https://doi.org/10.22319/rmcp.v13i3.5786

Article

# Effectiveness of zilpaterol hydrochloride in lamb finishing: Patent *vs.* Generic

Arnulfo Vicente Pérez [a,b]

Leonel Avendaño-Reyes [a]

Juan E. Guerra-Liera [b]

Rubén Barajas Cruz [b]

Ricardo Vicente-Pérez [c]

M. Ángeles López-Baca [a]

Miguel A. Gastelum Delgado [b]

Alfonso J. Chay-Canul [d]

Ulises Macías-Cruz [a]*

[a] Universidad Autónoma de Baja California. Instituto de Ciencias Agrícolas, 21705, Valle de Mexicali, BC., México.

[b] Universidad Autónoma de Sinaloa. Facultad de Medicina Veterinaria y Zootecnia, Culiacán, Sinaloa, México.

[c] Universidad de Guadalajara. CUCSUR-Departamento de Producción Agrícola, Autlán de Navarro, Jalisco, México.

[d] Universidad Juárez Autónoma de Tabasco. División Académica de Ciencias Agropecuarias, Villahermosa, Tabasco, México.

*Corresponding author: ulisesmacias1988@hotmail.com, umacias@uabc.edu.mx

**Abstract:**

The objective of this study was to compare the effect of the patent *vs.* generic sources of zilpaterol hydrochloride (ZH) on the productive performance, carcass characteristics, primary cut yields, and meat quality of lambs finished in feedlot. Thirty (30) Dorper×Pelibuey male lambs were distributed into 10 blocks, each with three lambs of similar initial live weight which were randomly assigned to the following treatments: 1) without ZH (control), 2) with patent ZH (PZH), and 3) with generic ZH (GZH). Treatment means were compared through two orthogonal contrasts: control *vs.* ZH (PZH+GZH) and PZH *vs.* GZH. ZH did not affect ($P \geq 0.15$) the productive performance, carcass weight, backfat thickness, or fat percentages (kidney-pelvic-heart, mesenteric or omental), but increased ($P \leq 0.05$) *Longissimus dorsi* muscle area and yields of carcass, shoulder, leg, and plain loin. As for the meat quality, ZH did not affect ($P \geq 0.24$) pH and shear force, but reduced ($P < 0.05$) redness, yellowness, and chroma color values at 24 h *post mortem*, as well as the redness value ($P < 0.01$) at 14 days of aging. With exception of carcass yield which tended ($P = 0.07$) to increase with PZH, all measured variables were similar ($P \geq 0.14$) between PZH and GZH. It has been concluded that both types of ZH at a dose of 0.10 mg per kg of live weight promote muscular hypertrophy in finishing lambs; however, this dosage is not sufficient to result in a better productive performance or carcass weight.

**Key words:** Adrenergic agonists, Meat quality, Carcass characteristics, Hair sheep.

Received: 29/08/2020

Accepted: 13/07/2021

# Introduction

The supply of sheep meat in Mexico is lower than the demand for it (~30 %). So, the sheep meat industry is constantly searching for low cost strategies that help increase feed efficiency and weight gain[1]. In the last two decades, several studies have shown that zilpaterol hydrochloride (ZH) effectively promotes growth in finishing lambs in feedlot, as it improves feed efficiency, growth rate, carcass weight and yield, and *Longissimus dorsi* muscle area, as well as decreases internal and external fat deposition in the body[2–5]. Despite this, the dietary addition of ZH also decreases the lamb meat quality, specifically maintaining a high ultimate pH, which causes discoloration and increases meat toughness[6,7].

Although, the results on the use of ZH in intensive fattening of lambs have mostly been positive, this product has increased economic cost and, in consequence, farmers have exhibited some resistance to adopting the use of ZH in sheep feeding. Once the patent of ZH had expired, various pharmaceutical companies began to produce generic ZH, and today they sell it 23 % cheaper than patent ZH. Recent studies carried out in sheep[8] and bulls[9] proved that, patent and Grofactor™ generic ZH are similarly effective as growth promotors at the dosage recommended on the label (0.15 mg per kg of live weight [LW]). For their part, Avendaño-Reyes *et al*[10] evidenced that the optimal dose of this generic ZH for hair sheep finished in feedlot is lower (0.10 mg per kg of live weight [LW]) than that recommended on the label of all ZH brands (i.e. 0.15 mg per kg of LW).

Based on the above, the generic ZH said could be used to reduce costs derived from the use of this technology, as it has a lower market price and its required dose (33.3 %) is lower than that indicated for patent ZH[11]. Despite the history of generic ZH effectiveness in the finishing lambs, it is necessary to verify whether the effectiveness of generic ZH is comparable to that of patent ZH at a dose of 0.10 mg per kg of LW. It is noteworthy that the molecule of ZH in this generic adrenergic agonist is bioequivalent to that of patent ZH, but differs in the manner in which it is attached to the vehicle, which may reduce its bioavailability and its mode of action[10]. Therefore, the objective of the present study was to compare the effect of the source of ZH (patent *vs.* generic) at a daily dose of 0.10 mg per kg of LW on productive performance, carcass characteristics, primary cut yields, and meat quality in hair male lambs finished in feedlot.

# Material and methods

## Location of the experiment

All management and care procedures of animals were carried out according to the Mexican Official Norms NOM-051-ZOO-1995 (Humane care of animals during mobilization) and NOM-033-ZOO-1995 (Slaughter of domestic and wild animals). The study was performed in spring at the sheep experimental unit of the Instituto de Ciencias Agrícolas, Universidad Autónoma de Baja California, located in the Valley of Mexicali, Baja California, México (32.8º N, 114.6º W).

## Animals and their experimental management

Thirty entire male lambs from the Dorper × Pelibuey cross (initial LW= 36.9 ± 6.9 kg and age= 5 mo) were utilized, having been adapted to individual pens and basal diet (Table 1) for 20 days previous to the onset of the experiment. The animals received two injections at the beginning of the adaptation period, an intramuscular one administering 1.0 ml of vitamins (Vigantol ADE Fuerte; Bayer, Mexico City) and a subcutaneous one with 0.5 ml of ivermectine (Sanfer, Mexico City). The individual pens were provided with food and water troughs and shade. The basal diet was formulated for a daily weight gain of 300 g in finishing lambs (2.8 Mcal of metabolizable energy per kg of dry matter [DM] and 16 % crude protein)[12].

Feed samples were collected on a weekly basis, and at the end of the experimental period they were brought together in order to obtain two subsamples, which were analyzed to determine its chemical composition[13,14,15]. In general, the diet was offered twice a day (at 0700 and 1800 h) during both the adaptation and the experimental period, guaranteeing a daily rejection rate of at least 10 %, while water was available *ad libitum*.

**Table 1:** Ingredients and chemical composition of the experimental diet

| **Ingredients (%)*** | | **Chemical makeup (% DM)** | |
|---|---|---|---|
| Alfalfa hay | 17.5 | Dry matter | 94.2 |
| Wheat straw | 11.0 | Organic matter | 92.9 |
| Ground wheat grains | 60.0 | Crude protein | 15.1 |
| Soybean meal | 7.0 | Ethereal extract | 4.2 |
| Soybean oil | 2.0 | Neutral detergent fiber | 17.9 |
| Limestone | 1.0 | Acid detergent fiber | 10.1 |
| Dicalcium phosphate | 1.0 | Ashes | 7.1 |
| Common salt | 0.5 | Calcium | 0.87 |
| | | Phosphorus | 0.54 |
| | | Metabolizable energy, Mcal/kg | 2.9 |

* The amount of each ingredient was calculated on a wet basis. DM= dry matter.

## Experimental design

A 32-d productive performance test was carried out after the adaptation period. On the first day of the test, all fasting male lambs were weighed individually (after 12 h without feed or water) and then grouped into 10 blocks, each containing three lambs of similar initial LW

(blocking factor). Thus, the male lambs in each block were randomly assigned to the treatments, which consisted in offering them a basal diet that included: 1) 0 mg of ZH / kg of LW (control); 2) 0.10 mg of patent ZH / kg of LW (Zilmax$^{TM}$, Intervet, Mexico City, Mexico; PZH), and 3) 0.10 mg of generic ZH per kg of LW (Grofactor$^{TM}$, Virbac Mexico, Guadalajara, Mexico; GZH). All male lambs were individually weighed every 10 d in order to adjust the amount of ZH in PZH and GZH treatments. The daily dose of the product was mixed with 30 g of ground wheat grains and offered in the morning, before the basal diet. The control group was fed 30 g ground wheat grains at the same time as in the PZH and GZH groups. Through the feedlot test, treatments were offered during the first 30 d, and the last two days were utilized as withdrawal period. The fasting male lambs were then transported to the meat workshop (located at a distance of 200 m from the pens), where they were slaughtered by the disgorging method.

## Productive performance

The variables evaluated for productive performance were initial and final LW (kg), average daily gain (DWG= TWG/32; kg/d/animal), total weight gain (TWG= final LW – initial LW; kg/period), daily dry matter intake (DMI= kilograms of fresh food ingested × [% DM/100], kg/animal), and feed efficiency (DWG/DMI). Lambs were fasting when the individual LW on day 1 (initial) and 33 (final) of the feedlot test was recorded, and these data were then used to calculate DWG and TWG.

## Body offal and carcass characteristics

The evaluation of offal and carcass characteristics was carried out as described by Avendaño-Reyes *et al*[10]. After slaughter, the bodies were eviscerated, and the weights of each organ, viscera and offal (skin, head, feet, testicles, blood, heart, liver, kidneys, lungs, spleen, full and empty gastrointestinal tract, rumen, intestines, and omental and mesenteric fat, as well as the fat surrounding kidneys, pelvic cavity and heart [KPH]) were recorded. The gastrointestinal content was estimated by difference between the weights of the empty and full gastrointestinal tract, while empty LW was calculated by subtracting the gastrointestinal content weight from the final LW. Thus, the weights of all organs, viscera and offal were expressed as percentages of the empty LW.

The hot carcass was weighed (HCW) and then cooled at 4 ºC during 24 h in order to record cold carcass weight (CCW), conformation, carcass length, thoracic depth, leg length and

perimeter, *Longissimus dorsi* muscle (LM) area, and fat thickness. The carcass conformation was assessed on an 8-point scale where 1 is bad and 8 is excellent[16]. A flexible measuring tape was utilized to take the carcass morphometric measurements[17]. Both LMA and fat thickness were measured between the 12$^{th}$ and 13$^{th}$ rib, performing a perpendicular cut to the loin at that height. The LM area was measured using a dot square grid (64 mm$^2$), while the fat thickness was determined with a caliper. Finally, the carcass yield was estimated by expressing the HCW as a percentage of the empty LW.

## Primary cut yields

Carcasses were cut along the middle line and the right half carcass was then divided into the following primary cuts[18]: forequarter, hindquarter, neck, shoulder, ribs, loin, plain loin, leg, and breast and flank. The right half-carcass and each primary cut were weighed; the yield of each cut was then calculated by expressing its weight as a percentage of the half-carcass weight.

## Meat quality

The meat quality was assessed in the LM. A piercing electrode (HACH model PHW57-SS, Colorado, USA) attached to a pH meter (HACH model H160G, HACH, Colorado, USA) was inserted into the carcass loin, between the 12$^{th}$ and the 13$^{th}$ rib, in order to record pH at 45 min and 24 h *post mortem*. Subsequently, the LM was dissected from the loin primary cut, and color parameters (a* [redness], b* [yellowness], L* [luminosity], C* [color saturation index], and h* [hue angle]) were measured at 24 h *post mortem*, using a portable colorimeter (X-rite model SP60, Michigan, USA). Finally, the LM was vacuum-packed and refrigerated at 4 ºC during 14 d, after which pH and color parameters were measured again, likewise shear force in matured meat was also measured. So, after the aging period, the LM was unpacked and exposed to blooming during 30 min before quality measurements. The pH was measured in a homogenized mixture of 5 g of meat and 25 ml of distilled water, using a liquid potentiometer (Hanna Instruments Digital model HI-2210, Woonsocker, Rhode Island). Color parameters were measured using the methodology described above in the evaluation at 24 h *post mortem*. Color measurements were carried out in triplicate, and, finally, the average for each parameter was estimated and recorded. For shear force, two (2.5 cm thick) LM steaks were cooked on an electric grill until they attained an internal temperature of 71 °C; the steaks were then cooled to ambient temperature (~25 ºC), and five prisms with a 1.27 cm diameter were obtained, in which the shear force was measured using a Warner-Bratzler

shear machine (Salter 235, Manhattan, KS, USA). The shear force per sample was recorded, averaging the three most homogenous values (variation coefficient <5 %).

### Statistical analysis

All data were analyzed using the ANOVA procedure of the SAS statistic software[19], applying the statistical model of a randomized complete block design. The model included to initial LW as blocking factor and the type of ZH as treatment. Means were compared through two orthogonal contrasts, establishing $P \leq 0.05$ as differences, and $0.05 > P \leq 1.0$ as trend. The first contrast compared the control group against the use of any source of ZH (C1: control *vs* PZH+GZH), and the second contrast compared between the sources of ZH (C2: PZH *vs* GZH).

## Results

### Control *versus* zilpaterol hydrochloride

Regardless of the source of ZH, the dietary addition of this $\beta_2$-adrenergic agonist ($\beta_2$-AA) did not affect ($P \geq 0.15$) the productive performance of animals (Table 2). In carcass, ZH increased carcass yield ($P \leq 0.01$) and LM area ($P \leq 0.05$); likewise, it exhibited a tendency ($P=0.09$) to improve conformation, but it did not affect ($P=0.09$) HCW, CCW, carcass morphometric measurements, or any variable associated with internal or external fat deposition (Table 3). As for the primary cut yields, ZH increased ($P \leq 0.03$) yields of forequarter, leg and plain loin, but reduced ($P \leq 0.01$) yields of hindquarter and shoulder, without affecting ($P \geq 0.27$) any of the other primary cuts (Table 4). In body offal (weights expressed as a percentage of the empty LW), the dietary addition of ZH reduced ($P \leq 0.05$) the weights of skin, liver, kidneys, spleen, and rumen, and exhibited a tendency ($P=0.06$) to decrease the feet weight (Table 5). The weight of the rest of body offal did not vary ($P \geq 0.12$) with the ZH inclusion.

**Table 2:** Productive performance of male lambs fed patent (PZH) or generic (GZH) zilpaterol hydrochloride

| Variables (kg) | Treatments | | | | Contrasts* | |
|---|---|---|---|---|---|---|
| | Control | GZH | PZH | SE | C1 | C2 |
| Initial weight | 36.9 | 36.8 | 36.9 | 2.19 | 0.98 | 0.96 |
| Final weight | 46.1 | 46.6 | 46.8 | 2.58 | 0.85 | 0.96 |
| Total weight gain | 9.18 | 9.80 | 9.85 | 0.69 | 0.45 | 0.96 |
| Daily weight gain | 0.30 | 0.31 | 0.31 | 0.02 | 0.32 | 0.96 |
| Daily DM intake | 1.59 | 1.51 | 1.56 | 0.06 | 0.26 | 0.62 |
| Feed efficiency | 0.18 | 0.20 | 0.20 | 0.01 | 0.15 | 0.28 |

* C1= control *s.* PZH+GZH; C2= PZH *vs* GZH. SE= standard error; DM= dry matter.

**Table 3:** Carcass characteristics of male lambs fed patent (PZH) or generic (GZH) zilpaterol hydrochloride

| Variables | Treatament | | | | Contrasts* | |
|---|---|---|---|---|---|---|
| | Control | GZG | PZH | SE | C1 | C2 |
| Hot carcass weight, kg | 22.00 | 22.59 | 23.52 | 1.32 | 0.51 | 0.62 |
| Cold carcass weight, kg | 21.82 | 22.42 | 23.36 | 1.31 | 0.51 | 0.61 |
| Carcass yield, % | 53.67 | 54.63 | 55.87 | 0.46 | 0.01 | 0.07 |
| LM area, $cm^2$ | 13.42 | 15.69 | 16.88 | 1.19 | 0.05 | 0.48 |
| Conformation, points | 6.17 | 6.40 | 6.80 | 0.20 | 0.09 | 0.17 |
| Carcass length, cm | 55.15 | 54.82 | 54.58 | 0.92 | 0.69 | 0.85 |
| Leg length, cm | 36.20 | 34.90 | 36.15 | 0.58 | 0.35 | 0.14 |
| Leg perimeter, cm | 47.23 | 49.91 | 47.97 | 2.04 | 0.50 | 0.50 |
| Thoracic depth, cm | 15.85 | 15.38 | 15.48 | 0.33 | 0.30 | 0.83 |
| Fat thickness, mm | 1.15 | 1.15 | 1.10 | 0.16 | 0.90 | 0.83 |
| Omental fat, % | 2.08 | 2.32 | 2.27 | 0.23 | 0.46 | 0.90 |
| Mesenteric fat, % | 1.87 | 1.85 | 1.66 | 0.16 | 0.36 | 0.21 |
| KPH fat**, % | 1.49 | 1.74 | 1.62 | 0.14 | 0.28 | 0.55 |

* C1= control *vs* PZH+GZH; C2= PZH *vs* GZH.

SE= standard error; LM= *Longissimus dorsi* muscle; KPH fat= Total fat located around kidneys, pelvic cavity and heart.

**Table 4:** Primary cut yields of male lambs fed patent (PZH) or generic (GZH) zilpaterol hydrochloride

| Variables (%)* | Treatment | | | | Contrasts** | |
|---|---|---|---|---|---|---|
| | Control | GZH | PZH | SE | C1 | C2 |
| Forequarter | 54.59 | 53.04 | 52.50 | 0.39 | <0.01 | 0.34 |
| Neck | 4.06 | 4.07 | 3.93 | 0.25 | 0.83 | 0.68 |
| Ribs | 9.72 | 9.83 | 9.71 | 0.27 | 0.88 | 0.73 |
| Loin | 9.70 | 10.2 | 9.95 | 0.25 | 0.27 | 0.54 |
| Shoulder | 31.0 | 28.9 | 29.9 | 0.67 | 0.01 | 0.96 |
| Hindquarter | 45.4 | 47.0 | 47.4 | 0.39 | <0.01 | 0.34 |
| Leg | 31.3 | 32.5 | 32.6 | 0.47 | 0.03 | 0.90 |
| Plain loin | 8.80 | 9.35 | 9.47 | 0.22 | 0.03 | 0.70 |
| breast and flank | 5.25 | 5.00 | 5.34 | 0.38 | 0.85 | 0.54 |

* Yields were calculated by expressing the weight of each cut as a percentage of the half-carcass weight.
** C1= control *vs* PZH+GZH; C2= PZH *vs* GZH. SE= standard error.

**Table 5:** Percentage in offal of male lambs fed patent (PZH) or generic (GZH) zilpaterol hydrochloride

| Variables (%)* | Treatment | | | | Contrasts** | |
|---|---|---|---|---|---|---|
| | Control | GZH | PZH | SE | C1 | C2 |
| Blood | 4.55 | 4.38 | 4.29 | 0.13 | 0.18 | 0.61 |
| Feet | 2.44 | 2.25 | 2.33 | 0.06 | 0.06 | 0.35 |
| Head | 5.61 | 5.68 | 5.71 | 0.16 | 0.69 | 0.88 |
| Skin | 9.69 | 8.99 | 8.68 | 0.24 | <0.01 | 0.37 |
| Heart | 0.48 | 0.45 | 0.45 | 0.01 | 0.19 | 0.79 |
| Liver | 2.33 | 2.17 | 2.06 | 0.06 | 0.01 | 0.24 |
| Kidneys | 0.30 | 0.27 | 0.28 | 0.01 | 0.03 | 0.64 |
| Lungs | 1.81 | 1.95 | 1.85 | 0.10 | 0.52 | 0.51 |
| Spleen | 0.22 | 0.17 | 0.18 | 0.01 | 0.01 | 0.66 |
| Rumen | 3.41 | 3.22 | 3.13 | 0.09 | 0.05 | 0.52 |
| Intestine | 3.22 | 2.84 | 2.90 | 0.17 | 0.12 | 0.81 |
| Testicles | 1.53 | 1.51 | 1.57 | 0.07 | 0.93 | 0.54 |

* Weights of each organ or viscera were expressed as percentages of the empty live weight.
** C1= control *vs* PZH+GZH; C2= PZH *vs* GZH; SE= standard error.

In the case of meat quality, ZH did not affect ($P \geq 0.23$) the post-mortem pH at 45 min, 24 h, or 14 d, but decreased ($P \leq 0.01$) $a^*$ and $C^*$ values, and tended ($P=0.07$) to reduce $b^*$ values at 24 h (Table 6). After 14 d post mortem, dietary inclusion of ZH reduced ($P<0.01$) $a^*$ values and increased ($P=0.05$) $h^*$ values, while it had no effects ($P=0.95$) on shear force. Values of $L^*$ were not affected ($P \geq 0.65$) by ZH in any of the evaluated time periods.

**Table 6:** Meat quality of male lambs fed patent (PZH) or generic (GZH) zilpaterol hydrochloride

| Variables | Treatment | | | | Contrasts** | |
|---|---|---|---|---|---|---|
| | Control | GZH | PZH | SE | C1 | C2 |
| $pH_{45\ min}$ | 6.54 | 6.59 | 6.57 | 0.05 | 0.60 | 0.82 |
| Evaluation at 24 h *post mortem* | | | | | | |
| pH | 5.83 | 5.93 | 5.92 | 0.06 | 0.24 | 0.88 |
| *L** | 39.1 | 37.7 | 38.9 | 1.30 | 0.65 | 0.51 |
| *a** | 10.3 | 8.17 | 9.01 | 0.44 | <0.01 | 0.19 |
| *b** | 9.51 | 8.46 | 8.82 | 0.38 | 0.07 | 0.51 |
| *C** | 13.7 | 12.0 | 12.6 | 0.43 | 0.01 | 0.34 |
| *h** | 43.8 | 44.3 | 44.4 | 1.33 | 0.76 | 0.92 |
| Evaluation after 14 d *post mortem* | | | | | | |
| pH | 5.83 | 5.95 | 5.98 | 0.08 | 0.23 | 0.81 |
| Shear force, $kg/cm^2$ | 2.04 | 1.87 | 2.25 | 0.24 | 0.95 | 0.28 |
| *L** | 41.2 | 42.5 | 41.1 | 1.20 | 0.70 | 0.39 |
| *a** | 9.15 | 7.76 | 7.98 | 0.36 | <0.01 | 0.66 |
| *b** | 10.26 | 9.74 | 9.19 | 0.50 | 0.21 | 0.45 |
| *C** | 13.8 | 12.5 | 13.2 | 0.56 | 0.18 | 0.39 |
| *h** | 45.9 | 51.3 | 49.5 | 1.66 | 0.05 | 0.45 |

** C1= control *vs* PZH+GZH; C2= PZH *vs* GZH; SE= standard error.

*L**= Luminosity, *a**= redness, *b**= yellowness, *C**= chroma, and *h**= hue angle.

## Patent *versus* generic zilpaterol hydrochloride

Productive performance (Table 2), carcass characteristics (except for carcass yield; Table 3), primary cut yields (Table 4), weight of the offal expressed as a percentage of the empty LW (Table 5), and meat quality (Table 6) exhibited no variation ($P \geq 0.23$) between PZH and GZH. The dietary addition of PZH showed a tend ($P = 0.07$) to increase carcass yield compared to GZH.

# Discussion

## Control *versus* zilpaterol hydrochloride

The addition of ZH to the finishing diet did not improve productive performance or carcass weight in hair male lambs. These results were not expected, as most studies including this $\beta_2$-AA report a greater DWG, feed efficiency, HCW, and CCW, with little consistent effects on DMI[4,5,8,18,20-22]. One might think that having administered a dose below the one recommended by the company (0.10 *vs* 0.15 mg/kg of LW) was the cause of this lack of effects, as most of those studies that report improvement added the product according to the indications on the label. Nevertheless, a previous study evidenced that 0.10 mg/kg of LW is an optimal dose for finishing male lambs in feedlot when this type of generic ZH is used[10]. Notably, those studies in which ZH improved productive performance and carcass weight, the control group exhibited lower DWG (168-280 g/d) than that determined in the present study. So, results in terms of productive performance and carcass weight may be due to the fact that the lambs expressed their maximum genetic potential for growth without the need to use ZH and, in consequence, this promoter had a limited margin to exert its positive effects on DWG and carcass weight. The literature indicates that hair lambs have a DWG of approximately 250 g/d (23), i.e., 50 g less than that observed in the control group of this study which are also hair sheep. According to this finding, Mersmann[24] mentions that the effectiveness of $\beta_2$-AA for improving body mass gain may be limited by the animal genetic potential.

While ZH did not affect LW gain or carcass weight in male lambs; this product improved carcass yield, LM area and yields of certain primary cuts (i.e., leg and plain loin). This suggests that the $\beta_2$-AA promoted muscular hypertrophy and, therefore, increased muscular mass deposition, although to a limited extent. The increase in carcass yield may be a consequence of the greater muscle mass deposition in body regions as plain loin and legs. These findings agree with results of other studies[5,10]; still in these, the effect was more pronounced which further supports the idea that external factors were more important than ZH itself in inducing the maximum expression of genetic growth potential by the sheep, limiting the mechanism of action of the $\beta_2$-AA[24].

The dietary inclusion of ZH did not affect the body internal or external fat deposition, but reduced the weights of some offal (skin, liver, kidneys, spleen, rumen, and feet). This suggests that the muscular hypertrophy observed in loin and legs of the male lambs was caused by an $\beta_2$-AA-promoted redistribution of nutrients from offal tissue toward the formation of skeletal muscle as previously reported with the addition of generic ZH[8,10,22].

On the other hand, feeding male lamb with ZH has been mainly associated with an increase in meat pH, which causes a reduction in color values and an increase in meat toughness[6,7,22]. However, there is evidence that ZH decreases meat color even with a normal pH[25]. In the present study, ZH did not affect *post mortem* pH (45 min, 24 h, or 14 d); this could partially explain because shear force and luminosity of the meat did not change with the daily inclusion of this $\beta_2$-AA. Given results for pH, the meat from ZH-treatment unexpectedly discolored without losing luminosity at 24 h *post mortem*; this effect persisted to a lesser extent after 14 d of maturation. Although the pH at 24 h and 14 d *post mortem* exhibited no significant change, the pH values in ZH meat (>5.9) remained above the normal range (≤5.8)[26]. This may have caused an increase in the mitochondrial respiration of oxidative fibers and a greater competition for oxygen with oxymyoglobin, increasing desoxymyoglobin and metmyoglobin concentrations—pigments which favor meat discoloration[27].

## Patent *versus* generic zilpaterol hydrochloride

Male lambs fed PZH and GZH exhibited no differences in their productive performance, carcass characteristics, primary cut yields, or meat quality, suggesting that both molecules are similarly effective as growth promoters at a daily dose of 0.10 mg per kg of LW in this type of animals. Although, this twofold finding must be taken with caution, since, as stated above, the dietary addition of patent and generic ZH in the sheep feeding promoted muscular hypertrophy, though not at a sufficient level to result in higher DWG, feed efficiency, or carcass weight. Nevertheless, the fact that generic ZH at the dose used promotes a degree of muscular hypertrophy comparable to that observed with patent ZH in finishing male lambs is rescued. This may be due to the fact that both products are similar in bioequivalence, chirality, and isomeric determination[9]. Despite this, they differ as they are attached to the vehicle (ground cob); while the patent ZH molecule is attached around the granules of the vehicle, the generic ZH molecule remains unattached to this[10]. This could reduce the bioavailability and, consequently, the effectiveness of the product. Results of this study suggest that the manner in which the molecule is attached in the vehicle, it is not a factor that decreases or enhances the functioning of ZH on the growth of hair male lambs finished in feedlot.

As in the present study, other authors[8] found no difference in productive performance, carcass characteristics, wholesale cut yields, or noncarcass component weights between lambs fed patent and generic ZH. On the other hand, in bulls, the source of ZH did not affect growth, carcass characteristics or meat quality[9].

It should be noted that neither of the sources of ZH promoted lipolysis in order to exert its hypertrophic effects on skeletal muscle[25]. This had already been documented using generic ZH[8,10,22]; however, patent ZH had regularly caused a lipolytic effect in fattening sheep[4,20,28]. This suggests that the mechanism of lipolytic action associated to patent ZH depends on the dose, as doses of 0.15 mg per kg of LW were used in previous studies, while the present study used 33.3 % less. Nevertheless, further research is required to confirm this finding.

# Conclusions and implications

The daily addition of 0.10 mg / kg of patent or generic ZH in the finishing diet of hair male lambs substantially promotes muscular hypertrophy in loin and legs, resulting in greater carcass yield, but not in better growth rate, feed efficiency, carcass weight, or meat color. Finally, further studies using different doses of AA-$\beta_2$ and sheep genotypes are recommended in order to determine whether generic ZH is equally effective as patent ZH for growth promotion.

**Acknowledgments**

The authors wish to express their gratitude to the Academic Group of Animal Physiology and Genetic for their support for this study, having financed and conducted it in its entirety in their facilities. They are grateful as well to the graduate students (Erick Gómez Aranda, Ricardo Vicente Pérez, Yolanda Osorio Marín, and Arnulfo Vicente Pérez) and laboratory technicians who collaborated in carrying out field phase. The first author also thanks Conacyt for the scholarship it granted him to carry out his doctoral studies.

**Literature cited:**

1. Hernández-Marín JA, Valencia-Posadas M, Ruíz-Nieto JE, Mireles-Arriaga AI, Cortez-Romero C, Gallegos-Sánchez J. Contribución de la ovinocultura al sector pecuario en México. Agroproductividad 2017;10(3):87-93.

2. Macías-Cruz U, Álvarez-Valenzuela FD, Torrentera-Olivera NG, Velázquez-Morales JV, Correa-Calderón A, Robinson PH, *et al*. Effect of zilpaterol hydrochloride on feedlot performance and carcass characteristics of ewe lambs during heat-stress conditions. Anim Prod Sci 2010;50(10):983.

3. Ríos Rincón FG, Barreras-Serrano A, Estrada-Angulo A, Obregón JF, Plascencia-Jorquera A, Portillo-Loera JJ, *et al.* Effect of level of dietary zilpaterol hydrochloride (β 2-agonist) on performance, carcass characteristics and visceral organ mass in hairy lambs fed all-concentrate diets. J Appl Anim Res 2010;38(1):33-38.

4. Lopez-Carlos MA, Ramirez RG, Aguilera-Soto JI, Rodríguez H, Carrillo-Muro O, Méndez-Llorente F. Effect of two beta adrenergic agonists and feeding duration on feedlot performance and carcass characteristics of finishing lambs. Livest Sci 2011;138(1-3):251-258.

5. Rojo-Rubio R, Avendaño-Reyes L, Albarrán B, Vázquez JF, Soto-Navarro SA, Guerra JE, *et al*. Zilpaterol hydrochloride improves growth performance and carcass traits without affecting wholesale cut yields of hair sheep finished in feedlot. J Appl Anim Res 2018;46(1):375-379.

6. Dávila-Ramírez JL, Avendaño-Reyes L, Macías-Cruz U, Torrentera-Olivera NG, Zamorano-Garcia L, Peña-Ramos A, *et al*. Effects of zilpaterol hydrochloride and soybean oil supplementation on physicochemical and sensory characteristics of meat from hair lambs. Small Ruminant Res 2013;114(2-3):253-257.

7. Dávila-Ramírez JL, Avendaño-Reyes L, Macías-Cruz U, Peña-Ramos EA, Islava-Lagarda TY, Zamorano-García L, *et al*. Fatty acid composition and physicochemical and sensory characteristics of meat from ewe lambs supplemented with zilpaterol hydrochloride and soybean oil. Anim Prod Sci 2017;57(4):767.

8. Rivera-Villegas A, Estrada-Angulo A, Castro-Pérez BI, Urías-Estrada JD, Ríos-Rincón FG, Rodríguez-Cordero D, *et al*. Comparative evaluation of supplemental zilpaterol hydrochloride sources on growth performance, dietary energetics and carcass characteristics of finishing lambs. Asian-Australas J Anim Sci 2019;32(2):209-216.

9. Avendaño-Reyes L, Meraz-Murillo FJ, Pérez-Linares C, Figueroa-Saavedra F, Correa A, Álvarez-Valenzuela FD, *et al*. Evaluation of the efficacy of Grofactor, a beta-adrenergic agonist based on zilpaterol hydrochloride, using feedlot finishing bulls. J Anim Sci 2016;94(7):2954-2961.

10. Avendaño-Reyes L, Torrentera-Olivera NG, Correa-Calderón A, López-Rincón G, Soto-Navarro SA, Rojo-Rubio R, *et al.* Daily optimal level of a generic beta-agonist based on zilpaterol hydrochloride for feedlot hair lambs. Small Ruminant Res 2018;165:48-53.

11. Ortiz Rodea A, Amezcua Barbosa M, Partida De La Peña JA, González Ronquillo M. Effect of zilpaterol hydrochloride on animal performance and carcass characteristics in sheep: A meta-analysis. J Appl Anim Res 2016;44(1):104-112.

12. NRC. Nutrient requirements of small ruminants: Sheep, goat, cervids, and new world camelids. Washington, D.C., USA: National Academic Press; 2007.

13. AOAC. Official methods of analysis. 15th ed. Washington, DC: Association of Official Analytical Chemists; 1990.

14. Van Soest PJ, Robertson JB, Lewis BA. Methods for dietary fiber, neutral detergent fiber, and nonstarch polysaccharides in relation to animal nutrition. J Dairy Sci 1991;74(10):3583-3597.

15. NRC. Nutrient requirements of sheep. 6th ed. Washington, D.C., USA: National Academy Press; 1985.

16. Smith GC, Griffin DB, Kenneth JH. Meat evaluation handbook. First ed. American Meat Science Association, ed. IL: American Meat Science Association; 2001.

17. Párez-Casanova PMP. Morphometric dimensions allow differentiation of lamb carcasses for some breeds. Egyptian J Sheep Goat Sci 2013;8(1):167-170.

18. Avendaño-Reyes L, Macías-Cruz U, Álvarez-Valenzuela FD, Águila-Tepato E, Torrentera-Olivera NG, Soto-Navarro SA. Effects of zilpaterol hydrochloride on growth performance, carcass characteristics, and wholesale cut yield of hair-breed ewe lambs consuming feedlot diets under moderate environmental conditions. J Anim Sci 2011;89(12):4188-4194.

19. SAS institute. SAS/STAT: User's Guide Statistics Released. 2004.

20. Estrada-Angulo A, Barreras-Serrano A, Contreras G, Obregón JF, Robles-Estrada JC, Plascencia A, *et al*. Influence of level of zilpaterol chlorhydrate supplementation on growth performance and carcass characteristics of feedlot lambs. Small Ruminant Res 2008;80(1-3):107-110.

21. Macías-Cruz U, Avendaño-Reyes L, Álvarez-Valenzuela FD, Torrentera-Olivera NG, Meza-Herrera C, Mellado Bosque M, *et al*. Crecimiento y características de canal en corderas tratadas con clorhidrato de zilpaterol durante primavera y verano. Rev Mex Cien Pecu 2013;4(1):1-12.

22. López-Baca MÁ, Contreras M, González-Ríos H, Macías-Cruz U, Torrentera N, Valenzuela-Melendres M, *et al*. Growth, carcass characteristics, cut yields and meat quality of lambs finished with zilpaterol hydrochloride and steroid implant. Meat Sci 2019;158:107890.

23. Muñoz-Osorio GA, Aguilar-Caballero AJ, Sarmiento-Franco LA, Wurzinger M, Cámara-Sarmiento R. Technologies and strategies for improve hair lamb fattening systems in a tropical region: A review. Rev Ecosist Rec Agropec 2016;3(8):267-277.

24. Mersmann HJ. Overview of the effects of beta-adrenergic receptor agonists on animal growth including mechanisms of action. J Anim Sci 1998;76(1):160-172.

25. Partida PJM, Casaya RTA, Rubio LMS, Méndez MRD. Efecto del clorhidrato de zilpaterol sobre las caracterísiticas de la canal en cruzas terminales de corderos Kathadin. Vet Mex 2015;2(2):1-13.

26. Ponnampalam EN, Hopkins DL, Bruce H, Li D, Baldi G, Bekhit AE. Causes and contributing factors to "dark cutting" meat: Current trends and future directions: A review. Compr Rev Food Sci Food Saf 2017;16(3):400-430.

27. Suman SP, Joseph P. Myoglobin chemistry and meat color. Annu Rev Food Sci Technol 2013;4(1):79-99.

28. Dávila-Ramírez JL, Macías-Cruz U, Torrentera-Olivera NG, González-Ríos H, Soto-Navarro SA, Rojo-Rubio, *et al.* Effects of zilpaterol hydrochloride and soybean oil supplementation on feedlot performance and carcass characteristics of hair-breed ram lambs under heat stress conditions. J Anim Sci 2014;92(3):1184-1192.