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# INFLUENCE OF DURATION OF ZILPATEROL SUPPLEMENTATION ON CARCASS CHARACTERISTICS AND MEAT QUALITY OF FINISHED LAMBS

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## ABSTRACT

**Supplementing zilpaterol hidrochloride (ZH) in lambs improves growth performance and carcass yield. Typically, ZH supplementation is initiated 32 d before slaughter, consisting of a 30-d feeding period followed by a 2-d withdrawal period. Previous studies have shown that ZH tend to be more effective when administered over short periods near the end of feedlot phase. The objective of this study was to evaluate the effect of supplementation duration (control, 10, 20 or 30 d) of zilpaterol hydrochloride (ZH) on carcass characteristics, cutability, and meat quality in forty 4-month-old Dorper x Kathadin male lambs (body weight = 34.6 ± 2.4 kg; 10 lambs per treatment). Omental fat deposition and shoulder percentage decreased (linear effect, P <0.05), whereas carcass weight and the proportions of loin and leg increased (linear effect, P<0.05) with increasing duration of ZH supplementation. However, no treatment effects were observed (P > 0.10) on the proportion of primary cuts or on post-mortem pH of the *L. thoracis* muscle (0.05). Meat shear force increased (linear effect, P <0.05) as the duration of ZH supplementation increased. ZH supplementation was economically profitable, regardless of the number of days it was administered, with greater efficiency observed as the supplementation period increased.**

**Keywords:** β2 adrenergic agonists, primary cuts, feedlot, ovine efficiency.

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## INTRODUCTION

Zilpaterol hydrochloride (ZH) supplementation in lambs improves growth performance and carcass yield (Macías-Cruz et al., 2013; Dávila-Ramírez et al., 2017; López-Baca et al., 2019; Cayetano et al., 2020). The beneficial effects of ZH are attributed to increased lipolysis and reduced lipogenesis, whereby nutrients are "repartitioned" toward enhanced lean tissue accretion (Hergenreder et al., 2017). Although β-agonist Lubabegron (Experior) has been approved by the US Food and Drug Administration (FDA) for use in steers and heifers fed in confinement during the last 14-91 d on feed prior to slaughter (Maaliki et al., 2024), ZH supplementation in lambs is typically initiated 32 d before slaughter, consisting of a 30-d supplementation period followed by a 2-d ZH withdrawal period. According to López-Carlos et al. (2011), ZH supplementation during the last 30 d before slaughter improves carcass yield, without adverse effects on marbling score or carcass fat characteristics, and without altering serum protein levels, energy status, or metabolites indicative of energy balance. Vahedi et al. (2014) reported that ZH supplementation for 28 to 42 d prior to slaughter improved certain carcass characteristics in lambs. The same authors reported that ZH supplementation for 42 d increased the shear force, without affecting other meat characteristic. The response to adrenergic agonist (β-AA) administration often diminishes over time (Aguilera-Soto et al., 2008). Oral administration of ZH for 45 d has been associated with negative effects on meat quality characteristics (Shook et al., 2009). Studies with β-AA shows that their effects are more pronounced when administered for short periods near the end of feedlot phase. Caetano et al. (2021) reported favorable results after 20 d of supplementation. However, the response diminishes over time; therefore, its use requires careful planning to determine the optimal supplementation period. Accordingly, the aim of this study was to evaluate the effect of reducing the duration of ZH supplementation on carcass characteristics and meat quality in crossbred finishing lambs.

## MATERIALS AND METHODS

The experiment was conducted at the Small Ruminant Experimental Unit of the Veterinary Research Institute of the Autonomous University of Baja California (UABC), in Mexicali, B.C. Mexico (32⁰37´40.1¨N, 115º27.268W´, altitude 8.23 m). All experimental procedures were carried out in accordance with approved guidelines for the care and handling of animals: including NOM-051-ZOO-1995 (humane handling of animals during transport), NOM- 024-ZOO-1995 (animal health requirements and conditions during transport), NOM-033-ZOO-1995 (humane slaughter of domestic and wild animals) and NOM-EM-015-ZOO-2002 (technical provisions for the control of β-agonists use in animals). Forty 4-month-old Dorper x Kathadin lambs (initial body weight (BW) 34.6 ± 2.4 kg) were obtained from a single flock. Upon arrival, lambs were dewormed (Ivermectin; Sanfer Laboratory, Mexico City; 0.5 mL/animal) and administered a subcutaneous injection of 100,000 IU vitamin A (Vigantol ADE Fuerte; Bayer, Mexico City, Mexico). Lambs were housed in individual, fully-shaded pens (1.2 x 2.0 m) with concrete flooring, each equipped with an individual feeder and drinker. The study lasted 52 d, including a 20-d adaptation period and a 32-d experimental period. During the adaptation period, all lambs received the same basal finishing diet (Table 1). Lambs were offered fresh feed twice daily at 0700 and 1500 h in a 40:60 proportion (as fed basis), allowing for a feed refusals of approximately 50 g $k\text{-}g^{-1}$ of feed offered. Feed bunks were visually assessed each morning at 0640 h, and residual feed was collected and weighed. Feed samples were collected daily and composited weekly for dry matter (DM) analysis (oven dried at 105°C until constant weight; method 930.15, AOAC, 2000). Lambs had *ad libitum* access to water, and health status was visually assessed daily.

Lambs were individually weighed on day 1 of the experimental period and stratified by weight into 10 blocks. Treatments consisted of zilpaterol hydrochloride (Zilmax, Intervet / Schering-Plough, Mexico) supplementation (10 mg $animal^{-1}$ $d^{-1}$) for 0, 10, 20 or 30 d followed by a 2-d withdrawal period (basal diet alone). Treatments were randomly assigned within blocks (n=10 lambs/treatment = 10 pens/treatment and one pen is one replicate). During the experimental period, feeders were thoroughly cleaned daily at 0640 h and the food present was weighed. At 0700 h, 50 g of basal diet, including the complete daily treatments, were served. After verifying complete consumption of the treatment, the remainder of the daily ration was served immediately.

At the end of the 32-day experimental period, lambs were individually weighed and slaughtered according to industry-accepted procedures at Meat Facility of the Institute of Agricultural Sciences-UABC.

Blood was collected at exsanguination via jugular puncture, transferred to plastic containers, and weighed and recorded.

**Table 1. Ingredients and chemical composition of the basal diet.**

| Ingredients | % |
|---|---|
| Flake corn grain | 46.00 |
| Alfalfa hay | 26.50 |
| DDGs[1] | 20.00 |
| Molasses | 6.00 |
| ZH, mg/animal/d | 10.00 |
| Minerals | 1.50 |
| **Nutrient composition (Dry matter basis)[2]** | |
| Dry matter | 88.96 |
| Metabolizabe energy (Mcal/kg) | 2.98 |
| Ether extract | 4.89 |
| Crude protein | 15.78 |
| Neutral detergent fiber | 12.48 |
| Acid detergent fiber | 4.84 |
| Ca | 0.85 |
| P | 0.68 |

[1]DDGs = Dried corn distillers grains with solubles.
[2]Based on tabular values for individual feed ingredients (NRC, 2007).

Subsequently, the head, feet, testes, and skin were removed from the body, and its weight was recorded. The carcass was opened along the ventral midline to allow removal and weighing of the entire gastrointestinal tract (GT), internal organs (lungs, liver, spleen, heart and, kidneys), and the different types of fats, including kidney, pelvic, and heart fat, (KPH), as well as omental and mesenteric fat. After weighing the GT, it was emptied and washed to determinate its empty weight (EW). Except for KPH fat weight, all organ weights were expressed as a percentage of the adjusted slaughter weight, calculated as slaughter weight x 0.96. The KPH fat weight was expressed as a percentage of the hot carcass weight (HCW). HCW was recorded after the organs and viscera were removed; carcass yield was expressed as HCW as a percentage of adjusted slaughter weight. Subsequently, carcasses were chilled at 4 ºC for 24 h to obtain cold carcass weight (CCW). Carcass conformation degree was assessed using the 8-point scale (1 = poor and 8 = excellent) proposed by Smith et al. (2001). Carcass length, neck circumference, thoracic depth, and legs length and circumference were measured. Subssequently, the carcasses were split along the dorsal midline, and the right half carcass was weighed. This half was then cut transversely at the intercostal space between the 12th and 13th ribs to determine the ribeye area (RA) and subcutaneous fat thickness. The RA was traced on to an acetate sheet and quantified using a benchtop leaf area meter (LI-3100C Area Meter, LI-COR Bioscience, Lincoln, NE, USA). Subcutaneous fat thickness was measured using a stainless-steel ruler placed perpendicular to the 12th rib, at two thirds of distance from the dorsal midline (USDA, 1992).

The right half carcass was sectioned in primary cuts according to the methodology described by Avendaño-Reyes et al. (2011) (neck, shoulder, rib, loin, flank, and leg), and the weight of each cut was recorded. The yield of each cut was calculated by expressing its weight as a percentage of carcass weight.

Meat quality was evaluated in the *Longissimus thoracis* (LT) muscle. The pH was recorded at 45 min, 24 h, and 14 d post-mortem directly on the carcass over the LT muscle. Subsequently, the LT muscle was removed, vacuum packed and stored at 4 ºC. After 14 d of aging, pH, color variables, and shear force were determined. Muscle pH at 45 min and 24 h post-mortem was measured using a portable pH meter (H160G, HACH, CA, USA) equipped with a penetration electrode (PHW57-SS, HACH, Ca, USA). The pH at 14 days post-mortem was determined using a potentiometer for liquids (Sension + pH, HACH, CA, USA), by homogenizing a 5 g sample of meat with 90 mL of distilled water for 1 min. Meat color was evaluated using a colorimetry equipment PANTONE (SP60 Series, X-rite, Michigan, USA). This equipment was placed directly on the LT muscle to record the color values L* (lightness), a* (redness), and b* (yellowness) values. For shear force determination, two LT muscle samples were cooked on an electric grill to an internal temperature of 70 ºC. The internal temperature was monitored with a penetration thermometer. Samples were then cooled to 30 ºC, and six cubes of (1 $cm^3$) were prepared from each sample. Cubes were sheared perpendicularly to the muscle fiber direction using a Warner-Bratzler shear force device (Salter Model 235, GR manufacturing company, Manhattan, KS, USA). For each sample, three Warner-Bratzler shear force (WBSF) measurements were averaged, and the coefficient of variation was ≤ 5%.

### Statistical analysis

All data were subjected to an analysis of variance (ANOVA) using the MIXED Procedure of SAS (SAS Institute Inc., Cary, NC, USA, 2002) under a randomized complete block design, with initial body-weight as the blocking factor. The pen was considered the experimental unit, and treatment was included as a fixed effect within block. Treatment means were analyzed using orthogonal polynomials, significance was declared at P≤0.05 and trends were discussed when P ≤ 0.05.

### Cost-benefit evaluation

Data were analyzed using the methodology of the Study Center for the Preparation and Socioeconomics Evaluation of Projects (SCPSEP, Mexico, 2018).

## RESULTS

The effects of ZH supplementation duration on carcass characteristics of lambs are presented in Table 2. Slaughter weight, hot and cold carcass weights, and ribeye area increased linearly (P <0.05) as the duration of ZH supplementation increased from 0 to 30 d. A summary of results on behavior testing and carcass characteristics was published previously by Sosa-Ventura et al. (2016) and López-Baca et al. (2016), respectively.

The ribeye area increased linearly (P<0.05) as the duration of ZH supplementation increased, whereas the remaining carcass variables were not affected (P> 0.05) by the length of the ZH supplementation period.

Table 3 presents the effect of ZH supplementation duration on organ weights expressed as a percentage of slaughter weight in finishing crossbred hair lambs. The percentage of testes howed a quadratic effect (P <0.05), whereas the percentage of the full gastrointestinal tract (GT) showed a cubic response (P <0.05) as the duration of ZH supplementation increased from 0 to 30 d. The highest testes percentage was observed in lambs supplemented for 10 and 20 d before slaughter. In contrast, the percentage of full gastrointestinal tract weight was higher in control lambs. Additionally, a linear decrease (P <0.05) in the percentage of feet and omental fat was observed with increasing duration of ZH

**Table 2. Effect of zilpaterol hydrochloride (ZH) supplementation duration on carcass characteristics of finishing crossbred hair lambs.**

| | Treatments[1] | | | | | Contrasts[2] | | |
|---|---|---|---|---|---|---|---|---|
| **Traits** | **Z0** | **Z10** | **Z20** | **Z30** | **SEM** | **L** | **Q** | **C** |
| Slaughter weight, kg | 39.39 | 40.92 | 40.91 | 41.73 | 0.95 | 0.04 | 0.64 | 0.48 |
| Hot carcass weight (kg) | 23.16 | 24.62 | 24.87 | 25.24 | 1.44 | 0.00 | 0.16 | 0.44 |
| Cold carcass weight (kg) | 18.57 | 20.12 | 20.41 | 20.61 | 1.42 | 0.00 | 0.07 | 0.47 |
| Dressing % | 59.07 | 60.29 | 60.93 | 60.64 | 0.79 | 0.11 | 0.32 | 0.92 |
| Conformation (units) | 5.90 | 6.10 | 5.70 | 5.90 | 0.40 | 0.61 | 1.00 | 0.13 |
| Ribeye area ($cm^2$) | 6.83 | 7.19 | 7.59 | 8.06 | 0.47 | 0.05 | 0.90 | 0.98 |
| KPH fat, (%)[3] | 1.99 | 2.14 | 2.02 | 1.86 | 0.31 | 0.52 | 0.39 | 0.77 |
| Fat thickness (mm) | 3.4 | 4.4 | 2.3 | 4.8 | 0.14 | 0.62 | 0.40 | 0.11 |
| Carcass length (cm) | 59.25 | 60.10 | 58.30 | 60.70 | 1.69 | 0.63 | 0.52 | 0.20 |
| Thoracic depth cm | 33.02 | 33.43 | 32.25 | 33.35 | 0.76 | 0.93 | 0.54 | 0.11 |
| Leg length (cm) | 29.60 | 29.85 | 28.65 | 30.50 | 1.01 | 0.67 | 0.31 | 0.20 |
| Leg circumference (cm) | 45.75 | 46.75 | 46.55 | 46.85 | 1.65 | 0.49 | 0.72 | 0.70 |
| Neck circumference (cm) | 33.60 | 34.20 | 34.00 | 33.55 | 1.24 | 0.93 | 0.57 | 0.89 |

[1] ZH supplemented during the last 0 (Z0 = control), 10 (Z10), 20 (Z20), and 30 (Z30) d of the feeding period. [2]Probabilities of linear (L), quadratic (Q), and cubic (C) effects due to treatments. [3]KPH fat = Kidney-pelvic-heart fat. SEM= Standard error of the mean. Means represent 10 replicate pens per treatment.

**Table 3. Effect of zilpaterol hydrochloride (ZH) supplementation duration on organs and viscera weights expressed as a percentage of slaughter weight in feedlot-finished hair crossbred lambs.**

| | Treatments[1] | | | | | Contrasts[2] | | |
|---|---|---|---|---|---|---|---|---|
| **Traits[3], %** | **Z0** | **Z10** | **Z20** | **Z30** | **SEM** | **L** | **Q** | **C** |
| Heart | 0.44 | 0.43 | 0.43 | 0.42 | 0.01 | 0.43 | 0.74 | 0.89 |
| Liver | 2.22 | 1.99 | 2.14 | 2.11 | 0.07 | 0.64 | 0.18 | 0.11 |
| Spleen | 0.16 | 0.17 | 0.17 | 0.16 | 0.01 | 0.71 | 0.44 | 0.96 |
| Kidney | 0.37 | 0.30 | 0.30 | 0.30 | 0.02 | 0.08 | 0.24 | 0.42 |
| Lungs | 1.30 | 1.23 | 1.27 | 1.20 | 0.06 | 0.17 | 0.93 | 0.24 |
| Blood | 4.31 | 4.49 | 4.38 | 4.37 | 0.11 | 0.85 | 0.38 | 0.39 |
| Testes | 0.98 | 1.13 | 1.13 | 1.01 | 0.06 | 0.78 | 0.02 | 0.87 |
| Head | 5.42 | 4.83 | 5.41 | 5.32 | 0.29 | 0.79 | 0.32 | 0.11 |
| Skin | 9.56 | 8.93 | 9.05 | 9.13 | 0.19 | 0.18 | 0.07 | 0.36 |
| Feet | 2.33 | 2.25 | 2.24 | 2.15 | 0.06 | 0.00 | 0.82 | 0.35 |
| GT[4] | 21.61 | 16.08 | 20.66 | 21.40 | 1.51 | 0.56 | 0.04 | 0.04 |
| EGT[5] | 6.24 | 6.18 | 6.52 | 6.55 | 0.24 | 0.22 | 0.84 | 0.49 |
| Omental fat | 2.17 | 1.90 | 1.71 | 1.68 | 0.21 | 0.00 | 0.35 | 0.86 |
| Mesenteric fat | 3.71 | 3.58 | 3.45 | 3.19 | 0.38 | 0.10 | 0.76 | 0.89 |

[1]ZH supplementation during the last 0 (Z0 = control), 10 (Z10), 20 (Z20), and 30 (Z30) d of the feeding trial.
[2]Probabilities of linear (L), quadratic (Q), and cubic (C) effects due to treatments.
[3]Organ and viscera weights were expressed as a percentage of the slaughter weight.
[4]GT = Gastrointestinal tract; [5]EGT = Empty gastrointestinal tract
SEM= Standard error of the mean. Means represent 10 replicate pens per treatment.

supplementation. Skin percentage was higher in Z0 and lower in Z10. No differences (P> 0.05) were found in the remaining organs and viscera as a result of ZH supplementation duration.

Table 4 presents the effects of ZH supplementation duration on the yield of primary cuts in finishing crossbred hair lambs. The percentage of adjusted carcass weight for some primary cuts, such as the loin and leg increased linearly (P <0.05), whereas the front shank decreased linearly (P <0.05), as the supplementation period increased, from 0 to 30 d. In contrast, ZH supplementation duration did not affect the yields of neck, rib, or breast (P> 0.05).

Table 5 presents the effect of ZH supplementation duration on meat quality in finishing crossbred hair lambs. ZH supplementation duration did not affect post-mortem pH at 45 min and 24 h in the *Longissimus thoracis* muscle (P> 0.05). However, pH at 14 d post-slaughter tended to show a quadratic effect as the supplementation period increased from 0 to 30 d. Color traits (L *, a *, and b *) decreased, while shear force increased linearly (P <0.05) with increasing length of ZH supplementation duration.

### Cost-benefit evaluation

Because carcass evaluation in sheep is not a standardized practice in Mexico and there is no formal market for different cuts, the analysis was based on the cold carcass weight, which is the primary marketing unit. ZH supplementation was economically profitable, regardless of the supplementation duration. The pH stability suggests that ZH supplementation does not compromise this aspect of meat quality, which may represent a positive attribute in the market. The benefits could outweigh the drawbacks if the market prioritizes weight, color, and total muscle mass. This efficiency improved as the supplementation duration increased.

## DISCUSSION

Carcass weight and the ribeye area increased with increasing duration of ZH supplementation, with 30 d being optimal compared to shorter periods (10 or 20 d). Favorable effects of ZH supplementation on carcass characteristics have been reported (Baxa et al., 2010). These results are attributed to greater muscle development because ZH function as a nutrient redistributor, increasing protein synthesis (Hausman et al., 2018). In addition, ZH stimulates muscle growth through increased muscle fiber hypertrophy (Beermann, 2002). Salinas-Chavira et al. (2006), observed that, when ZH was offered for 0, 20

**Table 4. Effects of zilpaterol hydrochloride (ZH) supplementation duration on primary cut yields of hair crossbred lambs finished in pens**

| | Treatments[1] | | | | | Contrasts[2] | | |
|---|---|---|---|---|---|---|---|---|
| Traits[3], % | Z0 | Z10 | Z20 | Z30 | SEM | L | Q | C |
| Neck | 4.97 | 4.45 | 4.70 | 4.49 | 0.22 | 0.24 | 0.48 | 0.22 |
| Front shank | 35.87 | 34.60 | 34.10 | 33.94 | 0.36 | 0.00 | 0.13 | 0.79 |
| Rib | 7.68 | 7.67 | 7.80 | 7.91 | 0.20 | 0.36 | 0.76 | 0.84 |
| Loin | 14.94 | 15.94 | 15.88 | 15.82 | 0.38 | 0.05 | 0.07 | 0.41 |
| Breast | 4.47 | 4.58 | 4.59 | 4.59 | 0.19 | 0.69 | 0.79 | 0.91 |
| Leg | 32.04 | 32.74 | 32.91 | 33.22 | 0.39 | 0.02 | 0.58 | 0.67 |

[1] ZH supplementation during the last 0 (Z0 = control), 10 (Z10), 20 (Z20), and 30 (Z30) d of the completion of the feeding trial.
[2]Probabilities of linear (L), quadratic (Q), and cubic (C) effects due to treatments.
[3]Primary cut weights were expressed as a percentage of adjusted average carcass weight.
SEM= Standard error of the mean. Means represent 10 replicate pens per treatment.

**Table 5. Effect of zilpaterol hydrochloride (ZH) supplementation duration on meat quality of the *Longissimus thoracis* muscle in finishing lambs.**

| | Treatments[1] | | | | | Contrasts[2] | | |
|---|---|---|---|---|---|---|---|---|
| Traits | Z0 | Z10 | Z20 | Z30 | SEM | L | Q | C |
| pH *post-mortem* | | | | | | | | |
| 45 min | 6.80 | 6.73 | 6.60 | 6.89 | 0.12 | 0.82 | 0.15 | 0.37 |
| 24 h | 6.51 | 6.50 | 6.49 | 6.53 | 0.02 | 0.59 | 0.27 | 0.55 |
| 14 d | 5.90 | 6.04 | 6.05 | 5.95 | 0.07 | 0.60 | 0.09 | 0.90 |
| Color[3] | | | | | | | | |
| L* (Lightness) | 42.18 | 40.28 | 40.06 | 39.18 | 0.99 | 0.05 | 0.11 | 0.75 |
| a* (Redness) | 19.64 | 18.0 | 16.69 | 16.52 | 0.47 | <0.01 | 0.15 | 0.57 |
| b* (Yellowness) | 10.45 | 9.54 | 8.15 | 7.96 | 0.44 | <0.01 | 0.22 | 0.22 |
| Shear force (kgf) | 1.33 | 1.46 | 1.58 | 2.17 | 0.19 | <0.01 | 0.21 | 0.55 |

[1]The treatments consisted of ZH supplementation during the last 0 (Z0 = control), 10 (Z10), 20 (Z20), and 30 (Z30) d of finishing period.
[2]Probabilities of linear (L), quadratic (Q), and cubic (C) effects due to treatments.
SEM= Standard error of the mean. Means represent 10 replicate pens per treatment.

and 30 d to Pelibuey lambs, no effect of length of the supplementation period on the ribeye area was found. Our finding contrast with those of other researchers who found greater benefits by using β-2-AA during the first two weeks of fattening in cattle; afterward, these effects tend to decrease (Beermann, 2002). The effect of ZH can vary between species, and the present study was carried out in male sheep, while in beef cattle a greater short-term effect of β-2-AA has been observed.

In line with the positive linear effect observed for HCW and CBW with increasing duration of ZH supplementation, López-Carlos et al. (2011) have reported increases in HCW and carcass yield in lambs supplemented with ZH for 0, 14, 28 and 42 d prior to slaughter. Vahedi et al. (2014) reported that is better to offer ZH for 42 d increase HCW, CCW, and carcass yield compared with 28 days in Lori-Bakhtiari lambs. Other studies have also shown that ZH improves HCW in lambs after 26 d of supplementation (Leyva-Medina et al. (2024), as well as dressing percentage in a 27-d feeding trial (Dávila-Ramos et al., 2026).

Internal fat deposition (KPH fat) and covering fat (backfat thickness) were not affected by the duration of ZH supplementation. In contrast, previous studies have reported either a decrease (Salinas-Chavira et al., 2006) or an increase (López-Carlos et al., 2011) in carcass fat deposition in lambs as supplementation duration increases. Consistent with the present findings, other studies have also reported no differences in carcass fat deposition between lambs supplemented with ZH and those not supplemented (Dávila-Ramírez et al., 2015). Leheska et al. (2009) reported that ZH acts by positively altering protein deposition in muscle with minimal change to fatty tissue, which may explain the fat results found in the present study.

Carcass conformation and zoometric measurements were not affected by the duration of ZH supplementation. Literature on this aspect is scarce, particularly concerning supplementation duration of adrenergic agonist. Rojo-Rubio et al. (2017) found that ZH supplementation does not alter carcass conformation, carcass length, thoracic depth, or leg measurements in crossbred lambs.

The duration of ZH supplementation in finishing lambs affected only some organ and offal weights (testes, feet, skin, full gastrointestinal tract, and kidneys) expressed as a percentage of slaughter weight. Except for testes, the weights of these organs decreased as the supplementation period increased. Previous studies in cattle (Montgomery et al., 2009) have shown that β-2-AA promote the repartitioning of nutrients away from visceral mass and organs towards carcass tissue formation. In addition, nutrients consumed by animals supplemented with β-2-AA are primarily partitioned toward muscle development rather than fat deposition and organ growth. Furthermore, the results suggest that extending ZH supplementation duration enhances the effectiveness of this mechanism to improve carcass traits.

Omental and mesenteric fats decreased with increasing duration of β-agonist supplementation. This response suggests that ZH in lambs partially improves the proportion of muscle in the carcass through a lipolytic effect. However, in the present study, this lipolytic response appeared to be limited to visceral fat depots, with no significant effects observed on internal and carcass fat. To the best of the authors' knowledge, no previous studies have evaluated the effect of ZH supplementation on omental and mesenteric fat deposition, as most research has focused on KPH fat and subcutaneous fat thickness. However, differences in lipid metabolism regulation among breeds must be considered (Nourozi et al., 2008). The proportion of testes was higher in lambs supplemented with ZH for 10 and 20 d, but decreased after 30 d to a similar level to those observed in non-supplemented with β-agonist animals. In partial agreement with the present study, Rojo-Rubio et al. (2017) reported no differences in testicular weight between control and ZH-supplemented lambs. In contrast, Odore (2007) Observed reduced testicular weight in fattening calves administered β-AA.

On the other hand, most organ weights, expressed as a percentage of slaughter weight, were not affected by the length of ZH supplementation period, which is consistent with the findings reported in previous studies (Avendaño-Reyes et al. 2011; Dávila-Ramírez et al., 2014).

The effects of ZH supplementation on the proportion of primary cuts in lamb have been inconsistent. The present study demonstrates that the duration of the ZH supplementation period influences the characteristics of primary cuts. Specifically, leg and loin yields increased, while shoulder yield decreased, as the duration of ZH administration lengthened. The leg and the loin are the cuts with the highest economic value in both national and international markets. Therefore, extending ZH supplementation to 30 d appears to be optimal when finishing lambs are intended for specialized markets emphasizing meat cuts. The loin and leg are characterized by a higher abundance of type II muscle fibers compared with other cuts, and these fibers are very sensitive to β-2-AA stimulation due to the high number of β-2 receptors they have (Beermann, 2002). In agreement with results of the present trial, Rojo-Rubio et al. (2017) reported an increase in leg perimeter without altering other primary cuts with ZH for 30 days. In addition, Dávila-Ramírez et al., (2014) conducyed a study in which ZH was administered during the last 30 d before slaughter to finishing lambs and found that the leg perimeter increased, whereas both shoulder and loin decreased. In general, the effects of ZH on primary cuts are inconsistent; therefore, other additional factors that could alter the ZH response should be evaluated. While some studies have reported beneficial and negative effects of this β2-AA to improve quality of some cuts (Dávila-Ramírez et al., 2014), others have reported no adverse effects (Macías-Cruz et al., 2016). Alvarado-García et al. (2021), reported higher pH values in meat from ZH-supplemented *Bos indicus* young bulls. In contrast, in the present study, no changes were observed in the postmortem pH of the *L. thoracic* muscle at 45 min, 24 h, and 14 d as the duration of ZH supplementation increased from 0 to 30 d. The pH stability suggests that ZH supplementation does not adversely affect this aspect of meat quality, which could represent a competitive advantage in the market. The benefits of ZH supplementation could outweigh drawbacks if markets that prioritize weight, color, and total muscle mass, with greater efficiency observed as the supplementation period increased. Similarly, Vahedi et al. (2014) reported that the duration of ZH supplementation (28 vs. 42 d) did not affect pH of the *L. thoracic* muscle at 14 d post-mortem. Other studies comparing lambs supplemented or not with ZH have shown that β-2-AA does not affect the pH of the *L. thoracic* muscle at 45 min and 24 h postmortem (Dávila-Ramírez et al., 2014), or at 14 d post-mortem (Partida et al., 2015). In contrast, meat color variables of the *L. thoracic* muscle decreased linearly as the duration of the ZH supplementation period increased. Cayetano et al. (2020) also suggested that ZH supplementation for 30 d reduces meat color of the *L. thoracic* muscle; however, no previous study has evaluated the effect of duration of β-2-AA supplementation on meat color. Thus, our results demonstrate that ZH reduces meat color proportionally to the duration of the ZH supplementation period in crossbred lambs.

Since ZH promotes muscle hypertrophy in the *L. thoracic* muscle, the reductions in a* and b* values were attributed to the fact that the oxymyoglobin and hemoglobin levels decreased in proportion to the increase in the β-agonist supplementation duration. According to Carrasco-García et al. (2020), the L* value is associated with cortisol and catecholamine levels; a high cortisol level results in lighter meat (higher L* value). Finally, a longer ZH supplementation duration led to a linear increase in shear force in the *L. thoracic* muscle. This coincides with reports in hair sheep (Dávila-Ramírez et al., 2013: Webb et al., 2024) where ZH supplementation for 30 d before slaughter produced less tender meat in the rib-eye area. This negative effect of ZH on shear force could be attributed to a decrease in intramuscular fat (Mondragón et al., 2010), reduced protein degradation (Fulton et al., 2024), an increase in connective tissue and type II fast-twitch fibers (Listrat et al., 2016). The activity of calpastatin, which inhibits the calpain enzymes and prevents the degradation of key structural proteins (Kemp et al., 2010), and consequently hampers the tenderization meat process.

In the present study, ZH supplementation in finishing crossbred hair male lambs improved carcass characteristics of economic importance, such as carcass weight and rib-eye area. Similar results have been reported in other studies in which ZH was included in the finishing diet during the last 30 d before lamb slaughter (Dávila-Ramírez et al., 2015; Rojo-Rubio et al., 2017). Because the evaluation of sheep carcasses is not a standardized practice in Mexico and there is no a formal market for the individual cuts, the economic analysis was based on cold carcass weight, which is the usual basic for commercialization. Compared with the control group, ZH supplementation improved economic efficiency, regardless of the duration of supplementation.

## CONCLUSIONS

Supplementation of zilpaterol hydrochloride (ZH) in finishing crossbred hair lambs enhanced muscle deposition, as reflected in increased carcass weight, rib-eye area, and the yield of high-value primary cuts, such as loin and leg. However, these results reaffirm that this adrenergic agonist negatively affects meat color and tenderness. Both the positive and negative effects of ZH were more evident as the supplementation duration increased. Given that ZH the most favorable response in carcass traits, and meat quality occurred at 30 d, compared to 10 and 20 d before slaughter, a 30 d ZH supplementation may optimize feedlot performance, carcass traits, and economic efficiency in finishing crossbred hair lambs.

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**Conflict of interest.** The authors of the article entitled "Effect of length of zilpaterol hydrochloride supplementation period on carcass characteristics and meat quality of finished lambs", declare that they do not have conflicts of interest of any kind.

**Compliance with ethical standards.** This research was conducted according to the regulations of the Committee of Ethics and Research of the Institute for Research in Veterinary Sciences-UABC and following the specific principles and guidelines presented in IACUC-290-30 and by the Guide for the Care and Use of Agricultural Animals in Agricultural Research and Teaching (Federation of Animal Science Societies [FASS]).

**Data availability.** The data are available with the corresponding author on request.

**Author contributions**

Active participation in literature review: María A. López-Baca, Martin F. Montaño-Gómez, Juan O. Chirino-Romero. Active participation in the development of the methodology: Martin F. Montaño-Gómez, María A. López-Baca, Juan O. Chirino-Romero, Miguel Mellado-Bosque. Active participation in the discussion of the results: Martin F. Montaño-Gómez, María A. López-Baca, Juan O. Chirino-Romero, Miguel Mellado-Bosque, César A. Flores-Dueñas, Martin F. Montaño-Hernández. Review and approval of the final version of the article: Martin F. Montaño-Gómez, Richard A. Zinn, Martin F. Montaño-Hernández, Miguel Mellado-Bosque.

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