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Effects of Azomite and zilpaterol supplementation in finishing hairy lambs: dietary energy utilisation and carcass traits

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Abstract

This study examined whether combining Azomite (a volcanic clay) with zilpaterol hydrochloride enhanced productive performance, dietary net energy utilisation, carcass traits, meat primal cuts, and visceral mass in finishing lambs. Twenty-four Pelibuey × Katahdin intact male lambs (38 ± 2.64 kg) were fed high-energy total mixed diets supplemented with 6 mg zilpaterol/kg diet (ZH), 0.75% Azomite (AZO), or 0.75% Azomite + 6 mg zilpaterol/kg diet (ZH+AZO). The trial lasted 34 days and zilpaterol was withdrawn three days before slaughter. Contrary to our hypothesis, ZH+AZO and ZH lambs had very similar responses for all measured variables. Compared with ZH and ZH+AZO, AZO lambs had a 16.7% lower average daily gain and 5.5% lower dietary net energy utilisation, without affecting dry matter intake. The expected-to-observed dietary net energy ratio was 2% higher than expected in AZO lambs, representing a 6% smaller increase than that seen in ZH and ZH+AZO lambs. Compared to ZH and ZH+AZO lambs, carcass weight (6.15%), dressing percentage (3.77%), and *Longissimus* muscle area (12%) were lower in AZO lambs, whereas kidney-pelvic fat percentage was higher (20%). Lambs in the AZO group had a lower percentage of lean in the shoulder tissue and a lower lean-to-fat ratio than ZH and ZH+AZO lambs. Similarly, leg yield (as a percentage of the cold carcass weight) was 6.4% lower and visceral fat was 13% higher in AZO lambs. The effects of zilpaterol supplementation were not improved by combining it with Azomite; therefore, combining Azomite with zilpaterol during the last finishing phase of lamb rearing offers no productive advantage.

Keywords: aluminosilicate, beta-agonist, finishing lambs, performance, visceral mass, volcanic clay

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Introduction

The inclusion of volcanic aluminosilicate clay as a functional ingredient in lamb diets during the growing and finishing stages is a common practice within feeding systems. The most popular aluminosilicate clay used in animal feed is zeolite (Stojković *et al.*, 2012). Owing to its molecular arrangement, it can lose and gain water and exchange cations without undergoing major structural changes (Trckova *et al.*, 2004). As a result of these characteristic sorbent properties, it modifies ruminal

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fluid viscosity (Spotti *et al*., 2005), increases binding to ammonia-nitrogen, and enhances the digestion of ruminal organic matter largely as a result of ruminal starch digestion (Urías-Estrada *et al*., 2018). Supplemental zeolite can improve energy efficiency by altering ruminal volatile fatty acid molar ratios, reducing the acetate to propionate ratio (Estrada-Angulo *et al*., 2017a,b; El-nil *et al*., 2021), and decreasing internal fat deposition (Coronel-Burgos *et al*., 2017). This has been demonstrated in several studies on the effects of zeolite inclusion in feedlot lamb diets, which have reported improvements in dietary energy efficiency in the finishing phase (Urías-Estrada *et al.,* 2021; Castro-Pérez *et al*., 2023; Urías-Estrada *et al*., 2023). However, different types of volcanic clay (for example, clipnotilolite or montmorillonite, among others) differ in their specific mineral composition, and could thus have different impacts on animal productivity when used as a feed ingredient in ruminant diets (Damato *et al*., 2022).

A volcanic aluminosilicate clay (Azomite, a dacitic and rhyolitic tuff breccia) that is mined in Utah, USA, was formed from volcanic ash that settled into an ancient seabed fed by several rivers rich in minerals and rare elements, giving it a unique mineral composition. In addition to iron, magnesium, manganese, selenium, zinc, copper, and rare earth elements such as lanthanides, the deposit contains over 70 measurable minerals. As such, it contains up to five times more mineral elements than other aluminosilicates, including zeolite, that are commonly used in animal feeds (Juzaitis-Boelter *et al.,* 2021). Moreover, a recent study (Vizcarra-Chávez *et al*., 2024) showed that Azomite included in a high-energy diet for lambs at 0.75% resulted in improvements of 6% in energy retention, 3.9% in hot carcass weight, and 1.6% in carcass dressing percentage. These improvements are greater than those generally obtained when zeolite is supplemented to finishing lambs (Estrada-Angulo *et al*., 2017a; Castro-Pérez *et al*., 2023; Urías-Estrada *et al*., 2023).

Zilpaterol hydrochloride, a beta-agonist agent widely used as a feed additive in fattening ruminants, increases growth rate, feed efficiency, and dietary energy utilisation when supplemented to lambs during the last 30–40 days of fattening (Ortíz-Rodea *et al*., 2016). These improvements are primarily attributed to zilpaterol's effects on gain composition, which result in a greater proportion of lean tissue and a decreased proportion of fat, relative to observed values in unsupplemented animals (Fulton *et al*., 2024). It is well known that the reduced efficiency of the final fattening phase stems from the increased deposition of fatty tissue rather than muscle tissue during this period, as fat accumulation requires 1.65 times more energy than muscle accretion (Galyean & Hales, 2023). In a previous study, when zeolite and zilpaterol were simultaneously supplemented in a lamb diet, the observed-to-expected dietary net energy (NE) ratio increased by 4.6%, compared to a diet supplemented with zilpaterol alone (Urías-Estrada *et al*., 2023). Likewise, Ponce-Barraza *et al*. (2025) observed that the *Longissimus* muscle area was 14.5% greater in lambs receiving combined zeolite and zilpaterol, compared to those that received zilpaterol supplementation alone.

Consequently, it is reasonable to expect that the magnitude of the effects of zilpaterol could be improved by the simultaneous inclusion of Azomite in the diet. This potential interaction between zilpaterol and Azomite in finishing lamb diets has not been previously studied. As such, this study sought to determine whether combining Azomite with the beta-agonist zilpaterol during the late finishing phase could enhance zilpaterol's beneficial effects on productive performance, dietary energy utilisation, carcass characteristics, meat primal cuts, and visceral mass.

Materials and methods

The ethics committee of the Faculty of Veterinary Medicine and Zootechnics of the Autonomous University of Sinaloa approved all animal management practices (protocol #04082025), which were carried out in accordance with federally and locally approved methods for animal use and care (NOM-062-ZOO-1999, NOM-051-ZOO-1995, and NOM-033-ZOO-1995; Estados Unidos Mexicanos, Secretaría de Agricultura, Ganadería, Desarrollo Rural, Pesca y Alimentación, 1995).

Study location

The study was conducted at the Autonomous University of Sinaloa Feedlot Lamb Research Unit, which is situated in Culiacán city (24°46'13" N, 107°21'14" W; 55 m above sea level), Mexico. Culiacán city has a tropical climate. The experiment was conducted between March and May of 2023, with an average temperature of 29.1 ± 2.8 °C and a relative humidity of 33.3 ± 7.3%.

Animals, diets, and experimental design

Twenty-four intact male cross-bred (Pelibuey × Katahdin) lambs (initial live weight: 38 ± 2.64 kg, average age: 160 ± 14 days) were used to assess the impact of combining Azomite with the beta-agonist zilpaterol during the late finishing phase on productive performance, dietary energy utilisation, carcass characteristics, whole cuts, and visceral mass. Four weeks prior to the commencement of the experiment, all lambs were treated for parasites (Albendaphorte 10%, Animal Health and Welfare, Mexico City, Mexico), vaccinated (One Shot Pfizer, Mexico City, Mexico), and received an injection of 106 IU of vitamins A, D, and E (Synt-ADE®, Zoetis, Mexico). All lambs were acclimatised to the facilities and to the maize-based high concentrate (concentrate to forage ratio of 90:10) finishing diets without additive supplementation (Table 1) three weeks prior to the commencement of the experiment.

Table 1 Composition of dietary treatments offered to lambs during the late finishing phase

	Dietary treatments		
	ZH[1]	**AZO[2]**	**ZH+AZO[3]**
Ingredient composition (g/kg on a dry matter basis)			
Dry-rolled maize	629.98	622.50	622.48
Sudan grass hay	100	100	100
Soybean meal	130	130	130
Yellow grease	40	40	40
Zilmax	0.0125	0.00	0.0125
Azomite	0.00	7.5	7.5
Sugar cane molasses	80	80	80
Mineral+protein premix[4]	20	20	20
Chemical composition[5] (on a dry matter basis)			
Dry matter (%)	89.25	89.40	89.30
Total crude protein (%)	15.08	14.93	14.93
Ether extract (%)	6.91	6.87	6.87
Neutral detergent fibre (%)	16.34	15.30	15.30
Calcium (%)	0.75	0.78	0.78
Phosphorus (%)	0.36	0.35	0.35
Calculated net energy content (Mcal/kg)			
Maintenance	2.17	2.15	2.15
Gain	1.50	1.49	1.49

[1] ZH: zilpaterol hydrochloride supplemented at 6 mg/kg diet for 31 days, with withdrawal three days before slaughter. [2] AZO: Azomite (hydrated sodium calcium aluminosilicate) supplemented at 0.75% of dry matter for 34 days. [3] ZH+AZO: zilpaterol supplemented at 6 mg/kg diet for 31 days and Azomite supplemented at 0.75% of dry matter for 34 days. [4] Mineral+protein premix: 57.5% crude protein, 21.8% calcium, 1.39% magnesium, 15.0% sodium chloride, 0.015% manganese, 0.015% selenium, 0.005% cobalt, and 0.100% zinc. [5] The chemical composition of the basal diet was determined using laboratory analyses, whereas the net energy was calculated based on tabulated net energy values for individual feed ingredients (NRC, 2007).

At the commencement of the experiment, all lambs (n = 24) were weighed prior to the morning feeding using an electronic scale with a precision of ± 0.05 kg (TORREY TIL/S: 107 2691, TOR REY Electronics Inc., Houston, TX, USA). The lambs were then divided into eight weight categories distributed across 24 pens, with eight replicates per treatment, based on a complete block design using initial live weight as the blocking criterion. The pens had 1 m long fence-line feed bunks, 6 m^2 of overhead shade, and plastic bucket waterers. Three dietary treatments were designed as follows, with cracked maize in the control diet being replaced by Azomite, where necessary:

1. ZH: 6 mg zilpaterol hydrochloride/kg diet for 31 days (withdrawn three days before slaughter),
2. AZO: Azomite at 0.75% of dry matter (DM) for 34 days, and

3. ZH+AZO: Azomite at 0.75% of DM for 34 days + 6 mg zilpaterol hydrochloride/kg diet for 31 days (zilpaterol withdrawn three days before slaughter).

The Azomite dose used was based on a previous study that found that including 0.75% Azomite in the final diet for lambs improved energy retention, hot carcass weight, and carcass yield (Vizcarra-Chávez *et al*., 2024). Azomite is a volcanic ash consisting of hydrated sodium calcium aluminosilicate and is distributed by Azomite Minerals Products Inc., Utah, USA. Similarly, a dose of 6 mg zilpaterol hydrochloride/kg of diet has consistently improved productive performance and carcass quality in lambs (Ortíz-Rodea *et al*., 2016). Zilpaterol hydrochloride was provided as Zilmax (MSD Salud Animal México, Santiago Tianguistenco, Mexico), which, according to the label, contains 4.8% zilpaterol hydrochloride. Thus, a dosage of 125 mg of Zilmax/kg diet provided a dietary zilpaterol hydrochloride concentration of 6 mg/kg diet on an as fed basis. Feed samples (*ca.* 50 g) were collected from each batch of feed and were stored at 4 °C in sealed bags until the determination of the nutritional composition.

The feeding trial lasted for 34 days. Clean water was available at all times and the lambs were provided with fresh feed twice daily at 08:00 and 14:00. A fixed amount of 300 g per lamb was offered in the morning, while in the afternoon, feed was provided *ad libitum* to allow for a feed residual of approximately 50 g per kg of the daily feed offering.

Analysis of feed and refusals

Residual feed was collected daily between 07:40 and 07:50 each morning, and was weighed and stored for subsequent DM analysis (AOAC, 2000). Dietary treatments were sampled weekly and composited for subsequent analyses. To determine the dry matter (method 930.15; AOAC, 2000), crude protein (N × 6.25, method 984.13; AOAC, 2000), and neutral detergent fibre (NDF; Van Soest *et al*., 1991) concentrations, the composited samples were first oven-dried at 105 °C.

Productive performance measurement

On day 1 and day 34 (the last day of the feeding trial), lambs were weighed just before their morning meal. To account for the contents of their digestive tracts, live weights on day 1 were multiplied by 0.96 to obtain the shrunken body weight (SBW) (Cannas *et al*., 2004). Before the final SBW measurement, all lambs were fasted for 18 hours (with access to water).

The average daily gain (ADG) was calculated by subtracting the initial SBW from the final SBW and dividing the result by the number of days of the trial. Gain efficiency was calculated by dividing the ADG by the average dry matter intake (DMI). One approach that can be used to evaluate the dietary energy utilisation efficiency in growth performance trials is the observed-to-expected dietary NE ratio. By comparing the observed NE content (based on growth performance metrics) to the projected dietary NE content (based on diet formulation), the efficiency of energy usage in growing-finishing trials may be evaluated.

In this study, the ADG and DMI experimental data and the energy requirement derivations for maintenance (EM, Mcal/d) and gain (EG, Mcal/d), as described by the NRC (2007), were used. The latter were calculated as follows:

$$EM\ (energy\ required\ for\ maintenance, Mcal/d) = 0.056 \times SBW^{0.75}$$

$$EG\ (energy\ required\ for\ gain, Mcal/d) = 0.276 \times ADG \times SBW^{0.75}$$

The coefficient used to calculate the EG (0.276) was as per the NRC (1985), assuming a mature weight of 113 kg for Pelibuey × Katahdin male lambs.

Then, the observed dietary NE for maintenance (NE_m) was calculated by means of the following quadratic formula:

$$x = \frac{-b \pm \sqrt{b^2} - 4ac}{2c}$$

where:
x = the observed dietary NE_m in Mcal/kg,
a = −0.41EM,

b = 0.877EM + 0.41DMI + EG, and
c = −0.877DMI.
The NE for gain (NE_g) was then calculated as per Zinn *et al*. (2008):

$$NE_g = 0.877NE_m - 0.41$$

Carcass characteristics, shoulder tissue composition, whole cuts, and visceral organ mass

All lambs were slaughtered on the same day by throat-cutting, based on the official Mexican standard for the humane slaughter of domestic animals (NOM-033-SAG/ZOO-2014). After slaughter, the lambs were skinned, and the gastrointestinal organs were removed. The mass (in grams) of each organ was then recorded. Carcasses (including kidneys and internal fat) were chilled at −2 to 1 °C for 24 hours, after which measurements of fat thickness, *Longissimus thoracis* muscle surface area, and kidney, pelvic, and heart fat were obtained according to the procedures described by the USDA (1992) and Quezada-Rubio *et al.* (2026).

Each carcass was divided in half to obtain two full sides. In accordance with the rules of the North American Meat Processors Association (NAMP, 2007), the left side was manufactured into wholesale cuts without trimming. The neck, breast (IMPS209), shoulder (IMPS206), shoulder (IMPS207), rack (IMPS204), and ribs (IMPS209A) were obtained from the foresaddle (IMPS202), and the loin (IMPS231), flank (IMPS232), and leg (IMPS233) were obtained from the hindsaddle (IMPS230). Each cut's weight was then recorded. The method outlined by Luaces *et al*. (2008) was used to dissect the shoulder in order to determine its tissue composition.

The components of the gastrointestinal tract were removed from the carcass and weighed. The gastrointestinal tract was then cleaned, drained, and weighed to determine its empty weight. The empty body weight was calculated by deducting the difference between the full and washed digesta-free gastrointestinal tract from the SBW. All tissue weights are reported on a fresh tissue basis. Organ weights are reported in grams of fresh tissue per kilogram of final empty body weight, which is calculated by subtracting the total digesta weight from the final full live weight. All visceral components (stomach complex + small intestine + large intestine + liver + lungs + heart), including digesta, were added to determine the total visceral mass. The stomach complex was calculated as the digesta-free total of the weights of the rumen, reticulum, omasum, and abomasum.

Statistical analysis

All data were assessed for normality using the Shapiro–Wilk test. Growth performance metrics (ADG, gain efficiency, and dietary energetics), DMI, and carcass data were analysed using a randomised complete block design. Each lamb was an experimental unit. The MIXED procedures of SAS software version 9.3 (SAS, 2007) were employed. Treatment and block were incorporated as fixed effects, with the experimental unit within treatment as a random effect. In all instances, contrasts were deemed significant when the *P*-value was less than 0.05. Tendencies were recognised when the *P*-value was greater than 0.05 but less than or equal to 0.10.

Results and discussion

No lambs had to be removed because of death or illness during the feeding trial. The air temperature and relative humidity averaged 29.8 °C and 43.5%, respectively. This results in a temperature-humidity index of 77.05, which falls within the environmental comfort range for the productivity of hair lambs and their crosses (Vicente-Pérez *et al*., 2020). Lambs receiving Azomite alone tended to have a lower ($P = 0.08$) ADG but a similar DMI ($P = 0.38$) to lambs supplemented with zilpaterol alone. Thus, the gain efficiency and dietary energy utilisation were 16.7% and 5.5% lower, respectively ($P < 0.02$), for AZO lambs than for lambs supplemented with zilpaterol (ZH and ZH+AZO lambs). Regarding the expected-to-observed dietary NE ratio, supplemental Azomite increased the NE by 2% above expected, while zilpaterol supplementation (alone or in combination with Azomite) increased the NE by 8% (Table 2).

The improvements in growth performance, dietary energy utilisation efficiency, and carcass traits observed with zilpaterol supplementation are consistent with previous reports (Rojo-Rubio *et al*., 2018; Rivera-Villegas *et al*., 2019). However, contrary to our hypothesis, these improvements were not enhanced when Azomite was included with zilpaterol in the diet (Tables 2–4).

Table 2 Effects of supplemental Azomite and zilpaterol hydrochloride on the growth performance and dietary energy utilisation of finishing lambs

	Treatments				
	ZH[1]	**AZO[2]**	**ZH+AZO[3]**	**SEM**	***P*-value**
Trial duration (days)	34	34	34		
Pen replicates	8	8	8		
Live body weight (kg)[4]					
Initial	38.571	38.857	38.471	0.279	0.611
Final	47.828^{A}	46.387^{B}	47.271^{AB}	0.393	0.067
Average daily gain (kg)	0.272^{A}	0.221^{B}	0.259^{AB}	0.021	0.081
Dry matter intake (kg/d)	1.170	1.093	1.155	0.040	0.381
Gain to feed ratio (kg/kg)	0.233^{a}	0.203^{b}	0.224^{a}	0.006	0.015
Observed dietary net energy utilisation (Mcal/kg)					
Maintenance	2.34^{a}	2.21^{b}	2.30^{a}	0.027	0.012
Gain	1.64^{a}	1.52^{b}	1.60^{a}	0.023	0.012
Observed-to-expected dietary net energy ratio					
Maintenance	1.08^{a}	1.02^{b}	1.07^{a}	0.012	0.022
Gain	1.09^{a}	1.03^{b}	1.08^{a}	0.015	0.019

[1] ZH: zilpaterol hydrochloride supplemented at 6 mg/kg diet for 31 days, with withdrawal three days before slaughter. [2] AZO: Azomite (hydrated sodium calcium aluminosilicate) supplemented at 0.75% of dry matter for 34 days. [3] ZH+AZO: zilpaterol supplemented at 6 mg/kg diet for 31 days and Azomite supplemented at 0.75% of dry matter for 34 days. [4] The initial body weight was reduced by 4% to adjust for gastrointestinal fill, and food was withdrawn from all lambs (with water provided) for 18 hours before recording the final body weight. [a,b] Means in the same row with different lowercase superscript letters differ at $P \leq 0.05$. [A,B] Means in the same row with different uppercase superscript letters differ at $P > 0.05$ and ≤ 0.10.

Treatment effects on carcass characteristics, shoulder tissue composition, and whole cuts are presented in Table 3. Carcass weight, carcass yield, and *Longissimus dorsi* muscle area were lower ($P \leq 0.01$) in AZO lambs, with these lambs also having a higher proportion of kidney-pelvic fat ($P = 0.023$). The percentage of lean tissue in the shoulder ($P = 0.01$) and the lean-to-fat ratio ($P = 0.03$) were lower in lambs supplemented with Azomite, compared to those supplemented with zilpaterol (ZH and ZH+AZO). Similarly, the proportion of leg (as a percentage of the cold carcass weight) was 6.4% lower ($P = 0.046$) and visceral fat was 13% higher ($P = 0.030$) in AZO lambs than in lambs supplemented with zilpaterol, alone or in combination.

In this experiment, we tested whether Azomite clay enhanced the effects of zilpaterol supplementation in finishing lambs when the two ingredients were combined in a high-energy diet. This proposal was based on a previous study in which an aluminosilicate clay (zeolite) improved the magnitude of responses to zilpaterol supplementation (Urías-Estrada *et al.*, 2023). When zeolite and zilpaterol were included in the diet simultaneously, the observed-to-expected dietary NE increased by 4.6% ($P < 0.05$), compared to the diet with zilpaterol supplemented alone (Urías-Estrada *et al.*, 2023). Likewise, Ponce-Barraza *et al.* (2025), observed that the *Longissimus thoracis* muscle area was 14.5% greater in lambs receiving both zeolite and zilpaterol, compared to those that received zilpaterol supplementation only.

However, it is important to note that, while zeolite and Azomite are both natural, mineral-rich, volcanic-derived aluminosilicates, they do not have the same characteristics. More than 70 trace minerals and rare elements are present in Azomite, positively influencing plant and animal metabolism (Juzaitis-Boelter *et al.,* 2021). In contrast, the primary benefit of zeolite is its unique porous structure, which allows it to filter and exchange ions efficiently (Li *et al.,* 2025). A considerable number of studies on Azomite as a feed additive have been conducted in non-ruminant species, including broilers (Pirzado *et al.*, 2020, 2021), pigs (Matthews *et al.*, 1999), and fish (Xu *et al.*, 2021). Regarding ruminant species, Vizcarra-Chávez *et al*. (2024) reported on the effects of Azomite on the productivity of finishing lambs. This study found that Azomite supplementation at 0.75% in a high-energy diet for lambs resulted in improvements of 6% in energy retention, 3.9% in hot carcass weight, and 1.6% in carcass dressing percentage. These improvements are greater than those generally obtained when zeolite is supplemented to finishing lambs (Estrada-Angulo *et al*., 2017a; Castro-Pérez *et al*., 2023; Urías-Estrada *et al*., 2023). Therefore, it was reasonable to expect a better response in the ZH+AZO lambs than in the lambs supplemented zilpaterol alone. However, it is important to note that in the scientific literature, there is only one report on the effects of combining zeolite with zilpaterol on productive performance (Urías-Estrada *et al*., 2023), one on the effects on carcass quality in lambs (Ponce-Barraza *et al.,* 2025), and one on the effects of Azomite on productivity (Vizcarra-Chávez *et al*., 2024), to the best of our knowledge.

Table 3 Effects of supplemental Azomite and zilpaterol hydrochloride on carcass characteristics, tissue composition, and whole cuts in long-term finishing lambs

	Treatments				
	ZH[1]	**AZO[2]**	**ZH+AZO[3]**	**SEM**	***P*-value**
Carcass characteristics					
Hot carcass weight (kg)	28.88[a]	26.86[b]	28.36[a]	0.238	<0.010
Dressing percentage	60.42[a]	57.95[b]	60.03[a]	0.525	0.012
Cold carcass weight (kg)	28.73[a]	26.66[b]	28.17[a]	0.260	<0.010
***Longissimus* muscle area (cm^2)**	16.62[a]	14.66[b]	16.68[a]	0.436	0.010
Fat thickness (cm)	0.198	0.194	0.196	0.007	0.900
Kidney-pelvic fat (%)	3.15[b]	4.07[a]	3.33[b]	2.180	0.023
Shoulder composition (%)					
Lean	66.97[a]	64.37[b]	66.65[a]	0.582	0.016
Fat	17.11[B]	19.03[A]	17.62[AB]	0.507	0.059
Bone	15.41	16.60	16.24	0.491	0.253
Lean:fat ratio	3.83[a]	3.39[b]	3.92[a]	0.132	0.033
Lean:bone ratio	4.37	3.90	4.14	0.156	0.146
Whole cuts (as percentages of the cold carcass weight)					
Forequarter (IMPS202)	40.08	40.14	40.34	0.415	0.898
Hindquarter (IMPS230)	37.87	37.75	37.74	0.405	0.972
Neck	9.61	9.26	9.31	9.20	0.325
Shoulder (IMPS206)	8.17	7.86	8.11	0.321	0.777
Shoulder (IMPS207)	13.96	14.07	14.10	0.229	0.905
Rack (IMPS204)	6.70	6.80	7.39	0.501	0.307
Breast (IMPS209)	4.85	4.78	4.81	0.222	0.976
Ribs (IMPS 209A)	6.86	6.99	7.03	0.257	0.891
Loin (IMPS231)	6.84	6.64	7.00	0.284	0.675
Flank (IMPS232)	7.26	7.10	7.24	0.179	0.803
Leg (IMPS233)	24.53[a]	23.05[b]	24.66[a]	0.444	0.046

[1] ZH: zilpaterol hydrochloride supplemented at 6 mg/kg diet for 31 days, with withdrawal three days before slaughter. [2] AZO: Azomite (hydrated sodium calcium aluminosilicate) supplemented at 0.75% of dry matter for 34 days. [3] ZH+AZO: zilpaterol supplemented at 6 mg/kg diet for 31 days and Azomite supplemented at 0.75% of dry matter for 34 days. [a,b] Means in the same row with different lowercase superscript letters differ at $P \leq 0.05$. [A,B] Means in the same row with different uppercase superscript letters differ at $P > 0.05$ and ≤ 0.10.

Table 4 Effects of supplemental Azomite and zilpaterol hydrochloride on relative visceral organ mass in finishing lambs

	Treatments				
	ZH[1]	**AZO**[2]	**ZH+AZO**[3]	**SEM**	***P*-value**
Gastrointestinal tract – full (kg)	4.06	3.89	4.12	0.197	0.715
Empty body weight (% of full weight)	91.51	91.60	91.31	0.351	0.843
Organs (g/kg of empty body weight)					
Stomach complex	22.65	22.91	21.71	0.894	0.621
Intestines	33.39	35.74	33.79	1.528	0.523
Liver	16.04	16.93	16.26	0.398	0.295
Heart + lungs	20.26	20.94	20.10	0.518	0.491
Kidney	2.48	2.70	2.58	0.106	0.364
Omental fat	34.87	39.78	36.07	1.779	0.149
Mesenteric fat	17.85[b]	20.83[a]	17.09[b]	0.969	0.050
Visceral fat	52.72[b]	60.61[a]	53.17[b]	2.031	0.030

[1] ZH: zilpaterol hydrochloride supplemented at 6 mg/kg diet for 31 days, with withdrawal three days before slaughter. [2] AZO: Azomite (hydrated sodium calcium aluminosilicate) supplemented at 0.75% of dry matter for 34 days. [3] ZH+AZO: zilpaterol supplemented at 6 mg/kg diet for 31 days and Azomite supplemented at 0.75% of dry matter for 34 days. [a,b] Means in the same row with different lowercase superscript letters differ at $P \leq 0.05$.

Contrary to our hypothesis, the supplementation of Azomite, in combination with zilpaterol, did not increase the magnitude of the responses in growth performance and carcass variables, as was observed for the combination of zeolite and zilpaterol. The additive effects of zeolite in diets supplemented with zilpaterol are unclear. The explanation provided by Urías-Estrada *et al.* (2023) for the improved response of dietary energy utilisation to supplemental zilpaterol in the presence of zeolite in the diet was that zeolite and zilpaterol use different mechanisms to improve the efficiency of dietary energy utilisation. While zeolite effects changes at the ruminal level – shifting ruminal fermentation patterns towards propionic fermentation, increased starch digestion, and greater ruminal nitrogen retention (Urías-Estrada *et al.*, 2017) – the mechanisms of zilpaterol are more focused on increasing nitrogen retention and decreasing fat deposition at the striated muscle level (Robles *et al.*, 2024). These changes can be synergistic, promoting better utilisation of energy from the diet.

To our knowledge, no information is currently available on the effects of Azomite on ruminal microbial populations and fermentation patterns. It has been indicated that Azomite acts as an absorbent gel, as well as being rich in minerals and other minor components (Zhao *et al,* 2021). In fish, it modified the intestinal microbiota, enhanced protease activity, and improved intestinal wall health (Xu *et al.*, 2021); however, no information is currently available on these potential effects in ruminant species. Based on the results of the current experiment, the effects of zilpaterol on productivity, efficiency, dietary energy, or carcass traits were not enhanced when Azomite was present in the diet. However, the inclusion of Azomite did not negatively affect any of the variables measured either. Further research is needed to determine how including Azomite in ruminant diets effects microbial population dynamics, digestion kinetics, blood profiles, and digestion and nutrient utilisation, because all of these variables play important roles in growth performance and dietary energy utilisation.

Based on the growth rate and DM intake, the energetic parameter 'observed dietary NE' can be accurately estimated. An effective method for evaluating dietary energy utilisation efficiency is to compare the dietary energy density, based on tabulated values for feed ingredients, with that observed, based on growth performance. A ratio of observed-to-expected dietary NE of 1.00 indicates that the observed and expected ADG are consistent, based on the DM intake and the formulated dietary energy density. When the ratio is less than 1.00, the energetic efficiency is lower than expected; conversely, when the ratio is greater than 1.00, the energetic efficiency is higher than expected. Urías-Estrada *et al.* (2021) demonstrated that this energetic approach can be used to evaluate the effects of clay on ruminant dietary energy utilisation. Based on this approach, a slight increase in dietary energy utilisation was observed in lambs supplemented with Azomite (observed was 2% more than expected). Using the same lamb breed, as well as a similar diet composition and the same level of Azomite supplementation, an improvement of 6% in the observed-to-expected dietary NE was reported by Vizcarra-Chávez *et al*. (2024).

It is unclear why we observed lower energy efficiency responses in this experiment, compared to those reported by Vizcarra-Chávez *et al*. (2024). Only one study on the effects of Azomite supplementation on growth performance and dietary energy efficiency in ruminants exists, and it is important to note that the results of studies on productive performance and energy efficiency in ruminants fed aluminosilicate clays have varied (Roque-Jiménez *et al*., 2018; Esteves *et al*., 2022; Castro-Pérez *et al*., 2023). Several factors may influence the response to clay supplementation. These include the level of supplementation, the animal's mineral status, the mineral concentration in the diet, the type of diet used (especially high-concentrate diets), and the presence of contaminants and biotic harmful agents in the diet (Nadziakiewicza *et al*., 2019; Teng *et al*., 2023).

The increases in growth performance (ADG, feed efficiency, and dietary energy utilisation) and carcass traits (dressing percentage, *Longissimus thoracis* muscle area, and leg cut), as well as the reductions in carcass and visceral fat depots, found in this study are consistent with previously reported responses to zilpaterol supplementation (Rojo-Rubio *et al*., 2018; Cayetano-De-Jesus *et al*., 2020; Mejia *et al*., 2025). The magnitudes of the responses to zilpaterol supplementation observed in the current experiment are also in good agreement with the results of a meta-analysis on the effects of zilpaterol on the growth performance and carcass yields of fattening lambs (Ortíz-Rodea *et al*., 2016). However, these responses did not improve when Azomite was added alongside the beta-agonist zilpaterol.

Conclusions

Azomite supplementation in diets containing zilpaterol neither improved nor negatively affected the productive performance and carcass characteristics of finishing lambs. From the perspective of productive performance (rate of gain, efficiency, and carcass yield), supplementing Azomite and zilpaterol at the same time during the last finishing phase of lambs is not justified.

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Authors' contributions

A.P. and A.E.A.: Conceptualisation, methodology, supervision, visualisation, and writing (review and editing). J.D.U.E.: Writing (review and editing of the final version of the manuscript). E.P.B. and C.A.V.C.: Writing (original draft preparation). B.I.C.P.: Data curation and statistical analyses. J.L.R.M., D.A.M.C., Y.J.A.W., and L.G.E.G.: Execution of the experiment, carcass evaluation, and sample analyses.

Conflict of interest declaration

The authors declare that they have no conflicts of interest.

References

AOAC, 2000. Official Method of Analysis of AOAC International (17th edition). Association of Official Analytical Chemists, Washington, DC, USA.

Castro-Pérez, B.I., Rodríguez-Vázquez, J., Estrada-Angulo, A., Ríos-Rincón, F.G., Urías-Estrada, J.D., Ponce-Barraza, E., Barreras, A., & Plascencia, A., 2023. Effect of particle size of zeolite clay included in high-energy diets for feedlot lambs: Growth performance, dietary energy, carcass traits, and visceral mass. *Journal of Advanced Veterinary and Animal Research*, 10(3):500–506. DOI: http://doi.org/10.5455/javar.2023.j703

Cannas, A., Tedeschi, L.O., Fox, D.G., Pell, A.N., & Van Soest, P.J., 2004. A mechanistic model for predicting the nutrient requirements and feed biological values for sheep. *Journal of Animal Science*, 82(1):149–169. DOI: https://doi.org/10.2527/2004.821149x

Cayetano-De-Jesús, J.A., Rojo-Rubio, R., Grajales-Lagunes, A., Avendaño-Reyes, L., Macías-Cruz, U., González-del-Prado, V., Chay-Canul, A., Olmedo-Juárez, A., & Lee-Rangel, A.H., 2020. Effect of zilpaterol hydrochloride on performance and meat quality in finishing lambs. *Agriculture*, 10(6):241–252. DOI: https://doi.org/10.3390/agriculture10060241

Coronel-Burgos, F., Plascencia, A., Castro-Pérez, B.I., Contreras-Pérez, G., Barreras, A., & Estrada-Angulo, A., 2017. Influencia de la sustitución parcial del maíz y dela pasta de soja por zeolita en ovinos en etapa de finalización: Características de la canal, composición tisular y masa visceral. *Archivos de Zootecnia*, 66(254):223–228.

Damato, A., Vianello, F., Novelli, E., Balzan, S., Gianesella, M., Giaretta, E., & Gabai, G., 2022. Comprehensive review on the interactions of clay minerals with animal physiology and production. *Frontiers in Veterinary Science*, 9:889612. DOI: https://doi.org/10.3389/fvets.2022.889612

El-Nile, A., Elazab, M., El-Zaiat, H., El-Azrak, K.E.D., Elkomy, A., Sallam, S., & Soltan, Y., 2021. *In vitro* and *in vivo* assessment of dietary supplementation of both natural or nano-zeolite in goat diets: Effects on ruminal fermentation and nutrients digestibility. *Animals*, 11(8):2215. DOI: https://doi.org/10.3390/ani11082215

Esteves, S.N., de Souza, C.A.C., de Sena O.M.C., Barioni-Júnior, W., & de Campos, B.A.C., 2022. Zeolite supplementation effects on lamb growth and gastrointestinal nematode infection, and economic analysis. *Revista Ciência Agronômica*, 53:e20207611. DOI: https://doi.org/10.5935/1806-6690.20220004

Estrada-Angulo, A., Coronel-Burgos, F., Castro-Pérez, B.I., López-Soto, M.A., Barreras, A., Angulo-Montoya, C., Contreras-Pérez, G., & Plascencia, A., 2017a. Efecto de la inclusión de zeolita (clinoptilolita) en ovinos en etapa de finalización: Respuesta productiva y energética de la dieta. *Archivos de Zootecnia*, 66(255):381–386. DOI: https://doi.org/10.21071/az.v66i255.2514

Estrada-Angulo, A., Urías-Estrada, J.D., Castro-Pérez, B.I., Contreras-Pérez, G., Angulo-Montoya, C., Barreras, A., & Plascencia, A., 2017b. Impact of dietary inclusion of clinoptilolite as substitute of soybean meal on growth performance, dietary energetics and carcass traits of feedlot ewes fed a corn-based diet. *Austral Journal of Veterinary Sciences*, 49(2):123–128. DOI: http://dx.doi.org/10.4067/S0719-81322017000200123

Fulton, J.O., Block, J.J., Underwood, K.R., Zuelly, S.M., Olson, K.C., & Blair, A.D., 2024. Effects of zilpaterol hydrochloride supplementation on growth performance, carcass characteristics and meat quality for steers differing in breed type. *Animals*, 14(4):607. DOI: https://doi.org/10.3390/ani14040607

Galyean, M.L. & Hales, K.H., 2023. Feeding management strategies to mitigate methane and improve production efficiency in feedlot cattle. *Animals*, 13(4):758. DOI: https://doi.org/10.3390/ani13040758

Juzaitis-Boelter, C.P., Benson, A.P., Ahammad, M.U., Jones, M.K., Ferrel, J., & Davis, A.J., 2021. Dietary inclusion of AZOMITE improves feed efficiency in broilers and egg production in laying and broiler breeder hens. *Poultry Science*, 100(6):101144. DOI: https://doi.org/10.1016/j.psj.2021.101144

Li, C., Li, T., Cui, Q., Wang, T., Wang, C., Yang, J., Shi, J., Bao, X., & Yue, Y., 2025. Ion exchange: an essential piece in the fabrication of zeolite adsorbents. *Physical Chemistry Chemical Physics*, 27(30):36500–36515. DOI: https://doi.org/10.1039/d5cp00894h

Luaces, M.L., Calvo, C., Fernández, B., Fernández, A., Viana, J.L., & Sánchez, L., 2008. Predicting equation for tissue composition in carcass of Gallega breed lambs. *Archivos de Zootecnia*, 57(217):3–14. URL: https://www.redalyc.org/pdf/495/49521701.pdf

Matthews, J.O., Southern, L.L., Bidner, T.D., Hays, V.W., & Larsen, L.M., 1999. Effect of a hydrated sodium calcium aluminosilicate on growth performance and carcass traits of pigs. *The Professional Animal Scientist*, 15(3):196–200. DOI: https://doi.org/10.15232/S1080-7446(15)31758-7

Mejía-Delgadillo, M.A., Leyva-Medina, K.H., Sánchez-Pérez, J.N., Lee-Rangel, H.A., López-Inzunza, H.J., Martínez-León, R., Molina-Gámez, G., Ponce-Covarrubias, J.L., Dávila-Ramos, H., & Robles-Estrada J.C., 2025. Effects of zilpaterol hydrochloride and virginiamycin on growth performance, carcass characteristics, and visceral organ mass in feedlot lambs. *Animal Bioscience*, 38(11):2443–2453. DOI: https://doi.org/10.5713/ab.24.0457

Nadziakiewicza, M., Kehoe, S., & Micek, P., 2019. Physico-chemical properties of clay minerals and their use as a health promoting feed additive. *Animals*, 9(10):714. DOI: https://doi.org/10.3390/ani9100714

NAMP, 2007. The meat buyer's guide (6th edition). North American Meat Processors Association, Washington, DC, USA.

Estados Unidos Mexicanos, Secretaría de Agricultura, Ganadería, Desarrollo Rural, Pesca y Alimentación, 1995. Normas Oficiales Mexicanas, Diario Oficial de la Federación (NOM-062-ZOO-1999, NOM-051-ZOO-1995 NOM-033-ZOO-1995): Trato Humanitario de Animales de Producción, de Compañía y Animales Silvestres Durante el Proceso de Crianza, Desarrollo de Experimentos, Movilización y Sacrificio. Available: https://dof.gob.mx/#gsc.tab=0 [18 February 2026].

NRC, 1985. Nutrient requirement of sheep (6th edition). National Academy Press, Washington, DC, USA.

NRC, 2007. Nutrient requirements of small ruminants: Sheep, goats, cervids, and new world camelids. National Academies Press, Washington, DC, USA. DOI: https://doi.org/10.17226/11654

Ortiz Rodea, A., Barbosa Amezcua, M., Partida de la Pena, J.A., & González Ronquillo, M., 2016. Effect of zilpaterol hydrochloride on animal performance and carcass characteristics in sheep: A meta-analysis. *Journal of Applied Animal Research*, 44(1):104–112. DOI: https://doi.org/10.1080/09712119.2015.1013966

Pérez, R.V., Macías, C.U., Avendaño, R.L., Correa, C.A., López, B.M.A., & Lara, R.A.L., 2020. Impacto del estrés por calor en la producción de ovinos de pelo. Revisión. *Revista Mexicana de Ciencias Pecuarias*, 11(1):205–222. DOI: https://doi.org/10.22319/rmcp.v11i1.4923

Pirzado, S.A., Hassan, F.U., Arain, M.A., Zhengke, W., Huiyi, C., Haile, T.H., & Guohua, L., 2021. Effect of azomite on growth performance, nutrient utilization, serum biochemical index and bone mineralization of broilers fed low protein diet. *Italian Journal of Animal Science*, 20(1):1282–1291. DOI: https://doi.org/10.1080/1828051X.2021.1953409

Pirzado, S.A., Zhengke, W., Jiao, L., Zheng, A., Huiyi, C., & Gouhua, L., 2020. Effect of azomite with low energy diet on growth, carcass performance and blood biochemical indexes in broiler chickens. *Journal of Aquaculture & Livestock Production*, 1(1):1–5. DOI: https://doi.org/10.47363/JALP/2020(1)105

Ponce-Barraza, E., Solís-Benítez, D.B., Estrada-Angulo, A., Castro-Pérez, B.I., Ríos-Rincón, F.G., Rodríguez-Gaxiola, M.A., Ramos-Méndez, J.L., Arteaga-Wences, Y.J., Plascencia, A., & Urías-Estrada, J.D., 2025. Combinación de zeolita y zilpaterol en ovinos: características de la canal, cortes primarios y masa visceral. *Archivos de Zootecnia*, 74(285):31–40. DOI: https://doi.org/10.21071/az.v74i285.5907

Quezada-Rubio, J.A., Estrada-Angulo, A., Castro-Pérez, B.I., Urías-Estrada, J.D., Ponce-Barraza, E., Escobedo-Gallegos, L. de G., Mendoza-Cortez, D.A., Barreras, A., Carrillo-Muro, O., & Plascencia, A., 2026. Effect of combining a prebiotic (autolyzed yeast from *Saccharomyces cerevisiae*) and probiotic (*Bacillus subtilis*) added in a high-energy diet on growth performance, dietary energetics, and carcass traits of fattening hairy lambs. *Animals*, 16:610. DOI: https://doi.org/10.3390/ani16040610

Rivera-Villegas, A., Estrada-Angulo, A., Castro-Pérez, B.I., Urías-Estrada, J.D., Ríos-Rincón, F.G., Rodríguez-Cordero, D., Barreras, A., Plascencia, A., González-Vizcarra, V.M., Sosa-Gordillo, J.F., & Zinn R.A., 2019. Comparative evaluation of supplemental zilpaterol hydrochloride sources on growth performance, dietary energetics and carcass characteristics of finishing lambs. *Asian Australasian Journal of Animal Science*, 32(2):209–216. DOI: https://doi.org/10.5713/ajas.18.0152

Robles, J.C., Sánchez-Pérez, J.N., Portillo-Loera, J.J., Contreras-Andrade, I., Figueroa-Saavedra, F., & Mario, A., 2024. Effect of supplementing zilpaterol hydrochloride during different periods on energetics, growth performance, carcass traits and fatty acid profile in meat of finishing lambs. *Veterinaria México OA*, 11(1):1–14. DOI: https://doi.org/10.22201/fmvz.24486760e.2024.1235

Rojo-Rubio, R., Avendaño-Reyes, L., Albarrán, B., Vázquez, J.F., Soto-Navarro, S.A., Guerra, J.E., & Macías-Cruz, U., 2018. Zilpaterol hydrochloride improves growth performance and carcass traits without affecting wholesale cut yields of hair sheep finished in feedlot. *Journal of Applied Animal Research*, 46(1):375–379. DOI: https://doi.org/10.1080/09712119.2017.1307756

Roque-Jiménez, J.A., Pinos-Rodríguez, J.M., Rojo-Rub, R., Mendoza, G.D., Vazquez, A., De Jesus, J.C., & Lee-Rangel, H.A., 2018. Effect of natural zeolite on live weight changes, ruminal fermentation and nitrogen metabolism of ewe lambs. *South African Journal of Animal Science*, 48(6):1148–1155. DOI: https://doi.org/10.4314/sajas.v48i6.19

Spotti, M., Fracchiolla, M.L., Arioli, F., Caloni, F., & Pompa, G., 2005. Aflatoxin B_1 binding to sorbents in bovine ruminal fluid. *Veterinary Research Communications*, 29(6):507–515. DOI: http://doi.org/10.1007/s11259-005-1867-2

Statistical Analytical System Institute Inc., 2007. SAS Proprietary Software Release 9.3. SAS Institute Inc. (SAS), Cary, NC, USA.

Stojković, J., Ilić, Z., Ćirić, S., Ristanović, B., Petrović, M.P., Caro Petrović, V., & Kurčubić, V., 2012. Efficiency of zeolite basis preparation in fattening lambs diet. *Biotechnology in Animal Husbandry*, 28(3):545–553. DOI: https://doi.org/10.2298/BAH1203545S

Teng, P.Y., Choi, J., Yadav, S., Marshall, B., Castro, F.L.S., Ferrel, J., & Kim, W.K., 2023. Evaluation of a *dacitic* (*rhyolitic*) *tuff breccia* use on performance, inflammatory, and antioxidant responses in broilers mildly challenged with *Eimeria* spp. *Poultry Science*, 102(7):1–9. DOI: https://doi.org/10.1016/j.psj.2023.102697

Trckova, M., Matlova, L., Dvorska, L., & Pavlik, I., 2004. Kaolin, bentonite, and zeolites as feed supplements for animals: health advantages and risks. *Veterinární Medicína*, 49(10):389–399. DOI: https://doi.org/10.17221/5728-VETMED

Urías-Estrada, J.D., Estrada-Angulo, A. Castro-Pérez, B.I., Ponce-Barraza, E., Ramos-Méndez, J.L., Ríos-Rincón, F.G., Rodríguez-Gaxiola, M.A., & Plascencia, A., 2023. Impact of presence of zeolite in diets for lambs supplemented with zilpaterol hydrochloride: Growth performance and dietary energetics. *Chilean Journal of Agricultural Research*, 83(6):768–774. DOI: http://dx.doi.org/10.4067/S0718-58392023000600768

Urías-Estrada, J.D., Estrada-Angulo, A., Zinn, R.A., & Plascencia, A., 2021. The role of zeolite as feed additive in finishing diets for ruminants: An approach under energetic perspective. *EC Veterinary Science*, 6(6):45–49.

Urías-Estrada, J.D., López-Soto, M.A., Barreras, A., Aguilar-Hernández, J.A., González-Vizcarra, V.M., Estrada-Angulo, A., & Plascencia, A., 2018. Influence of zeolite (clinoptilolite) supplementation on characteristics of digestion and ruminal fermentation of steers fed a steam-flaked corn-based finishing diet. *Animal Production Science*, 58(7):1239–1245. DOI: https://doi.org/10.1071/AN16128

USDA, 1992. United States Standards for Grades of Lamb, Yearling Mutton, and Mutton Carcasses. United States Department of Agriculture, Washington, DC, USA. Available: https://www.ams.usda.gov/sites/default/files/media/Lamb%2C_Yearling_Mutton_and_Mutton_Standard%5B1%5D.pdf [27 January 2026]

Van Soest, P.V., Robertson, J.B., & Lewis, B.A., 1991. Methods for dietary fiber, neutral detergent fiber, and nonstarch polysaccharides in relation to animal nutrition. *Journal of Dairy Science*, 74(10):3583–3597. DOI: https://doi.org/10.3168/jds.S0022-0302(91)78551-2

Vizcarra-Chávez, C.A., Urías-Estrada, J.D., Ponce-Barraza, E., Estrada-Angulo, A., Arteaga-Wences, Y.J., Castro-Pérez, B.I., & Plascencia, A., 2024. Effect of long-term supplementation of AZOMITE (hydrated sodium calcium aluminosilicate) in finishing diets on growth performance, dietary energy, and carcass yield of hairy lambs. *Animals,* 14(20):3018. DOI: https://doi.org/10.3390/ani14203018

Xu, X., Li, X., Xu, Z., Yao, W., & Leng, X., 2021. Dietary Azomite, a natural trace mineral complex, improved the growth, immunity response, intestine health and resistance against bacterial infection in largemouth bass (*Micropterus salmoides*). *Fish & Shellfish Immunology*, 108:53–62. DOI: https://doi.org/10.1016/j.fsi.2020.11.016

Zhao, Y., Wang, W., & Yi, H., 2021. Mineral adsorbents and characteristics. In: Adsorption at Natural Minerals/Water Interfaces. Engineering Materials. Eds: Song, S. & Li, B., Springer, Cham, Switzerland. pp. 1–54. DOI: https://doi.org/10.1007/978-3-030-54451-5_1

Zinn, R.A., Barreras, A., Owens, F.N., & Plascencia, A., 2008. Performance by feedlot steers and heifers: daily gain, mature body weight, dry matter intake, and dietary energetics. *Journal of Animal Science*, 86(10):2680–2689. DOI: https://doi.org/10.2527/jas.2007-0561