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ARTICLE

Evaluation of standardized mixture of synbiotic-glyconutrients supplemented in lambs finished during summer season in tropical environment: growth performance, dietary energetics, and carcass characteristics

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Abstract: Twenty-four Pelibuey × Katahdin lambs (36.4 ± 2.9 kg initial weight) were used in a 77 d feeding trial in a randomized complete block design to evaluate the influence of a standardized synbiotic-glyconutrient combination (GLY) on growth performance, dietary energetic, and carcass characteristics of lambs finished during a period of high ambient temperature. Dietary treatments consisted of a high-energy basal diet supplemented (% of diet dry matter basis) with 0% versus 0.4% GLY. Throughout the study, the average temperature humidity index (THI) was 76.23, corresponding to the "alert" range, but daily maximum THI exceeded 80 for 2 to 6 h of each day of the 77 d study. Daily GLY intake averaged 0.10 g GLY·kg^{-1} live weight. Supplemental GLY increased (P = 0.04) daily water intake, but dry matter intake was not affected. Supplemental GLY increased (P < 0.03) initial 56-d, and overall (77-d) average daily gain, gain efficiency and estimated dietary net energy. Lambs fed GLY had greater ($P \leq$ 0.05) hot carcass weight and fat thickness, and decreased (P = 0.02) kidney-pelvic-heart fat. Supplemental GLY did not affect ($P \geq$ 0.16) shoulder tissue composition or relative weight of visceral mass. Synbiotic-glyconutrient combination improved growth performance, dietary energy, and carcass weight in lambs finished in high ambient temperatures. Enhancements in growth performance and dietary energetics were most appreciable during the first 56 d of the 77 d finishing period.

Key words: finishing lambs, synbiotic, performance, carcass, ambient temperature (high).

Résumé : Vingt-quatre agneaux Pelibuey × Katahdin (poids initial de 36,4 ± 2,9 kg) ont été utilisés pendant une étude d'alimentation de 77 jours de design expérimental par blocs complets aléatoires afin d'évaluer l'influence d'une combinaison normalisée symbiotique-éléments glyconutritifs (GLY) sur la performance de croissance, l'énergie alimentaire et les caractéristiques de carcasse des agneaux en finition pendant une période de grande température ambiante. Les traitements alimentaires consistaient d'une diète de base forte en énergie avec suppléments (sur une base de % des matières sèches) de 0 et 0,4 % GLY. Pendant toute l'étude, l'indice moyenne de température et d'humidité (THI — « temperature humidity index ») était de 76,23, ce qui correspond à la plage « alerte », mais le THI maximal quotidien dépassait 80 de 2 à 6 heures chaque jour de l'étude de 77 jours. La consommation moyenne de GLY était de 0,10 g GLY/kg de poids vif. Les suppléments de GLY ont augmenté (P = 0,04) la consommation quotidienne d'eau, mais il n'y a pas eu d'effet sur la consommation des matières sèches. Les suppléments de GLY ont augmenté (P < 0,03) le gain moyen quotidien lors des 56 premiers jours ainsi que le gain moyen quotidien de la période complète de 77 jours, le gain en efficience, et l'énergie nette alimentaire estimée. Les agneaux ayant reçu le GLY avaient de plus grands ($P \leq$ 0,05) poids de carcasse chaude et épaisseurs de gras,

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et une diminution (P = 0,02) du gras rein-pelvien-cœur. Les suppléments de GLY n'ont pas eu d'effet ($P \geq 0{,}16$) sur la composition des tissus de l'épaule ni sur le poids relatif de la masse viscérale. La combinaison symbiotique-éléments glyconutritifs a amélioré la performance de croissance, l'énergie alimentaire, et le poids de carcasse chez les agneaux en finition pendant une période de grandes températures ambiantes. Les améliorations de performance de croissance et d'énergétique alimentaire étaient particulièrement notables pendant les 56 premiers jours de la période de finition de 77 jours. [Traduit par la Rédaction]

Mots-clés : agneaux en finition, symbiotique, performance, carcasse, température ambiante (grande).

Introduction

Increases in ambient temperature or the lengthening of the warm seasons by global warming and climate change alters, directly or indirectly, the production efficiency of livestock. A high ambient heat load can affect feed intake, nutrient utilization, and health (Rojas-Downing et al. 2017). Even when hair lambs are better adapted to high ambient temperatures, during finishing phase, heat stress markedly alters the energetics of weight gain altering carcass characteristics and meat quality (Mahjoubi et al. 2015; Vicente-Pérez et al. 2020). With the aim of reducing the negative effects of heat stress several strategies have been developed, within them the use of feed additives such as antibiotics have been shown to reduce maintenance energy requirements in cattle under high ambient heat load (Barreras et al. 2013). Due to concerns regarding their residue in meat and milk products, and potential role in development of antibiotic resistance, supplementation with antibiotics and ionophores for the purpose of growth performance enhancement has come under increased scrutiny. Consequently, nutritionists have been looking for alternative feed additives. Probiotics (beneficial living microorganisms) and prebiotics (fiber, cell wall material, mannan polysaccharides derived through hydrolysis of yeast cell walls) are feed additives that may have beneficial extra-nutritional pharmaceutical and (or) metabolic effects on livestock health and growth performance (Bertoni et al. 2013; Uyeno et al. 2015). Due to differences in modes of action, their combination may have additive effects, resulting in the term "synbiotics" (Radzikowski 2017). Nutraceuticals, such as glyconutrients (the most common being fucose, galactose, glucose, mannose, N-acetylgalactosamine, N-acetylglucosamine, N-acetylneuraminic acid, and xylose) enhance cell signaling, promoting general immune responses with a generalized reduction in cellular stress (Murray 2006). The combination of glyconutrients in combination with ß-glucans and probiotics (GLY) has been evaluated in both nonruminant and bovines species. In broiler supplemental GLY increased feed efficiency (Zheng et al. 2017*a*), while in nursery pigs, supplemental GLY decreased the occurrence of diarrhea and decreased the level of oxidative stress in the small intestine (Zheng et al. 2017*b*). Supplemental GLY enhanced nitrogen utilization (increasing flow of microbial protein to the small intestine and nitrogen absorption), increased ruminal pH, and decreased ruminal butyrate proportion in steers fed high-energy diets (Núñez-Benítez et al. 2021). In 2 wk old calves infected with diarrhea, supplemental GLY reduced plasma cortisol, non-esterified fatty acids and urea-nitrogen concentration, and increased plasma glucose (López-Valencia et al. 2017). These findings denote that supplemental GLY may enhance energetic efficiency of cattle subjected to stressful conditions (although there are no reports available that evaluate these effects). Pelibuey breeds and their crosses adapt well to elevated ambient temperatures and are extensively used in tropical areas in Mexico (Romero et al. 2013). However, under extreme conditions [i.e., >78 temperature humidity index (THI)], their growth performance and energetic efficiency may be compromised (Macías-Cruz et al. 2013; Vicente-Pérez et al. 2020). The beneficial effects of GLY on nutrient absorption, ruminal fermentation, and physiological stress parameters could alleviate the negative effects of ambient heat load on dietary energy utilization in hairy lambs. From the perspective of efficient dietary energy utilization for production, the use of GLY may be an additional strategy to reduce the negative effects of the high environmental heat load on the productivity of growing-finishing lamb. For this reason, the objective of this study was to evaluate effects of supplementation of a standardized blend of synbiotic and glyconutrients on growth performance, dietary energetics, and carcass characteristics of lambs finishing during a period of high ambient heat load.

Materials and Methods

Experimental location

Animal management procedures were conducted within the guidelines of locally approved techniques for animal use and care according to Norma Oficial Mexicana (NOM 1999). These regulations are in accordance with the principles and specific guidelines presented in the Guidelines for the Care and Use of Agricultural Animals in Agricultural Research and Teaching (Federation of Animal Science Societies 2010).

This experiment was conducted at the Feedlot Lamb Research Unit of the Universidad Autónoma de Sinaloa, located in the Culiacán, México (24° 46′ 13″ N and 107° 21′ 14″ W). Culiacán is about 55 m above sea level, and has a tropical climate with yearly maximum and minimum temperatures of 36 and 12 °C, respectively.

Weather measurement and THI estimation

Climatic variables (ambient temperature and relative humidity) were obtained every hour from on-site weather equipment (Thermo-hygrometer Avaly, Mod. DTH880, Mofeg S.A., Zapopan, Jalisco) throughout the experimental period. The THI was calculated using the following formula: THI = $0.81 \times T + (\mathrm{RH}/100) \times (T - 14.40) + 46.40$ (Hahn 1999), where: T is the temperature expressed Celsius grade, and RH is the relative humidity.

Animals, source of synbiotic-glyconutrients, and treatments

Twenty-four crossbred intact male lambs (Pelibuey × Katahdin, 36.45 ± 2.92 kg initial shrunk weight) were used in a 77 d growth performance experiment to evaluate the effects of treatments. Four weeks before initiation of the experiment, lambs were adapted to the basal diet offered in the experiment, treated against parasites [1.5 mL per 10 kg live weight (LW); Albendaporte plus, Animal Health and Welfare, México] and injected with 1×10^6 IU vitamin A (1 mL·animal^{-1}; Synt-ADE, Fort Dodge Animal Health, Mexico). Upon initiation of the experiment, lambs were weighed just prior to the morning meal (electronic scale; TORREY TIL/S: 107 2691, TOR REY Electronics Inc, Houston TX, USA). Lambs were then blocked by initial weight and randomly assigned within weight groupings to 12 pens, 2 lambs·pen^{-1}. Dietary treatments were randomly assigned to pens within blocks. Pens were 6 m^2 with overhead shade, automatic waterers, and 1 m fence-line feed bunks. Treatments consisted of the basal diet supplemented with 0% or 0.4% GLY [dry matter (DM) basis]. Ingredients and chemical composition of the basal diet are shown in Table 1. The source of GLY was a standardized mixture synbiotics-glyconutrients (Maxcell Global Co. LTD, Seoul, Rep. Korea) containing a minimum 1×10^7 CFU·g^{-1} of *Lacticaseibacillus casei* strain KCTC 3135, *Bacillus subtilis* strain KACC 93267P, and *Saccharomyces cerevisiae* strain KCTC 3189, plus yeast cell wall ß-Glucans (5% *w/w*; extracted from *S. cerevisiae*), and glyconutrients (7% *w/w*, N-acetylglucosamine, D-xylose, and fucose, in a proportion of 40:40:20, respectively). Dose of GLY used was based on prior studies where dosage of 0.11 mg·kg^{-1} LW enhanced nutrient digestion, and health status in ruminants, specifically cattle (López-Valencia et al. 2017; Núñez-Benítez et al. 2021) and weight gain and gain efficiency in nonruminants (poultry and swines; Zheng et al. 2017*a*, 2017*b*). The GLY dosage level (4 g·kg^{-1} DM) to achieve and average intake of 0.11 g·kg^{-1} LW was determined based on initial weight of lambs at the beginning of the experiment, and the expected daily gain and DM intake for the lamb breed (Rojas-Román et al. 2017; Estrada-Angulo et al. 2018; Rivera-Villegas et al. 2019). Supplemental GLY was hand-weighed using a precision balance (Ohaus, mod AS612, Pine Brook, NJ, USA), and premixed for 5 min with the other minor dietary ingredients (urea, limestone, and mineralized salt) before incorporation into complete mixed basal diet using a 2.5 m^3 capacity paddle mixer (mod 30910-7, Coyoacán, México). To avoid cross-contamination, the mixer was thoroughly cleaned between each treatment.

Table 1. Composition of experimental diets.

Item	Control	GLY
Ingredients, % DM basis		
Cracked corn	62.00	62.00
Distillers dried grains with soluble	14.00	14.00
Sudangrass hay	11.00	11.00
Tallow	4.00	4.00
Cane molasses	6.00	5.60
Urea	0.50	0.50
Mineralized salt[a]	2.50	2.50
Glycozyme[b]	—	0.40
Diet composition[c], % DM basis		
Dry matter	89.33	89.33
Crude protein	14.02	14.02
Neutral detergent fiber	19.50	19.50
Ether extract	6.54	6.54
Estimated net energy[d], Mcal·kg^{-1}		
Maintenance	2.16	2.16
Gain	1.50	1.50

Note: DM, dry matter.

[a]Mineralized salt contained: Ca, 13.58%; Na, 7.8%; Cl, 12.2%; P, 2.2%; Mg, 1.0%; K, 0.7%; $CoSO_4$, 0.068%; $CuSO_4$, 1.04%; $FeSO_4$, 3.57%; ZnO, 1.24%; $MnSO_4$, 1.07%, KI 0.052%.

[b]Commercial standardized mixture of probiotics (*L. casei*, *B. subtilis*, and *S. cerevisiae*), ß-Glucan and glyconutrients (GLY; Maxcell Global Co. LTD, Seoul, South Korea).

[c]Dietary composition was determined by analyzing subsamples collected and composited throughout the experiment. Accuracy was ensured by adequate replication with acceptance of mean values that were within 5% of each other.

[d]Net energy was calculated based on tabular net energy values for individual feed ingredients (NRC 2007).

To ensure additive consumption, the total daily dosage of GLY was provided in the morning feeding (GLY added to 350 g of basal diet, as fed basis). All lambs were fed the basal control diet in the afternoon feeding. Thus, lambs were provided fresh feed twice daily at 0800 and 1400 h. In the morning feeding, all lambs were fed a constant amount (350 g, as fed basis). Whereas, in the afternoon, feed delivery was adjusted to allow for a total daily feed residual ~50 g·kg^{-1}. Residual feed was collected daily between 0740 and 0750 h each morning, and weighed. Feed intake was determined as the difference between quantities offered minus refusals. Feed samples were collected from each elaborated batch. Feed refusal were collected daily and composited weekly for subsequent analyses. Water intake was measured daily at 0700 h by dipping a graduated rod into the tank drinker (one watering tank for each pen). Once the measure was taken, the remaining water was drained, and the tanks were refilled with fresh water.

Originally, the experiment was programmed to last 84 d, but due to the risk of arrival of a tropical storm during the final phase of the experiment, it was decided to shorten the experimental period by 1 wk (lasted 77 d). In this way, lambs were weighed just prior to the morning feeding on days 1, 56, and 77 (final day). Live weights on days 1 and 56 were converted to shrunk body weight (SBW) by multiplying LW by 0.96 to adjust for the gastrointestinal fill (Cannas et al. 2004). All lambs were fasted (drinking water was not withdrawn) for 18 h before recording the final LW.

Feed and feed refusal samples were subject to DM analysis [method 930.15; Association of Official Analytical Chemists (AOAC) 2000]. Feed samples subjected to the following analyses: crude protein (CP; nitrogen × 6.25, method 984.13; AOAC 2000), ether extract (method 920.39; AOAC 2000), and neutral detergent fiber [NDF; Van Soest et al. 1991, corrected for NDF-ash, incorporating heat stable α-amylase (Ankom Technology, Macedon, NY)].

Calculations

Average daily gain (ADG) was computed by subtracting the initial SBW from intermediate (56 d) and final (77 d) SBW and dividing the result by the corresponding number of days on feed. Feed efficiency was computed by dividing ADG by the corresponding average daily dry matter intake (DMI). One approach for evaluation of the efficiency of dietary energy utilization in growth performance trials is the ratio of observed-to-expected DMI and observed-to-expected dietary net energy (NE). Based on diet NE concentration and measures of growth performance, there is an expected energy intake. This estimation of expected DMI is performed based on observed ADG, average SBW, and NE values of the diet (Table 1): expected DMI, $\mathrm{kg{\cdot}d^{-1}} = (\mathrm{EM/NE_m}) + (\mathrm{EG/EN_g})$, where EM (energy required for maintenance, $\mathrm{Mcal{\cdot}d^{-1}}$) = 0.056 × $\mathrm{SBW^{0.75}}$, EG (energy gain, $\mathrm{Mcal{\cdot}d^{-1}}$) = 0.276 × ADG × $\mathrm{SBW^{\,0.75}}$, and $\mathrm{NE_m}$ and $\mathrm{NE_g}$ are corresponding NE values based on the ingredient composition of the experimental diet [Table 1; National Research Council (NRC) 2007]. The coefficient (0.276) was taken from NRC (1985) assuming a mature weight of 113 kg for Pelibuey × Katahdin male lambs (Canton and Quintal 2007). The observed dietary NE was calculated using EM and EG values, and DMI observed during experiment by means of the quadratic formula: $x = (-b - \sqrt{b^2 - 4ac})/2c$, where $x = \mathrm{NE_m}$ ($\mathrm{Mcal{\cdot}kg^{-1}}$), $a = -0.41\mathrm{EM}$, $b = 0.877\mathrm{EM} + 0.41\mathrm{DMI} + \mathrm{EG}$, and $c = -0.877\mathrm{DMI}$ (Zinn et al. 2008).

Carcass, shoulder tissue composition, and visceral mass data

Carcass

All lambs were harvested on the same day. Lambs were stunned (captive bolt), exsanguinated, and skinned. The gastrointestinal organs were separated and weighed, the omental and mesenteric fat were weighed, as well hot carcass weight (HCW) was registered. After carcasses (with kidneys and internal fat included) were chilled at −2 to 1 °C for 24 h, the following measurements were obtained: (1) cold carcass weight (CCW); (2) body wall thickness (distance between the 12th and 13th ribs beyond the ribeye, five inches from the midline of the carcass); (3) subcutaneous fat (fat thickness), which was taken over the 12th to 13th thoracic vertebrae; (4) longissimus muscle (LM) area, measured using a grid reading of the cross-sectional area of the LM between 12th and 13th rib, and (5) kidney and pelvic fat (KP) was removed manually and afterward weighed and reported as a percentage of the CCW (USDA 1982).

Shoulder tissue composition

Shoulders were obtained from the forequarter. The weights of shoulder were subsequently recorded. The shoulder tissue composition was assessed using physical dissection by the procedure described by Luaces et al. (2008).

Visceral mass

All tissue weights are reported on a fresh tissue basis. Organ mass was expressed as grams of fresh tissue per kilogram of final empty body weight (EBW). Final EBW represents the final LW minus the total digesta weight. The stomach complex was calculated as the digesta-free sum of the weights of the rumen, reticulum, omasum and abomasum.

Statistical analyses

Performance traits (DMI, gain, gain efficiency, observed dietary NE, observed-to-expected dietary NE ratio, and observed-to-expected DMI), carcass characteristics, shoulder tissue composition, and visceral organ mass data were analyzed as a randomized complete block design using the MIXED procedure of SAS software (SAS 2004). All the data were tested for normality using the Shapiro-Wilk test. HCW was used as a covariate in evaluation of treatment effects on carcass characteristics. In the analysis of shoulder tissue composition, the CCW effect was included as a covariate. Treatment effects were considered significant when the P value was ≤ 0.05 and Tukey's multiple comparison procedures were used.

Results and Discussion

The experiment was conducted during the summer season. During the course of the experiment temperature and relative humidity averaged 28.29 °C (20.1 to 35.0 °C) and 48.6% (26.1% to 68.1%). The minimum and maximum estimated THI were 64.30 and 86.09, respectively (Table 2). Daily maximal THI exceeded the 80 "danger or "emergency" range (Mader et al. 2006)

Table 2. Ambient temperature, mean relative humidity and mean calculated temperature humidity index[a] registered during the experiment.

Week	Mean T_a, °C	Min T_a, °C	Max T_a, °C	Mean RH, %	Min RH, %	Max RH, %	Mean THI	Min THI	Max THI
1	26.79 ± 0.6	21.86 ± 0.9	31.71 ± 1.1	50.46 ± 5.1	32.83 ± 3.6	68.10 ± 6.9	75.22 ± 1.2	66.56 ± 1.2	83.87 ± 1.9
2	26.36 ± 1.0	20.71 ± 1.9	32.00 ± 1.6	48.21 ± 2.6	33.04 ± 2.3	63.38 ± 4.5	74.391.6 ±	65.29 ± 2.3	83.49 ± 2.7
3	27.00 ± 0.7	20.14 ± 0.9	33.86 ± 0.9	42.30 ± 1.9	27.71 ± 2.0	59.89 ± 3.8	74.59 ± 0.9	64.30 ± 0.9	84.89 ± 1.3
4	27.79 ± 1.7	22.29 ± 1.5	33.29 ± 2.2	41.07 ± 4.7	26.13 ± 2.4	57.45 ± 6.3	75.33 ± 1.9	66.49 ± 1.5	84.17 ± 3.0
5	27.14 ± 1.7	21.71 ± 1.9	32.86 ± 1.5	47.87 ± 4.5	33.94 ± 1.8	61.79 ± 7.9	75.46 ± 2.0	66.47 ± 2.2	84.45 ± 2.9
6	28.36 ± 1.1	22.00 ± 1.1	34.71 ± 1.1	42.96 ± 3.6	28.96 ± 2.5	56.97 ± 4.9	76.26 ± 1.6	66.43 ± 1.3	86.09 ± 1.9
7	27.93 ± 0.6	22.43 ± 1.3	33.44 ± 1.1	44.83 ± 2.7	27.71 ± 1.8	61.96 ± 3.8	76.02 ± 0.7	66.78 ± 1.3	85.27 ± 1.8
8	29.00 ± 0.8	24.29 ± 1.1	33.71 ± 1.3	42.85 ± 3.3	31.54 ± 1.0	54.17 ± 5.3	76.66 ± 0.9	69.19 ± 1.2	84.13 ± 1.3
9	30.14 ± 0.6	25.86 ± 1.1	34.43 ± 0.5	44.85 ± 3.2	33.38 ± 2.0	56.33 ± 4.7	78.36 ± 0.4	71.33 ± 1.2	85.56 ± 1.0
10	29.71 ± 0.7	25.29 ± 0.8	34.14 ± 0.7	42.06 ± 1.5	31.92 ± 1.8	52.21 ± 1.7	77.35 ± 0.7	70.35 ± 0.8	84.36 ± 0.9
11	30.79 ± 0.6	26.57 ± 0.1	35.00 ± 0.1	42.94 ± 2.5	31.88 ± 1.4	54.00 ± 4.2	78.83 ± 0.6	71.80 ± 1.1	85.86 ± 1.5
Mean	28.29 ± 1.5	23.01 ± 2.1	33.56 ± 2.1	44.58 ± 3.0	30.82 ± 2.7	58.48 ± 4.8	76.23 ± 1.5	67.71 ± 2.5	84.74 ± 0.9

Note: T_a, ambient temperature; RH, relative humidity; THI, temperature humidity index.
[a]THI = 0.81 × ambient temperature + [(relative humidity/100) × (ambient temperature − 14.4)] + 46.4. THI code (Normal THI < 74; Alert >74–79; Danger 79–84, and Emergency > 84).

during a period of 2 to 6 h for each day of the 77 d study. The average THI (76.2) during experiment corresponded to the "alert" range (Mader et al. 2006). However, Vicente-Pérez et al. (2020) indicate that hair sheep begin to show signs of heat stress from THI values between 78 and 79 units. Based on THI coding, the period of time that lambs were exposed to conditions of "stressful" ambient heat load may be classified as "short-to-moderate" (Silanikove 2000). The average net daily intake of GLY·pen^{-1} (9.24 g) corresponds to 0.10 g GLY·kg^{-1} LW. This intake is in good agreement with the targeted dose of 0.11 g GLY·kg^{-1} LW, considered optimal for enhancement of nutrient digestion in steers (Núñez-Benítez et al. 2021), and metabolic profiles in treatment of calves infected with diarrhea (López-Valencia et al. 2017).

The effects of GLY supplementation on water intake, growth performance, and dietary energetics are shown in Table 3. Average water intake during the first 56 d was very similar (1.02) to expected for lambs under thermoneutral conditions (NRC 2007), but during the last 21 d, the average water intake was 26% greater than expected for lambs subjected to thermoneutrality. Overall average daily water intake was greater (P = 0.04) for GLY (3.79 vs. 3.24 L·d^{-1}) than for controls. The basis for the small, yet appreciable differences in water intake of GLY vs. control lambs is uncertain. To our knowledge, there are no reports of studies evaluating the effects of probiotics, prebiotics, or its combination on water intake in ruminants. Under comparable conditions (breed, diet, climatic conditions), water intake may increase with weight gain rate (Schoeman and Viser 1995). Accordingly, the small increase in water intake with GLY may correspond to the increased daily gain rather than a direct effect of GLY on water intake, per se. Indeed, water intake per rate of gain (L·g^{-1}) was similar for control and GLY, averaging 0.0173 and 0.0167 L·g^{-1}, respectively.

Observed dry matter intake was not affected (P > 0.15) by treatments in any period. Overall DMI averaged 1.110 kg·d^{-1}. Ambient heat load has a lesser influence on DMI of hairy lambs than non-adapted breeds (Vicente-Pérez et al. 2020). In some cases, DMI in hair lambs was not appreciably affected by ambient conditions (winter vs. summer) in semi-arid environments (Nicolás-López et al. 2021; Macías-Cruz et al. 2020). However, Macías-Cruz et al. (2013) observed an 8.3% reduction in DMI of hairy lambs finished in a semi-arid environment during summer versus spring seasons. In our experiment, we registered a DMI 13% lower than the average DMI of previous experiments performed at this center using lambs of similar breeding, weight, and dietary NE concentration when lambs were finished during periods of less stressful ambient temperature under tropical conditions (average THI = 74.4; Estrada-Angulo et al. 2013; Estrada-Angulo et al. 2018).

Table 3. Effect of supplemental synbiotics-glyconutrients[a] on growth performance and dietary energy in finishing lambs.

	GLY level, % of diet DM[b]			
Item	0	0.4	SEM	*P* value
Replicas	6	6		
Shrunk weight, kg[c]				
Initial	36.60	36.30	0.14	0.18
56 d	46.94	49.30	0.57	0.03
Final	51.10	53.66	0.82	0.03
Water intake, L				
1–56 d	2.74	3.38	0.151	0.09
56–77 d	4.58	4.91	0.123	0.12
1–77 d	3.24	3.79	0.105	0.04
Daily gain, kg·d^{-1}				
1–56 d	0.185	0.232	0.014	0.02
56–77 d	0.198	0.211	0.012	0.33
1–77 d	0.188	0.226	0.011	0.02
Dry matter intake, kg·d^{-1}				
1–56 d	1.020	1.115	0.056	0.15
56–77 d	1.184	1.262	0.059	0.24
1–77 d	1.064	1.155	0.051	0.14
Gain-to-feed ratio				
1–56 d	0.181	0.209	0.005	<0.01
56–77 d	0.167	0.167	0.006	0.90
1–77 d	0.177	0.196	0.004	<0.01
Dietary net energy, Mcal·Kg^{-1}				
1–56 d NE_m	2.11	2.23	0.02	<0.01
1–56 d NE_g	1.44	1.54	0.02	<0.01
56–77 d NE_m	2.12	2.15	0.03	0.38
56–77 d NE_g	1.45	1.47	0.03	0.38
1–77 d NE_m	2.12	2.20	0.02	<0.01
1–77 d NE_g	1.45	1.52	0.03	<0.01
Observed-to-expected diet NE				
1–56 d NE_m	0.98	1.03	0.006	<0.01
1–56 d NE_g	0.96	1.03	0.008	<0.01
56–77 d NE_m	0.98	0.99	0.011	0.38
56–77 d NE_g	0.97	0.98	0.015	0.38
1–77 d NE_m	0.98	1.02	0.006	<0.01
1–77 d NE_g	0.96	1.01	0.006	<0.01
Observed-to-expected DMI				
1–56 d	1.035	0.971	0.005	<0.01
56–77 d	1.025	1.014	0.009	0.38
1–77 d	1.031	0.985	0.006	<0.01

Note: DM, dry matter; SEM, standard error of the mean; NE, net energy; NE_m, net energy for maintenance; NE_g, net energy gain; DMI, dry matter intake.

[a]Commercial standardized mixture of probiotics (*L. casei*, *B. subtilis*, and *S. cerevisiae*), ß-Glucan, and glyconutrients (GLY; Maxcell Global Co. LTD, Seoul, South Korea).

[b]Supplemental level of 0.4% GLY·kg^{-1} of diet DM represent an average net daily consumption of 4.62 g GLY·lamb^{-1}.

[c]Initial shrunk weight is the full live weight reduced 4% to adjust for gastrointestinal fill, while final shrunk weight was obtained following an 18 h fast (food but not drinking water was withdrawn).

During the initial 56 d GLY supplementation increased ADG (20%, $P < 0.01$), feed efficiency (GF; ADG/DMI; 15%, $P < 0.01$), and observed dietary NE (6%, $P < 0.01$). Accordingly, compared with control, GLY supplementation decreased observed-to-expected DMI (6%, $P < 0.01$). Overall, GLY supplementation increased final SBW

Table 4. Effect of supplemental synbiotics-glyconutrients[a] on carcass characteristics and chemical composition of shoulder.

Item	GLY level, % of diet DM[b] 0	0.4	SEM	P value
Hot carcass weight, kg	29.19	30.57	0.52	0.05
Dressing percentage, %	58.68	58.40	0.33	0.44
Cold carcass weight, kg	28.94	30.35	0.51	0.05
LM area, cm^2	16.93	18.15	0.57	0.09
Fat thickness, mm	2.77	3.36	0.20	0.04
KP, %	3.56	3.14	0.11	0.02
Shoulder composition, %				
Muscle	62.89	62.25	0.39	0.16
Fat	16.35	16.88	0.63	0.44
Bone	20.76	20.87	0.91	0.90
Muscle:fat ratio	3.89	3.70	0.14	0.25
Muscle:bone ratio	3.04	2.99	0.15	0.76

Note: DM, dry matter; SEM, standard error of the mean; LM, longissimus thoracis muscle; KP, kidney and pelvic fat.

[a]Commercial standardized mixture of probiotics (*L. casei*, *B. subtilis*, and *S. cerevisiae*), ß-Glucan and glyconutrients (GLY; Maxcell Global Co. LTD, Seoul, South Korea).

[b]Supplemental level of 0.4% GLY·kg^{-1} of diet DM represents an average net daily consumption of 4.62 g GLY·$lamb^{-1}$.

(5%, $P < 0.03$), ADG (17%, $P < 0.02$), GF (9%, $P < 0.01$), dietary energy (4%, $P < 0.01$), and decreased observed-to-expected DMI (4%, $P < 0.01$). The basis for enhanced ADG and energetic efficiency observed during first 56 d is not clear. One possible explanation is that GLY promotes an enhancement of metabolizable protein (MP) supply to small intestine. This potential benefit is most likely reflected during the early growing phase; affecting ADG, gain efficiency, and dietary NE. Enhanced ADG, gain efficiency, and dietary NE due to increased MP have been noted in both feedlot cattle (Torrentera et al. 2017) and feedlot lambs (Estrada-Angulo et al. 2018). Based on NRC (1985), the estimated MP supply for control and GLY treatments during the initial 56 d period was similar (0.97 and 0.98 of requirement, respectively). However, Núñez-Benítez et al. (2021) observed that supplemental GLY (0.11 g GLY·kg^{-1} LW) increased MP supply (10.4%) in feedlot cattle. They noted that the increase in MP supply was due to an increase in net ruminal microbial protein synthesis, a decrease in ruminal feed nitrogen degradation, and an increased post-ruminal nitrogen digestion. However, the concomitant effects of GLY on decreasing cortisol levels (improved insulin-glucose system) and improved immunity system may have also contributed to enhancements in energy efficiency and rate of gain, helping to strengthen this adaptive mechanism (Nicolás-López et al. 2021).

Heat load has been associated with a 7% to 25% increase in maintenance energy requirements (NRC 1981, 2007), largely due to energy costs for dissipation of accumulated heat load (Salah et al. 2014; Lees et al. 2019). observed-to-expected DMI and observed-to-expected dietary net energy are important and practical applications of current standards for energetics in nutrition research (Zinn et al. 2008). The estimation of dietary NE based on measures of growth-performance and the ratio of observed-to-expected DMI (apparent energy retention per unit DMI) reveal differences in the efficiency of energy utilization of the diet itself, independently of confounding effects of ADG and DMI associated with gain-to-feed ratios. Thus, it provides important insight into potential treatment effects on the efficiency of energy utilization. An observed-to-expected dietary NE ratio of 1.00 indicates that performance is consistent with dietary NE values based on tables of feedstuff standards and observed DMI. A ratio that is greater than 1.00 is indicative of greater efficiency of dietary energy utilization. Whereas, a ratio that is lower than 1.00 indicates lower than expected efficiency of energy utilization. In the case of the observed-to-expected DMI, the interpretation of the ratio is exactly the opposite. Values below 1.00 means greater energy retention per unit of DMI. In this sense, GLY lambs appear to have greater (1.03) estimated efficiency of energy utilization, with a lower observed-to-expected DMI value (0.97). In contrast, control lambs had a lower observed-to-expected diet NE value (0.96). Accordingly, observed DMI was 4% greater than expected based on growth performance and dietary NE concentration calculated using information publish by NRC (2007).

As mentioned previously, changes in energetic efficiency under conditions of elevated ambient conditions may be largely a reflection of increased maintenance

Table 5. Effect of supplemental synbiotics-glyconutrients[a] on organ mass of lambs.

	GLY level, % of diet DM[b]			
Item	0	0.4	SEM	*P* value
EBW, percentage of full weight	89.98	89.38	0.46	0.41
Organs, g·kg^{-1} EBW				
Stomach complex[c]	31.55	31.34	0.59	0.82
Intestines	40.70	41.08	0.79	0.75
Heart + lungs	19.77	20.23	0.67	0.65
Liver + spleen	17.95	18.72	0.42	0.25
Kidney	2.37	2.31	0.06	0.54
Omental fat	34.67	35.00	1.83	0.90
Mesenteric fat	8.00	7.25	1.09	0.64

Note: DM, dry matter; SEM, standard error of the mean; EBW, empty body weight.

[a]Commercial standardized mixture of probiotics (*L. casei*, *B. subtilis*, and *S. cerevisiae*), ß-Glucan, and glyconutrients (GLY; Maxcell Global Co. LTD, Seoul, South Korea).

[b]Supplemental level of 0.4% GLY·kg^{-1} of diet DM represent an average net daily consumption of 4.62 g GLY·lamb^{-1}.

[c]Stomach complex = (rumen + reticulum + omasum + abomasum), without digesta.

energy requirements. Given that the changes in efficiency of energy retention is affected solely by the environmental effects on the maintenance coefficient (MQ), the MQ for the present study can be estimated as follows: MQ = $\{NE_m \times [DMI - (EG/NE_g)]/SBW^{0.75}\}$, where NE corresponds to the NE values of the diet (Table 1) according to NRC tables (NRC 1985), EG = 276 × ADG × SBW$^{0.75}$ and SBW is the average SBW (NRC 1985). Accordingly, in non-supplemented lambs, elevated ambient temperature increased 8% the MQ above specified standard [0.056 Mcal·SBW$^{0.75}$; NRC (2007)], while lambs received GLY show no change in MQ.

The effects on energetic efficiency and growth performance observed in the present experiment are consistent with the positive effects of GLY supplementation on positive energy balance in calves infected with diarrhea, and on characteristics of digestion and protein metabolism reported previously (López-Valencia et al. 2017; Núñez-Benítez et al. 2021).

The effects of supplemental GLY on carcass characteristics, tissue composition, and visceral organ mass are shown in Tables 4 and 5. Lambs fed GLY had greater HCW (4%, P = 0.05) and fat thickness (16%, P = 0.04), but lower (12%, P = 0.02) KPH. Supplemental GLY tended to increase (P = 0.09) LM area. Because there were no treatment effects on dressing percentage, the increase on HCW and the tendency of the increase on LM area are largely a reflection of differences between treatments on ADG and final SBW. Generally, the effects of synbiotics on carcass characteristics have been small and not appreciable (Zerby et al. 2011; Ribeiro et al. 2015). The basis for reduced KPH (internal fat deposition) with GLY supplementation is uncertain. It has been proposed that manipulation of volatile fatty acid production by probiotics and prebiotics provision could lead to differences in fat synthesis and distribution (Elam et al. 2003). However, in a previous study (Núñez-Benítez et al. 2021), effects of GLY supplementation on ruminal volatile fatty acid molar proportions were not appreciable. There were no treatments effects on shoulder tissue composition (expressed as g·kg^{-1} of shoulder weight) or visceral mass (g·kg^{-1} EBW). The absence of effects of GLY on visceral organ mass is consistent with previous report involving probiotic (Belewu and Jimoh 2005; Estrada-Angulo et al. 2013) or prebiotic supplementation of feedlot lambs (Picón-Rubio et al. 2010).

Conclusion

It is concluded that synbiotic-glyconutrient combination supplemented at a level of 0.4% of diet DM (equivalent to 0.10 mg GLY·kg^{-1} LW) increases growth performance, dietary energy, carcass weight, and fat thickness in lambs finished in the summer season in tropical climate. As lambs may have experienced heat stress only during a brief period each day, the beneficial effect of GLY may be independent of environmental conditions. The net benefits on growth performance and dietary energetics were most apparent during the first 56 d of the 77 d growing-finishing period.

Disclosure Statement

The authors report no potential conflicts of interest.

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