Misan Journal of Agricultural and Environmental Sciences

RESEARCH ARTICLE

Productive response and apparent Nutrient Digestibility in hamdani lambs as affected by varying dietary Zeolite concentrations

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ABSTRACT

This study examined dietary zeolite at different levels on growth and nutrient digestibility in Hamdani lambs. Sixty lambs aged 6-7 months with initial body weight of 30.49 ± 0.09 kg were allocated to four groups: T1 (control, 0% zeolite), T2 (2.5% zeolite), T3 (3.5% zeolite), and T4 (4.5% zeolite). Growth parameters, apparent nutrient digestibility coefficients, and rumen fermentation were assessed. Results revealed that T3 showed significantly greater ($p<0.05$) final body weight (45.15 ± 0.14 kg), total weight gain (14.69 ± 0.11 kg), and average daily gain (190.50 ± 1.55 g/day) compared to other treatments. Feed conversion ratio was most efficient in T3 (8.07 ± 0.16), while T4 showed reduced feed intake. Digestibility coefficients for dry matter, organic matter, crude protein, and crude fiber were highest in T3, whereas ether extract digestibility peaked in T2 (84.80 ± 0.01%). Rumen ammonia nitrogen concentrations decreased with increasing zeolite levels, with T4 recording the lowest values at all sampling times, while rumen pH remained relatively stable across treatments. The 3.5% zeolite level optimized nutrient utilization and growth performance, whereas the 4.5% level depressed both digestibility and weight gain. The findings concluded that moderate zeolite at 2.5-3.5% of dietary dry matter can efficiently improve production traits in Hamdani lambs.

Keywords: *Livestock, Microbial protein, zeolite, digestibility*

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Received: 18/10/2025
Accepted: 26/11/2025
Published: 31/12/2025
DOI: https://doi.org/10.64333/MJAE.25.4.1
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INTRODUCTION

The rising global demand in small ruminant production systems has intensified the need for high-quality animal protein for feed efficiency, enhancing growth, and efficiency (Kim *et al.*, 2019). Feed cost strategies in livestock farming improve nutrient digestibility and animal health (Ragkos *et al*., 2021). The strategies of dietary feed additives share a significant portion of operating expenditures and are constantly planned to improve nutrient utilization, including probiotics, enzymes, and specific mineral supplements (Jawla *et al*., 2026). Natural zeolites, characterized by a three-dimensional porous structure, attracted significant interest for their potential to modify rumen fermentation (El-Nile *et al*., 2021). The unique physicochemical properties of zeolites are regarded as a class of crystalline hydrated aluminosilicates and economically viable feed additives in ruminant nutrition (Valpotić *et al*., 2017).

High cation exchange capacity across various sheep and cattle breeds enhances microbial protein synthesis and volatile fatty acid production, which enables them to sequester ammonia in the rumen (Sallam *et al*., 2022). The more stable nitrogen profile can modify fermentation pathways and positively affect growth performance (Kumar *et al*., 2011). The dietary zeolite with reduced ruminal ammonia-N concentrations leads to increased propionate production and reduced methane emissions in small ruminants (Khachlouf *et al*., 2018). Furthermore, outcomes vary significantly across animal species and breeds because it depends on zeolite type, inclusion level, and basal diet composition (Sallam *et al*., 2022). Moderate zeolite inclusion levels highlight the critical importance of dose optimization and improve the rumen parameters that alter production and fermentation indicators (Ahmed *et al*., 2023; Wang *et al*., 2024). The Hamdani lamb is regarded as a local breed in Middle Eastern production systems for its adaptability to harsh environmental conditions (Liu *et al*., 2025).

It is also famous for its acceptable growth potential and remains an essential genetic resource for regional meat supply (Zulfiqar *et al*., 2025). The optimal zeolite supplementation level for Hamdani lambs under different management regimes improves the growth performance and nutrient digestibility (Vanvanhossou *et al*., 2021). Despite its economic and cultural significance, a significant gap exists in the breed-specific nutritional supplement level; therefore, there is an urgent need to produce sign-based feeding recommendations for the Hamdani lamb.

Therefore, this study assessed the incorporation of changed dietary levels of zeolite on designated production traits and the apparent digestibility coefficients to provide actionable, breed-specific dietary recommendations to producers, thereby contributing to the growth of more efficient and sustainable lamb production systems

MATERIALS AND METHODS

Experimental Animals and Housing

This study was conducted to examine the effects of dietary zeolite on growth, nutrient digestibility, rumen fermentation characteristics, and feed utilization. This study was conducted in the sheep field of the Special Farm in Qushtapa, Erbîl, Iraq, and sixty Hamdani lambs aged 6 and 7 months and 30.49 ± 0.09 were selected for the experiment. Lambs were placed in cages, each with an area of 1 x 2 m2, in a closed barn. Each cage was equipped with plastic containers for concentrated feed and coarse feed (wheat hay), and a drinking water fountain. Cubes of mineral salts were placed in front of the lambs throughout the experiment. Before commencing the experiment, the lambs were clinically

examined, dewormed, vaccinated against enterotoxemia using Covexin 8 (MSD Animal Health, Boxmeer), and provided fresh water ad libitum throughout the study with the basal feed during the acclimatization period (Dschaak *et al*., 2010).

Experimental Design and Feed Formulation

Four nutritional groups in triplicate were designed, such as T1: Basal diet (Control), T2: Basal diet + 2.5% zeolite, T3: Basal diet + 3.5% zeolite, and T4: Basal diet + 4.5% zeolite. The lambs were fed at a rate of 3% of their live weight. A total of 60 animals, five animals were assigned to each replicate of each group. All groups' diets were formulated to be isonitrogenous and isoenergetic in their content of metabolic energy and crude protein, but differed in the percentage of zeolite (0, 2.5, 3.5, 4.5%). Zeolite was purchased from Al-Muhandis Scientific Bureau, Iraq. It was supplied in airtight polypropylene bags, with each bag holding 20 kg of finely ground zeolite powder and stored at room temperature. Crushed wheat straw was used as a roughage source, while soybean meal, crushed yellow corn, wheat bran, and crushed barley were incorporated as the main protein and energy ingredients. Additionally, a blend of minerals, vitamins, and table salt was included to meet the nutrient requirements of growing lambs (Yang *et al*., 2021). The estimation of dry matter, organic matter, crude protein, crude fat, and crude fibre was conducted using the Dawodu *et al.* (2013) guidelines. The nitrogen free extract was determined by calculating the difference between the total dry matter and the sum of the other components (Table 1).

Table (1): shows the chemical composition of the feed materials used in the experiment

Feed materials	**Treatments**			
	0 zeolite%	**2.5 zeolite%**	**3.5 zeolite %**	**zeolite 4.5%**
Barly	40	40	40	40
Soybean meal	8	8	8	8
yellow corn	25	25	25	25
Wheat bran	25	25	25	25
Vitamins and salts	2	2	2	2
Crud protein (CP)	130.3	130.3	130.3	130.3
Organic matter (OM)	944.3	944.3	944.3	944.3
Ether Extract (EE)	35.2	35.2	35.2	35.2
Crud Fibers (CF)	78.8	78.8	78.8	78.8
Ash	55.7	55.7	55.7	55.7
NFE Extract	700	700	700	700
metabolism Energy (MJ/kg DM)	12.84	12.84	12.84	12.84

Feeding Management

The quantity of feed allocated to the animals was modified in accordance with their updated weight every week. Animals were given feed twice daily in the same quantity during the morning and evening feeding schedules. Feed offered and feed refusals were recorded daily to determine feed intake. The animals remained in a state of excellent health throughout the trial, with no instances of disease or digestive issues recorded.

Growth Performance Measurements

At the end of the experimental period, all lambs were exposed to a 12 h overnight fasting period to lessen the effects of gastrointestinal fill (Ahmed *et al*., 2026). After that, the growth parameters of each lamb were assessed by recording initial body weight, final body weight, total weight gain, average daily gain (ADG), daily feed intake, and feed conversion ratio (FCR). The following formulas were used for the measurement of the following growth performance parameters (Shafiq *et al*., 2025).

$$\text{Total Weight Gain (kg)} = \text{Final Body Weight} - \text{Initial Body Weight}$$

$$\text{ADG (g/day)} = \frac{\text{Final Body Weight} - \text{Initial Body Weight}}{\text{Experimental Period (days)}}$$

$$\text{FCR} = \frac{\text{Total Feed Intake (kg)}}{\text{Total Weight Gain (kg)}}$$

$$\text{Feed Intake (g)} = \text{Feed Offered (g)} - \text{Feed Refused (g)}$$

Digestibility Trial

During the last 10 days of the feeding period, each Hamdani lamb was transferred into a metabolic cage for the separate collection of feces and urine to determine the apparent nutrient digestibility. During this period, the feed given to the animals was accurately measured, and the manure produced was collected daily to determine feed intake. Total feces of each lamb were collected every morning before feeding and weighed using a digital electronic balance (OHAUS Defender 3000; accuracy ±1 g). 10% of the daily fecal output sample from each animal was collected and stored until chemical analysis. After the end of the collection period, feed and fecal samples were systematically mixed and dehydrated in an oven at 60°C for 48 h. The dried samples were crushed using a laboratory mill (Cyclotec™ 1093 Sample Mill) to pass through a 1-mm screen and stored in airtight polyethylene bottles pending laboratory analyses.

Chemical Analysis

The chemical composition of feed and fecal samples was determined by following the Association of Official Analytical Chemists method AOAC (2019). Dry matter was determined by oven

drying at 105°C (AOAC Method 934.01), ash content was determined by combustion in a muffle furnace at 550°C (AOAC Method 942.05), crude protein was determined by applying the Kjeldahl nitrogen method (AOAC Method 984.13), ether extract was examined using the Soxhlet extraction method (AOAC Method 920.39), and crude fiber was assessed according to AOAC Method 978.10.

$$\text{Organic matter (\%)} = \text{DM (\%)} - \text{Ash (\%)}$$
$$\text{Nitrogen-free extract NFE (\%)} = 100 - (\text{CP} + \text{EE} + \text{CF} + \text{Ash})$$

$$\text{Digestibility (\%)} = \frac{\text{Nutrient Intake} - \text{Nutrient Excreted in Feces}}{\text{Nutrient Intake}} \times 100$$

$$\text{Dry Matter Digestibility D (\%)} = \frac{\text{DM Intake} - \text{DM in Feces}}{\text{DM Intake}} \times 100$$

$$\text{Organic Matter Digestibility OMD (\%)} = \frac{\text{OM Intake} - \text{OM in Feces}}{\text{OM Intake}} \times 100$$

$$\text{Crude Protein Digestibility CPD (\%)} = \frac{\text{CP Intake} - \text{CP in Feces}}{\text{CP Intake}} \times 100$$

$$\text{Ether Extract Digestibility EED (\%)} = \frac{\text{EE Intake} - \text{EE in Feces}}{\text{EE Intake}} \times 100$$

$$\text{Crude Fiber Digestibility CFD (\%)} = \frac{\text{CF Intake} - \text{CF in Feces}}{\text{CF Intake}} \times 100$$

$$\text{Nitrogen-Free Extract Digestibility NFED (\%)} = \frac{\text{NFE Intake} - \text{NFE in Feces}}{\text{NFE Intake}} \times 100$$

Rumen Fluid Collection and Analysis

Rumen fluid samples were collected from each lamb before feeding and after feeding at 3 and 6 hours. 50–100 mL of rumen fluid was collected and filtered through four layers of sterile cheesecloth. The pH of the filtered rumen fluid was recorded using the pH meter (Hanna Instruments Inc., Woonsocket, RI, USA). The ammonia nitrogen of filtered rumen fluid was determined using the phenol-hypochlorite colorimetric method as described by Odenyo *et al.* (1999), and it was expressed as mg NH_3-N/100 mL rumen fluid

Statistical Analysis

The data were statistically analyzed using the SPSS statistical software to investigate the impact of parameters on the studied traits. One-way analysis of variance was conducted to determine the significant differences in the groups using Duncan's Multiple Range Test.

RESULTS AND DISCUSSION

The growth of Hamdani lambs fed different levels of zeolite (0%, 2.5%, 3.5%, and 4.5%) is presented in Table 2. It revealed significant differences ($P<0.05$) among treatments. The final body weight of lambs was significantly affected, with T3 (3.5% zeolite) recording the highest final weight (45.15 ± 0.14 kg), which was significantly greater than T1 (44.20 ± 0.24 kg), T2 (42.44 ± 0.34 kg), and T4 (42.50 ± 0.08 kg). While T2 and T4 showed the lowest values with no significant change, average daily gain was significantly influenced by zeolite. T3 presented the maximum ADG (190.50 ± 1.55 g/day), which was significantly higher than other treatments. T1 showed moderate ADG (173.24 ± 0.98 g/day), while T2 (156.50 ± 4.62 g/day) and T4 (156.75 ± 2.98 g/day) recorded the lowest ADG values with no significant in groups. Feed intake also varied significantly among treatments. T1, T2, and T3 showed comparable feed intake values of 1535.83 ± 17.60, 1536.95 ± 12.87, and 1538.89 ± 23.05 g, respectively, with no significant differences among them. However, T4 had significantly lower feed intake (1477.21 ± 11.98 g) than all other treatments. The total weight gain followed a similar pattern to the final weight. T3 demonstrated the maximum total gain (14.69 ± 0.11 kg), significantly outclassing T1 (13.34 ± 0.22 kg), T2 (12.10 ± 0.34 kg), and T4 (12.11 ± 0.24 kg). T1 showed restrained total gain, while T2 and T4 had the lowest gains with comparable values. The FCR was significantly affected by zeolite levels. T3 demonstrated the most efficient FCR (8.07 ± 0.16), which was significantly better than T1 (8.86 ± 0.09), T2 (9.84 ± 0.29), and T4 (9.42 ± 0.17). T1 showed intermediate FCR, while T2 exhibited the poorest feed conversion efficiency. T4 showed FCR values that were statistically similar to T2 but lesser to T1 and T3.

This study was conducted to demonstrate the different levels of zeolite in Hamdani lambs. Superior growth performance was observed with 3.5% zeolite (T3), with the highest final BW, TWG, and AWG, and the most effective FCR (8.07). Similarly, Sallam *et al*. (2022) also reported improved average daily gain and feed conversion efficiency compared to controls in sheep by supplementation of natural clinoptilolite at moderate levels. Abdelrahman *et al*. (2021) and Al Sulivany *et al*. (2024) also documented enhanced growth performance with the positive effect on weight gain by the

supplementation of diets containing zeolite in sheep. Alrez *et al*. (2024) reported that Awassi lambs showed the best performance at moderate zeolite, which is consistent with the present study findings in Middle Eastern breeds. El-Nile *et al*. (2021) documented reduced growth performance with a higher level of zeolite in the diet of goats, which is aligned with the present study findings that, at a 4.5 zeolite level, depressed growth performance is observed. The present study's finding, which recorded better growth, aligns with Leung *et al*. (2007), who reported that clinoptilolite had a better feed conversion ratio and nitrogen retention.

Table (2): Growth performance parameters of Hamdani lambs fed different levels of zeolite (0%, 2.5%, 3.5%, and 4.5%)

Treatments	Start weight kg	Final weight) kg	Total weight (gm)	Average daily gain (gm)	Feed Intake gm	FCR
T1	30.86± 0.03	44.20±0.24 b	13.34±0.22 b	173.24±0.98 b	1535.83±17.60 a	8.86±0.09b
T2	30.33±0.0 5	42.44±0.34 c	12.10±0.34 c	156.50±4.62 c	1536.95±12.87 a	9.84±0. 29a
T3	30.46±0.2 1	45.15±0.14 a	14.69±0.11 a	190.50±1.55 a	1538.89±23.05 a	8.07±0.16c
T4	30.39±0.2 7	42.50±0.08 c	12.11±0.24 c	156.75±2.98 c	1477.21±11.98 b	9.42±0.17a b

(Table 3) demonstrated a significant influence ($P<0.05$) on dry matter digestibility with the dietary zeolite supplementation. T2 (2.5% zeolite) and T1 (0% zeolite) showed intermediate and comparable DMD values of 75.75 ± 0.23% and 75.43 ± 0.06%, respectively, with no significant difference, while the T3 (3.5% zeolite) exhibited the highest DMD at 78.60 ± 0.48%, which was significantly greater than all other treatments. T4 (4.5% zeolite) recorded the lowest DMD at 74.42 ± 0.05%, which was significantly lower than all other treatments. Organic matter digestibility in T1 and T4 recorded the lowest values with no significant difference, while T3 demonstrated the highest OMD (75.16 ± 0.37%), significantly superior to T2 (71.52 ± 0.10%), T1 (70.72 ± 0.13%), and T4 (70.40 ± 0.17%). T2 showed intermediate OMD. Crude protein digestibility was significantly improved by the addition of zeolite. T2 exhibited intermediate CPD, while T1 and T4 had the lowest values with no significant difference in the groups. T3 showed the highest CPD at 85.44 ± 0.24%, which was significantly greater than T2 (83.39 ± 0.11%), T1 (81.32 ± 0.07%), and T4 (81.63 ± 0.10%). Ether extract digestibility in T2 recorded the highest EED at 84.80 ± 0.01%, which was significantly better than T1 (80.35 ± 0.09%), T3 (79.46 ± 0.32%), and T4 (75.23 ± 0.05%). T1 showed midway EED, followed by T3, while T4 recorded the lowest EED. Crude fiber digestibility was significantly improved; T3

demonstrated the highest CFD at 76.50 ± 0.20%, significantly greater than T1 (69.86 ± 0.03%), T2 (67.72 ± 0.01%), and T4 (65.20 ± 0.38%). T1 exhibited intermediate CFD, followed by T2, while T4 recorded the lowest CFD. Nitrogen-free extract digestibility in T3 showed the highest NFED at 72.31 ± 0.04%, significantly greater than T2 (70.31 ± 0.04%), T1 (69.48 ± 0.14%), and T4 (69.31 ± 0.09%). T2 revealed intermediate NFED, while T1 and T4 recorded the lowest values with no significant difference in treatments.

This study documented the highest dry matter digestibility in T3, which is similar to the findings of Amr *et al*. (2023), who demonstrated improved nutrient digestibility, including dry matter and organic matter. Grabherr *et al*. (2009) also reported that zeolite can change rumen fermentation near acetate production, dropping propionate accessibility and increasing energy losses. Kardaya *et al*. (2025) also documented boosted dry matter digestibility with the zeolite in sheep. The crude protein digestibility findings of the present study were also similar to those of Marono *et al*. (2015), who described that zeolite can enhance microbial protein synthesis and improve protein digestibility, while Jawla *et al*. (2026) also observed improved crude protein digestibility with the natural zeolite in dairy goats. The findings of the ether extract digestibility also align with Alrez *et al*. (2024), who studied higher zeolite levels and recorded improved fat digestibility in Awassi lambs and also explained that the depressed ether extract digestibility can adsorb fatty acids onto the zeolite surface, forming indigestible complexes. Toprak *et al.* (2016) findings also supported the present findings related to crude fiber, and recorded that zeolite above 3% improved fiber digestion but did not affect the daily gain in sheep. Urías-Estrada *et al.* (2018) also documented improved fiber digestibility with restrained zeolite.

Table (3): demonstrated a significant influence on dry matter digestibility with the dietary zeolite supplementation

Treatments	Dry matter	Organic matter	Crud protein	Ether extract	Crud fibers	NFED
T1	75.43±0.06b	70.72±0.13c	81.32±0.07c	80.35±0.09b	69.86±0.03b	69.48±0.14c
T2	75.75±0.23b	71.52±0.10b	83.39±0.11b	84.80±0.01a	67.72±0.01c	70.31±0.04b
T3	78.60±0.48a	75.16±0.37a	85.44±0.24a	79.46±0.32c	76.5±0.20a	72.31±0.04a
T4	74.42±0.05c	70.40±0.17c	81.63±0.10c	75.23±0.05d	65.20±0.38d	69.31±0.09c

The pH at 3 hours decreased in most treatments after feeding, except for T2 and T3 which showed slight increases. T4 maintained the highest pH at 6.80 ± 0.05, which was significantly greater than T1 (6.36 ± 0.12). T2 (7.00 ± 0.12) and T3 (7.00 ± 0.06) showed intermediate values, with T3 being

statistically similar to T4. The rumen pH at 0 hours values ranged from 6.80 to 7.00 across treatments. T4 (4.5% zeolite) showed the highest pH at 7.00 ± 0.08, which was significantly greater ($P<0.05$) than T1 (6.80 ± 0.05). T2 (6.86 ± 0.08) and T3 (6.90 ± 0.08) exhibited intermediate pH values that were not significantly different from either T1 or T4. At 6 hours T4 continued to show the highest pH at 6.98 ± 0.03, which was significantly greater than T1 (6.13 ± 0.08) and T2 (6.00 ± 0.17). T3 (6.70 ± 0.05) exhibited intermediate pH values. Ammonia concentrations at 0 hours ranged from 7.47 to 10.43 mg/100 mL. T1 (control) showed the highest ammonia level at 10.43 ± 0.65 mg/100 mL, which was significantly greater than T4 (7.47 ± 0.82 mg/100 mL). T2 (9.00 ± 0.27 mg/100 mL) and T3 (8.60 ± 0.56 mg/100 mL) showed intermediate values that were not significantly different from either T1 or T4. At 6 hours, the T1 maintained the highest ammonia concentration at 15.36 ± 0.82 mg/100 mL, while T2 showed 14.00 ± 0.70 mg/100 mL. Both were significantly higher than T4 (9.12 ± 1.09 mg/100 mL). T3 showed an intermediate value of 10.90 ± 0.73 mg/100 mL, which was not significantly different from T1, T2, or T4. Ammonia concentrations at 3 hours increased in all treatments, reflecting protein degradation in the rumen. T1 (14.16 ± 0.72 mg/100 mL) and T2 (16.63 ± 0.64 mg/100 mL) showed the highest ammonia levels, which were significantly greater than T3 (10.00 ± 0.40 mg/100 mL) and T4 (9.13 ± 0.66 mg/100 mL) (Table 4).

This study recorded decreased rumen ammonia nitrogen concentrations with the higher level of zeolite, which is consistent with the findings of AL-Sinjari *et al*. (2019) and Tánori *et al.* (2024), who reported that zeolite can decrease ruminal ammonia-N concentrations in the rumen. Papaioannou *et al*. (2005) similarly documented the reduced ammonia concentrations in goats with the zeolite diets and demonstrated the ammonia-binding capacity of zeolites. Yadav *et al.* (2023) studied zeolite and reported reduced ammonia concentrations, and Elsherbeni *et al.* (2024) also reported no additional benefits with the higher level of zeolite in sheep and decreased nitrogen ammonia. The present study reported stable rumen pH in T4, which is aligned with the findings of Wang *et al.* (2023), who reported that zeolite can maintain optimal pH for microbial fermentation in the rumen. Mahdavirad *et al.* (2021) and Mohammed *et al.* (2023) documented more stable rumen pH in sheep supplemented with zeolite. The ammonia concentration finding of this study is also consistent with Tánori *et al.* (2024), who reported that increased zeolite levels can efficiently bind ammonia and drop its concentration in the rumen fluid. Khachlouf *et al.* (2018) similarly reported a reduction in rumen ammonia with higher levels of zeolite inclusion. Kebreab *et al.* (2002) noted lower nitrogen excretion with lower rumen ammonia, which

reduces environmental pollution. Forouzani *et al.* (2004), who reported that zeolite can reduce nitrogen losses in sheep.

Table (4): Effect of zeolite on rumen pH and ammonia nitrogen concentration (mg/100 mL) in Hamdani lambs

Treatments	**Ph rumen**			**Ammonia mg/ 100 mL**		
	0 hour	after 3 hours	after 6 hours	0 hour	after 3 hours	after 6 hours
T1	6.80±0.05b	6.36±0.12c	6.13±0.08c	10.43±0.65a	14.16±0.72a	15.36±0.82a
T2	6.86±0.08ab	7,00±0.12bc	6.00±0.17bc	9.00±0.27ab	16.63±0.64a	14.00±70a
T3	6.90±0.08ab	7.00±0.06ab	6.70±0.05ab	8.60±0.56ab	10.00±0.40b	10.90±0.73a
T4	7.00±0.08a	6.80±0.05a	6.98±0.03a	7.47±0.82b	9.13±0.66b	9.12±1.09b

CONCLUSION

In Hamdani lambs, dietary supplementation with natural zeolite significantly influenced growth performance, apparent nutrient digestibility, and rumen fermentation characteristics. The empirical results demonstrated that Treatment 3 (3.5% zeolite) achieved the highest final body weight, total weight gain, and average daily gain, alongside the most efficient feed conversion ratio. Furthermore, the 3.5% inclusion level optimized the apparent digestibility coefficients for dry matter, organic matter, crude protein, and crude fiber. Although lower zeolite levels (2.5%) showed improvements in specific parameters such as ether extract digestibility, the overall productive performance clearly establishes 3.5% of dietary dry matter as the optimal and recommended inclusion rate for practical feeding systems in Hamdani lambs to maximize profitability, nutrient utilization, and sustainable livestock production

CONFLICT OF INTEREST

The authors declare no conflicts of interest associated with this manuscript.

ETHICAL APPROVAL

Any animal experiment was conducted in compliance with the institutional guidelines of animal care and use in research. Ethical approval was received through the College of Agricultural Engineering Sciences, University of Duhok, Iraq (Approval No. CAES-2025-031).

ACKNOWLEDGMENTS

The authors are thankful to the College of Agricultural Engineering Sciences, University of Duhok, Iraq, for supporting the conduct of the study

AUTHOR CONTRIBUTIONS

MAA: Conceptualization, methodology, investigation, data curation, formal analysis; BSAS: Methodology, validation, resources, data curation, writing original draft; BZ and MSH: review and editing; MO: review and proofreading.

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