organ mass.

Blood Metabolites

The duration and the treatment × duration interaction for blood metabolites were not significant ($P < 0.05$). Serum urea N concentration was reduced ($P = 0.04$) by RH or ZH administration regardless of feeding program period (Figure 2). Plasmatic total proteins, creatinine, triglycerides, or cholesterol were unaffected ($P \geq 0.16$) by β-AA inclusion in lamb diets. Concentrations of blood metabolites of this experiment were within normal limits reported for lambs (Bórnez et al., 2009).

Russell and Roussel (2007) explained that urea is generated in the liver by urea cycle by means of the detoxification of ammonia, a by-product of protein catabolism, and is therefore influenced by diet and hepatic function. However, the decrease in serum urea N concentrations observed in the present trial could be explained by the mode of action of the β-AA, which promotes muscle protein synthesis and utilization of N (Johnson and Chung, 2007).

Creatinine is a breakdown product of creatine phosphate from normal skeletal muscle metabolism, and therefore the concentration of creatinine in serum may be considered an index of endogenous protein catabolism directly related to muscle mass (Russell and Roussel, 2007). López-Carlos et al. (2010) did not observe effects on blood creatinine, total protein, and triglyceride concentrations with oral administration of ZH or RH in finishing hair sheep lambs. However, Chikhou et al. (1993) reported an increase in serum concentration of creatinine in a long-term treatment with cimaterol in Friesian cattle. In this regard, Istasse et al. (1990) reported that serum creatinine concentration is positively correlated with carcass weight, dressing percentage, and the proportion of lean meat in the carcass. The lack of an effect of RH or ZH on creatinine but reduction in plasma urea concentration reported in this study may indicate that both β-AA have a much greater effect on increasing protein accretion than decreasing protein degradation, regardless of the feeding program implemented.

Serum total proteins are formed mainly by albumin and globulin fractions and constitute a major index of protein status (Evans and Duncan, 2003). Increases in serum total proteins reflect hepatic alterations or a chronic inflammatory process, whereas reduction of serum proteins may be associated with a reduction of protein digestion and absorption, or failure in protein synthesis by liver disease (Russell and Roussel, 2007). Oral administration of both β-AA tested in this study did not seem to compromise general protein status or protein hepatic synthesis.

In this study, energy metabolites cholesterol and triglycerides were unaffected ($P \geq 0.16$) by β-AA administration, which is in agreement with previous reports in beef cattle (Eisemann and Bristol, 1998) and sheep (López-Carlos et al., 2010). Peterla and Scanes (1990) reported that β-AA (isoproterenol, cimaterol, clenbuterol, and RH) decreased porcine adipose tissue in vitro. They reported that lipolysis was stimulated by isoproterenol, cimaterol, or ractopamine but not by clenbuterol, whereas lipogenesis was inhibited by all β-adrenergic agonists tested. Moreover, Beermann (1987) reported that plasma FFA increased sharply after administration of cimaterol within the first 4 to 10 h, returning to baseline concentrations, consistently with an acute lipolytic effect of β-AA. Furthermore, Kim et al. (1989) reported that increased plasma concentrations of fatty acids and triglycerides were associated with adipocyte size reduction in lambs fed cimaterol.

Conclusions

In summary, growth performance of ram lambs was improved when RH or ZH were supplemented in the diet, but increasing doses of RH or ZH augmented the growth performance response over time. Moreover, RH step-up feeding program improved carcass weight, but ZH step-up program improved carcass weight, dressing percentage, LM area, and reduced FT. Supplementation with β-AA had no adverse effects on LM characteristics (pH, moisture loss, and chemical composition), organ mass weight, or blood metabolites, but the increased LM fiber diameter of lambs fed ZH step-up program could be unfavorable because of the potential negative effect on tenderness.

LITERATURE CITED

Abney, C. S., J. T. Vasconcelos, J. P. McMeniman, S. A. Keyser, K. R. Wilson, G. J. Vogel, and M. L. Galyean. 2007. Effects of ractopamine hydrochloride on performance, rate and variation in feed intake, and acid-base balance in feedlot cattle. J. Anim. Sci. 85:3090–3098.

Aguilera-Soto, J. I., R. G. Ramirez, C. F. Arechiga, F. Mendez-Llorente, M. A. Lopez-Carlos, J. M. Silva-Ramos, R. M. Rincon-Delgado, and F. M. Duran-Roldan. 2008. Zilpaterol hydrochloride on performance and sperm quality of lambs fed wet brewers grains. J. Appl. Anim. Res. 34:17–21.

AOAC. 2006. Official Methods of Analysis. 18th ed. Assoc. Off. Anal. Chem. Int., Washington, DC.

Baker, P. K., R. H. Dalrymple, D. L. Ingle, and C. A. Ricks. 1984. Deposition in lambs use of a β-adrenergic agonist to alter muscle and fat. J. Anim. Sci. 59:1256–1261.

Baxa, T. J., J. P. Hutcheson, M. F. Miller, J. C. Brooks, W. T. Nichols, M. N. Streeter, D. A. Yates, and B. J. Johnson. 2010. Additive effects of a steroidal implant and zilpaterol hydrochloride on feedlot performance, carcass characteristics, and skeletal muscle messenger ribonucleic acid abundance in finishing steers. J. Anim. Sci. 88:330–337.

Beermann, D. H. 1987. Effects of beta adrenergic agonists on endocrine influence and cellular aspects of muscle growth. 40th Reciprocal Meat Conference Proceedings. American Meat Science Association. 40:57–63.

Beermann, D. H. 2002. Beta-adrenergic receptor agonist modulation of skeletal muscle growth. J. Anim. Sci. 80(Suppl. 1):E18–E23.

Beermann, D. H. 2009. ASAS Centennial Paper: A century of pioneers and progress in meat science in the United States leads to new frontiers. J. Anim. Sci. 87:1192–1198.

Boler, D. D., S. F. Holmer, F. K. McKeith, J. Killefer, D. L. VanOverbeke, G. G. Hilton, R. J. Delmore, J. L. Beckett, J. C. Brooks, R. K. Miller, D. B. Griffin, J. W. Savell, T. E. Lawrence, N. A. Elam, M. N. Streeter, W. T. Nichols, J. P. Hutcheson, D. A. Yates, and D. M. Allen. 2009. Effects of feeding zilpaterol hydrochloride for twenty to forty days on carcass cutability and subprimal yield of calf-fed Holstein steers. J. Anim. Sci. 87:3722–3729.

Bórnez, R., M. B. Linares, and H. Vergara. 2009. Haematological, hormonal and biochemical blood parameters in lambs: Effect of age and blood sampling time. Livest. Sci. 121:200–206.

Canchi, D. R., N. Li, K. A. Foster, P. V. Preckel, A. P. Schinckel, and B. Richert. 2010. Optimal control of desensitizing inputs: The case of paylean. Am. J. Agric. Econ. 92:56–69.

Carr, S. N., D. J. Ivers, D. B. Anderson, D. J. Jones, D. H. Mowrey, M. B. England, J. Killefer, P. J. Rincker, and F. K. McKeith. 2005b. The effects of ractopamine hydrochloride on lean carcass yields and pork quality characteristics. J. Anim. Sci. 83:2886–2893.

Carr, S. N., P. J. Rincker, J. Killefer, D. H. Baker, M. Ellis, and F. K. McKeith. 2005a. Effects of different cereal grains and ractopamine hydrochloride on performance, carcass characteristics, and fat quality in late-finishing pigs. J. Anim. Sci. 83:223–230.

Chikhou, F. H., A. P. Moloney, P. Allen, J. F. Quirke, F. H. Austin, and J. F. Roche. 1993. Long-term effects of cimaterol in Friesian steers: I. Growth, feed efficiency, and selected carcass traits. J. Anim. Sci. 71:906–913.

Dikeman, M. E. 2007. Effects of metabolic modifiers on carcass traits and meat quality. Meat Sci. 77:121–135.

Eisemann, J. H., and D. G. Bristol. 1998. Change in insulin sensitivity or responsiveness is not a major component of the mechanism of action of ractopamine in beef steers. J. Nutr. 128:505–511.

Estrada-Angulo, A., A. Barreras-Serrano, G. Contreras, J. F. Obregon, J. C. Robles-Estrada, A. Plascencia, and R. A. Zinn. 2008. Influence of zilpaterol chlorhydrate supplementation on growth performance and carcass characteristics of feedlot lambs. Small Rumin. Res. 80:107–110.

Evans, E. W., and J. R. Duncan. 2003. Proteins, lipids and carbohydrates. Pages 162–192 in Duncan & Prasse's Veterinary Laboratory Medicine: Clinical Pathology. 4th ed. K. S. Latimer, E. A. Mahaffey, and K. W. Prasse, ed. Iowa State Press, Ames.

FASS. 2010. Guide for the care and use of agricultural animals in research and teaching. 3rd ed. Fed. Anim. Sci. Soc., Champaign, IL.

Felix, A., A. Estrada-Angulo, F. G. Rios, C. H. Ramos, and A. B. Perez. 2005. Effect of Zilpaterol chlorhydrate on growth performance and carcass traits in finishing sheep. J. Anim. Sci. 83(Suppl. 1):63. (Abstr.)

Geesink, G. H., F. J. Smulders, H. L. van Laack, J. H. van der Kolk, T. Wensing, and H. J. Breukink. 1993. Effects on meat quality of the use of clenbuterol in veal calves. J. Anim. Sci. 71:1161–1170.

Gonzalez, J. M., S. E. Johnson, A. M. Stelzleni, T. A. Thrift, J. D. Savell, T. M. Warnock, and D. D. Johnson. 2010. Effect of ractopamine-HCl supplementation for 28 days on carcass characteristics, muscle fiber morphometrics, and whole muscle yields of six distinct muscles of the loin and round. Meat Sci. 85:379–384.

Hilton, G. G., J. L. Montgomery, C. R. Krehbiel, D. A. Yates, J. P. Hutcheson, W. T. Nichols, M. N. Streeter, J. R. Blanton Jr., and M. F. Miller. 2009. Effects of feeding zilpaterol hydrochloride with and without monensin and tylosin on carcass cutability and meat palatability of beef steers. J. Anim. Sci. 87:1394–1406.

Holland, B. P., C. R. Krehbiel, G. G. Hilton, M. N. Streeter, D. L. VanOverbeke, J. N. Shook, D. L. Step, L. O. Burciaga-Robles, D. R. Stein, D. A. Yates, J. P. Hutcheson, W. T. Nichols, and J. L. Montgomery. 2010. Effect of extended withdrawal of zilpaterol hydrochloride on performance and carcass traits in finishing beef steers. J. Anim. Sci. 88:338–348.

Istasse, L., C. VanEenaeme, A. Gabriel, A. Clinquart, G. Maghuin-Rogister, and J. M. Bienfait. 1990. The relationship between carcass characteristics, plasma hormones and metabolites in young fattening bulls. Vet. Res. Commun. 14:19–26.

Johnson, B. J., and K. Y. Chung. 2007. Alterations in the physiology of growth of cattle with growth-enhancing compounds. Vet. Clin. Food. Anim. 23:321–332.

Kim, Y. S., T. H. Lee, and Y. J. Choi. 1995. Effect of intermittent and stepwise administration of a beta-adrenergic agonist, L644,969, on rat growth performance and skeletal muscles. Comp. Biochem. Physiol. C. 110:127–132.

Kim, Y. S., Y. B. Lee, and R. H. Dalrymple. 1987. Effect of the repartitioning agent cimaterol on growth, carcass and skeletal muscle characteristics in lambs. J. Anim. Sci. 65:1392–1399.

Kim, Y. S., Y. B. Lee, W. N. Garrett, and R. H. Dalrymple. 1989. Effects of cimaterol on nitrogen retention and energy utilization in lambs. J. Anim. Sci. 67:674–681.

Kirchofer, K. S., C. R. Calkins, and B. L. Gwartney. 2002. Fiber-type composition of muscles of the beef chuck and round. J. Anim. Sci. 80:2872–2878.

Koohmaraie, M., S. D. Shackelford, and T. L. Wheeler. 1996. Effects of a β-adrenergic agonist (L-644,969) and male sex condition on muscle growth and meat quality of callipyge lambs. J. Anim. Sci. 74:70–79.

Li, Y. Z., R. J. Christopherson, B. T. Li, and J. A. Moibi. 2000. Effects of a beta-adrenergic agonist (L-644969) on performance and carcass traits of growing lambs in a cold environment. Can. J. Anim. Sci. 80:459–465.

López-Carlos, M. A., R. G. Ramírez, J. I. Aguilera-Soto, C. F. Aréchiga, F. Méndez-Llorente, H. Rodríguez, and J. M. Silva. 2010. Effect of ractopamine hydrochloride and zilpaterol hydrochloride on growth, diet digestibility, intake and carcass characteristics of feedlot lambs. Livest. Sci. 131:23–30.

Mader, C. J., Y. R. Montanholi, Y. J. Wang, S. P. Miller, I. B. Mandell, B. W. McBride, and K. C. Swanson. 2009. Relationships among measures of growth performance and efficiency with carcass traits, visceral organ mass, and pancreatic digestive enzymes in feedlot cattle. J. Anim. Sci. 87:1548–1557.

McElligott, M. A., A. Barreto Jr., and L. Y. Chaung. 1989. Effect of continuous and intermittent clenbuterol feeding on rat growth rate and muscle. Comp. Biochem. Physiol. C. 92:135–138.

Mersmann, H. J. 2002. Beta-adrenergic receptor modulation of adipocyte metabolism and growth. J. Anim. Sci. 80(E. Suppl. 1):E24–E29.

Mills, S. E. 2002. Implications of feedback regulation of beta-adrenergic signaling. J. Anim. Sci. 80(Suppl. 1):E30–E35.

Moloney, A. P., P. Allen, D. B. Ross, G. Olson, and E. M. Convey. 1990. Growth, feed efficiency and carcass composition of finishing Friesian steers fed the beta-adrenergic agonist L-644,969. J. Anim. Sci. 68:1269–1277.

Montgomery, J. L., C. R. Krehbiel, J. J. Cranston, D. A. Yates, J. P. Hutcheson, W. T. Nichols, M. N. Streeter, D. T. Bechtol, E. Johnson, T. TerHune, and T. H. Montgomery. 2009. Dietary zilpaterol hydrochloride. I. Feedlot performance and carcass traits of steers and heifers. J. Anim. Sci. 87:1374–1383.

Moody, D. E., D. L. Hancock, and D. B. Anderson. 2000. Phenethanolamine repartitioning agents. Pages 65–95 in Farm Animal Metabolism and Nutrition. J. P. F. D'Mello, ed. CAB Int., New York, NY.

Nourozi, M., M. Abazari, M. Raisianzadeh, M. Mohammadi, and A. ZareShahne. 2008. Effect of terbutaline and metaproterenol (two beta-adrenergic agonists) on performance and carcass composition of culled Moghani ewes. Small Rumin. Res. 74:72–77.

NRC. 2007. Nutrient Requirements of Small Ruminants: Sheep, Goats, Cervids, and New World Camelids. Natl. Acad. Press, Washington, DC.

Peterla, T. A., and C. G. Scanes. 1990. Effect of beta-adrenergic agonists on lipolysis and lipogenesis by porcine adipose tissue. J. Anim. Sci. 68:1024–1029.

Plascencia, A., N. G. Torrentera, and R. A. Zinn. 2008. Influence of the β-agonist, zilpaterol, on growth performance and carcass characteristics of feedlot steers. J. Anim. Vet. Adv. 7:1257–1260.

Pringle, T. D., C. R. Calkins, M. Koohmaraie, and S. J. Jones. 1993. Effects over time of feeding a beta-adrenergic agonist to wether lambs on animal performance, muscle growth, endogenous muscle protein-ase activities, and meat tenderness. J. Anim. Sci. 71:636–644.

Rikhardsson, G., K. A. Johnson, and D. E. Johnson. 1991. Effects of cimaterol on energetics and carcass characteristics of Suffolk ewe lambs. J. Anim. Sci. 69:396–404.

Robles-Estrada, J. C., A. Barreras-Serrano, G. Contreras, A. Estrada-Angulo, J. F. Obregón, A. Plascencia, and F. G. Ríos. 2009. Effect of two β-adrenergic agonists on finishing performance and carcass characteristics in lambs fed all-concentrate diets. J. Appl. Anim. Res. 36:33–36.

Russell, K. E., and A. J. Roussel. 2007. Evaluation of the ruminant serum chemistry profile. Vet. Clin. Food Anim. 23:403–426.

Salinas-Chavira, J., R. G. Ramirez, M. Dominguez-Muñoz, R. Palomo-Cruz, and V. H. López-Acuña. 2004. Influence of zilpaterol hydrochloride on growth and carcass characteristics of Pelibuey lambs. J. Appl. Anim. Res. 26:13–16.

Scramlin, S. M., W. J. Platter, R. A. Gomez, W. T. Choat, F. K. McKeith, and J. Killefer. 2010. Comparative effects of ractopamine hydrochloride and zilpaterol hydrochloride on growth performance, carcass traits, and longissimus tenderness of finishing steers. J. Anim. Sci. 88:1823–1829.

See, M. T., T. A. Armstrong, and W. C. Weldon. 2004. Effect of a ractopamine feeding program on growth performance and carcass composition in finishing pigs. J. Anim. Sci. 82:2474–2480.

Shackelford, S. D., J. W. Edwards, E. K. Smarr, and J. W. Savell. 1992. Retail cut yields of Rambouillet wether lambs fed the beta-adrenergic agonist L644,969. J. Anim. Sci. 70:161–168.

Strydom, P. E., L. Frylinck, J. L. Montgomery, and M. F. Smith. 2008. The comparison of three β-agonists for growth performance, carcass characteristics and meat quality of feedlot cattle. Meat Sci. 81:557–564.

Trapp, S. A., F. P. Rice, D. T. Kelly, A. Bundy, A. P. Schinckel, and B. T. Richert. 2002. Evaluation of four ractopamine use programs on pig growth and carcass characteristics. Accessed Oct. 15, 2011. http://www.ansc.purdue.edu/swine/swineday/sday02/10.pdf.

USDA. 1992. Official United States Standards for grades of lamb, yearling mutton and mutton carcasses. USDA, Agric. Mark. Serv., Washington, DC.

Williams, P. E. V., L. Pagliani, G. M. Innes, K. Pennie, C. I. Harris, and P. Garthwaite. 1987. Effects of a β-agonist (clenbuterol) on growth, carcass composition, protein and energy metabolism of veal calves. Br. J. Nutr. 57:417–428.

Winterholler, S. J., G. L. Parsons, D. K. Walker, M. J. Quinn, J. S. Drouillard, and B. J. Johnson. 2008. Effect of feedlot management system on response to ractopamine-HCl in yearling steers. J. Anim. Sci. 86:2401–2414.