Research Article

Assessing the Effects of AZOMITE Supplementation on Growth Performance, Nutrient Digestibility, and Meat Quality in Male Goats: A Novel Approach to Mineral-Based Feed Enhancement

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Abstract | This study evaluated the Influence of AZOMITE (AZM) in enhancing the production performance, nutrient retention and physico-chemical properties in male goats. A total of 32 male goats (9.0 ± 1.0 kg initial body weight) were randomly assigned to four dietary treatments: a control group (CONT) receiving a basal diet without AZM, and three treatment groups supplemented with AZM; i.e., AZM-0.2 (0.2% AZM), AZM-0.4 (0.4% AZM), and AZM-0.6 (0.6% AZM). The results revealed that AZM supplementation significantly improved growth performance, with the AZM-0.4 group showing the highest final live body weight (FLBW), weight gain (WG) and average daily gain (ADG) ($P < 0.01$). Feed efficiency (FE) was also significantly enhanced, particularly in the AZM-0.4 group ($P < 0.01$). Nutrient retainability of dry matter (DM), crude protein (CP), fat, acid detergent fiber (ADF), and neutral detergent fiber (NDF) were significantly higher in goats fed AZM-0.4 ($P < 0.05$). Carcass weight, dressing percentage and major primal cuts, including hind leg, fore leg, loin, ribs, and shoulder were significantly increased ($P < 0.01$) in goats receiving AZM-0.4. Additionally, meat quality traits such as water-holding capacity (WHC) improved; while cooking loss (CL) and drip loss (DL) were significantly reduced in the AZM-0.4 group ($P < 0.05$). Overall, dietary inclusion of AZM-0.4 (0.4% AZM) in the basal diet was the most effective strategy for enhancing growth performance, nutrient utilization, carcass yield, and meat quality in male goats.

Keywords | Azomite, Goat, Growth, Carcass, Nutrient digestibility, Meat quality

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INTRODUCTION

Livestock depend heavily on minerals for proper growth, functioning, and nutrient proficiencies, and the importance of copper, zinc, and manganese trace minerals is even more pronounced as integral constituents of certain enzymes controlling fundamental metabolic activities (Vatankhah *et al*., 2025). The majority of high meat producing animals stay deficit in consumption of a certain trace mineral because roughages rarely contain minerals in sufficient amounts. Hence, supplementation of diet is warranted. Research has established the role of water-soluble smart hydroxy trace minerals for the maintenance of rumen health and their adequacy for performance in weight gain animals. The simulation of rumen fermentation with different sources of hydroxy trace minerals, for instance copper and zinc, has positively affected the production of volatile fatty acids and gas which signify improvements in rumen fermentation efficiency and subsequently enhanced dry matter digestibility, animal tissue weight, and health in general (Byrne and Murphy, 2022). In addition, growth performance and nutrient assimilation of small ruminants is positively impacted by the other trace minerals as well.

AZOMITE (AZM) is a certified, naturally occurring mineral compound free from synthetic components. It is a unique mineral deposit formed from volcanic ash that settled into an ancient seabed and was later mined from a distinct geological region in Utah, USA. AZM is recognized globally as a valuable natural mineral supplement. It has been certified and approved as safe by several regulatory bodies and organizations, including the Organic Materials Review Institute (OMRI, USA), the U.S. Food and Drug Administration (FDA) as Generally Recognized as Safe (GRAS) for use in food production, the China Ministry of Agriculture (Feed Additive License, 2012, the Zhunzi 19th), and the Association of American Feed Control Officials (AAFCO). AZM is widely used as a natural mineral enhancer or 'booster' in livestock, aquaculture feeds, and organic agriculture due to its rich and diverse trace mineral content.

AZOMITE is the mixture of animal, plants residues and variety of minerals. It contains more than 70 trace and other minerals, especially rich in rare earth elements. According to an official analysis report, AZM contains Calcium (Ca) 5.17%, Potassium (K) 5.18%, Sodium (Na) 2.00%, Magnesium (Mg) 0.78%, Sulfur (S) 0.21%, Iron (Fe) 1.37%, Manganese (Mn) 0.02%,Zinc (Zn) 64.3 ppm, Cobalt (Co) 22.3 ppm, Copper (Cu) 13.5 ppm, Molybdenum (Mo) 12.6 ppm, Fluorine (F) 320 ppm, Lithium (Li) 859 ppm, Boron (B) 29 ppm, Chromium (Cr) 7.85 ppm, Lanthanum (La) 257 ppm, Cerium (Ce) 360 ppm, Praseodymium (Pr) 26.75 ppm, Tungsten (W) 31.00 ppm, Vanadium (V) 9.35 ppm, Nickel (Ni) 2.27 ppm and Tin (Sn) 2.90 ppm (Azomite, 2023).

Previous studies in poultry, fish, and lambs have confirmed that dietary AZM supplementation does not exert adverse effects on health status and overall performance, indicating its suitability as a natural mineral-based feed additive (Xu *et al*., 2021; Pirzado *et al*., 2022; Vizcarra-Chávez *et al*., 2024).

Interestingly, in various studies AZM is well established and widely used as natural feed additive in aquaculture and poultry feed industry to improve the growth performance and digestibility of nutrients and carcass characteristics (Azam *et al*., 2016; Pirzado *et al*., 2020). AZM is an important trace mineral and immune enhancer which has been used in the aquatic feed industry, livestock and organic agriculture for last two decades. Several research works pointed out that the addition of AZM in diets is effective on feed quality, weight gain, feed conversion ratio, nutrient utilization in shrimp, tilapia and Catfish (Liu *et al*., 2011; Mustafa *et al*., 2016: Batool *et al*., 2018). AZM also increases the nutrient digestibility and activity of digestive enzymes in tilapia (*Ctenopharyngodon idellus*) and broilers (Azam *et al*., 2016; Pirzado *et al*., 2022). Despite having findings on non-ruminant species, currently there is no reported studies are available on the effects of AZM in goats. Thus, this study was designed to assess growth performance, nutrient digestibility, and meat quality in male goats with dietary AZM supplementation.

MATERIALS AND METHODS

Animal ethics

All experimental procedures involving animals were conducted in accordance with the guidelines and regulations approved by the Institutional Animal Ethics Committee (IAEC) of the Faculty of Animal Husbandry and Veterinary Sciences, Sindh Agriculture University, Tandojam (Approval No. 679/2024). Proper care and management were ensured throughout the experimental period to minimize animal discomfort and stress.

Animal management, sample collection and digestibility analysis

For this research trial thirty-two castrated male goats, approximately 3–4 months of age with an initial average body weight of 9.0±1.0 kg, were utilized in this study. The goats were purchased from local livestock market and subjected to a 15-day acclimatization period under uniform management conditions. During this phase, goats were dewormed using a broad-spectrum anthelmintic, and health monitoring was conducted twice daily to ensure their fitness for the trial. The animals were individually housed in well-ventilated pens measuring 2.5 × 4.0 ft, with concrete flooring to facilitate hygiene and daily cleaning. Each pen was equipped to provide ad libitum access to fresh drinking water. Following acclimatization, goats were randomly allocated into four dietary treatment groups (n= 8 per group): A control group (CONT) receiving the basal diet, and three experimental groups supplemented with AZM- 0.2 (AZM-0.2 %), AZM-0.4 (AZM-0.4%), and AZM-0.6 (AZM-0.6%) of the total feed, respectively. All goats were offered a total mixed ration (TMR) twice daily, at 07:00 and 17:00 h. The feeding trial was conducted for 105 days, inclusive of the acclimatization period, during which standard animal welfare and management practices were strictly maintained. The TMR formulation are given in Table 1.

Table 1: Diet Composition and Nutrient Levels of ration (DM basis %).

Ingredients %*	CONT	AZM-0.2	AZM-0.4	AZM-0.6
Maize fodder	58	58	58	58
Wheat bran	11.5	11.5	11.5	11.5
Rice polish	05	05	05	05
Maize	05	05	05	05
Molasses	02	02	02	02
Cotton seed cake	04	04	04	04
Guar meal	07	07	07	07
Soybean	05	05	05	05
Salt	01	0.8	0.6	0.5
MM	0.5	0.5	0.5	0.5
Limestone	01	01	01	0.9
AZM	0.0	0.2	0.4	0.6
Total	100	100	100	100
Calculated nutrient %				
DM	54.81	54.81	54.81	54.81
CP	16.06	16.02	16.0	15.99
ME (kcal/kg)	2380	2380	2380	2380
Fat	4.3	4.3	4.3	4.3
Fiber	15.6	15.6	15.6	15.6
ADF	22.22	22.22	22.22	22.22
NDF	26.88	26.88	26.88	26.88
Calcium (%)	1.09	1.10	1.10	1.11
Phosphorus (%)	0.73	0.73	0.73	0.73
Magnesium (%)	0.46	0.46	0.46	0.46
Potassium (%)	1.37	1.38	1.39	1.40
Sodium (%)	0.70	0.70	0.70	1.69
Phosphorus (%)	0.73	0.73	0.73	0.73
Magnesium (%)	0.46	0.46	0.46	0.46
Iron (ppm)	167.32	167.32	167.32	167.33
Zinc (ppm)	118.05	118.18	118.31	118.44
Copper (ppm)	19.17	19.20	19.22	19.25
Manganese (ppm)	107.00	107.00	107.00	107.00
Selenium (ppm)	0.56	0.56	0.56	0.56
Cobalt (ppm)	0.99	1.03	1.08	1.12
Iodine (ppm)	0.93	0.94	0.94	0.95
Molybdenum(ppm)	12.60	12.63	12.65	12.68
Chromium(ppm)	0.0	0.02	0.03	0.05
Lanthanum(ppm)	0.0	0.51	1.03	1.54
Cerium(ppm)	0.0	0.72	1.44	2.16
Praseodymium(ppm)	0.0	0.05	0.11	0.16
Tungsten(ppm)	0.0	0.06	0.12	0.19
Vanadium(ppm)	0.0	0.02	0.04	0.06
Nickel(ppm)	0.0	0.005	0.009	0.014
Tin(ppm)	0.0	0.006	0.012	0.017

*MM: Mineral mixture (The premix provided the following per kg of the diet: VA 3 000 IU, VD3 750 IU, VE 6 mg, nicotinamide 11 mg, Cu (as copper sulfate) 11 mg, Fe (as ferrous sulfate) 40 mg, Mn (as manganese sulfate) 50 mg, Zn (as zinc sulfate) 50 mg, Se (as sodium selenite) 0.25 mg, Co (as cobalt chloride) 0.5 mg, I (as calcium iodate) 0.4 mg); AZM: Azomite; DM: dry matter; CP: crude protein; ME: metabolizable energy; ADF: acid detergent fiber; NDF: neutral detergent fiber.

Growth and digestibility analysis

Following the adaptation period, initial body weights were individually recorded. Final live body weights were measured on the 90th day of the experimental trial. To measure feed intake, feed refusals were recorded daily for each animal. Growth performance parameters, including weight gain (WG), average daily gain (ADG), average daily dry matter intake (ADDMI), and feed efficiency (FE), were calculated using the following standard formulas:

$$WG = FBW - IBW$$

$$ADG = \frac{WG}{Duration\ of\ trial}$$

$$ADDMI = \frac{Total\ dry\ matter\ intake}{Duration\ of\ trial}$$

$$FE = \frac{ADDMI}{ADG}$$

For the determination of nutrient digestibility, excreta samples were collected individually from each animal in treatment (*n*= 08 goats) continuously during the last week of the study. Freshly voided feces were immediately frozen at −20 °C, then subsequently dried in a forced-air oven at 65 °C for 48 hours. The dried samples were ground to a uniform particle size and stored at 4 °C until further chemical analysis. Both feed and fecal samples were analyzed for dry matter (DM; method 930.15), crude protein (CP; Kjeldahl method, N × 6.25; method 954.01), ether extract (EE; method 991.36), and ash (method 942.05) using standard procedures outlined by the Association of Official Analytical Chemists (AOAC, 2000). The concentrations of acid detergent fiber (ADF) and neutral detergent fiber (NDF) were determined following the procedures described by Van Soest *et al.* (1991). The digestibility of nutrients was calculated using following formula.

$$Nutrient\ digestibility = \frac{(Nutrient\ intake - Nutrient\ in\ feces)}{Nutreint\ intake} \times 100$$

Carcass cuts and meat quality parameters

The goats were fasted for about 6 hours before to slaughter, with free access to water. The animals were slaughtered following the halal method, confirming complete bleeding. After whole blood removed, carcass was deskinned, and visceral organs were carefully removed before subsequent carcass and meat quality evaluations. Carcass characteristics, including carcass weight, dressing percentage, and leg length, were recorded following the procedures outlined by Lawler *et al.* (2004). 500g meat samples were obtained from the longissimus dorsi (LD) muscle for physico-chemical analysis. The LD muscle was excised from the left side of each carcass between the 8th and 11th thoracic vertebrae, as described by Honikel (1998), and all visible fat was carefully removed prior to analysis.

The pH of the longissimus dorsi (LD) muscle was assessed 24 hours post-slaughter to determine the ultimate pH. A representative 10 g sample of LD muscle was mechanically homogenized in 90 mL of distilled water, and pH was subsequently measured using a calibrated digital pH meter, following the procedure described by Ockerman (1985). Water-holding capacity (WHC) was assessed following the procedure by Wardlaw *et al.* (1973). Briefly, 8 g of meat was mixed with 12 mL of 0.6 M NaCl solution in a test tube and centrifuged at 10,000 rpm for 15 minutes at 4 °C. The supernatant was discarded, and WHC was calculated and expressed as a percentage. Cooking loss was evaluated based on the method of Kondaiah *et al.* (1985). A 20 g meat sample was sealed in a polyethylene bag and heated in a water bath until the internal temperature reached 72 °C. The sample was then cooled, and the weight difference before and after cooking was used to calculate cooking loss. Drip loss was measured following the protocol described by Sen *et al.* (2004). A 100 g meat sample was placed in a sealed polyethylene bag and stored at 4 °C for 24 hours. After refrigeration, the sample was removed, gently blotted with filter paper, and reweighed. The difference in weight before and after storage was recorded as drip loss. Chemical composition of the meat including moisture, crude protein, ether extract, and ash was determined using standard methods outlined by the Association of Official Analytical Chemists (AOAC, 2000).

Statistical analysis

The complete dataset was analyzed using a one-way ANOVA in SPSS version 24 (IBM Corp., Armonk, NY, USA). Normality of the data was evaluated via the Shapiro–Wilk test, and homogeneity of variances was examined using Levene's test. The comparison of treatment means was performed with the Tukey post hoc test. Results were expressed as mean ± standard error (SE). Statistical significance was established at $P < 0.05$.

RESULTS

Growth performance

The impact of dietary AZM supplementation on the growth performance of male goats is presented in Table 2. The final live body weight (FLBW), weight gain (WG), and average daily gain (ADG) were significantly improved ($P < 0.05$) in goats fed AZOMITE, with the highest values observed in the AZM-0.4 group. Average dry matter intake (ADMI) was significantly influenced by treatment ($P<0.05$), with higher values in AZM-0.2 and AZM-0.4 groups compared to the control. Feed efficiency (FE) was significantly enhanced ($P < 0.05$) by AZM supplementation, with lower FE values indicating better efficiency in AZM-supplemented groups, especially AZM-0.4.

Table 2: Effect of AZOMITE on growth performance of male goats.

Items	Dietary treatments				SE	P value
	CONT	AZM-0.2	AZM-0.4	AZM-0.6		
IBW (kg)	9.08	9.07	9.10	9.6	0.08	0.953
FLBW (kg)	15.49^{d}	18.51^{b}	19.63^{a}	16.50^{c}	0.79	<0.001
WG (kg)	6.41^{d}	9.44^{b}	10.53^{a}	7.44^{c}	0.27	0.0027
ADG (g)	71.30^{d}	104.89^{b}	117.04^{a}	82.74^{c}	3.04	<0.001
ADDMI (g)	499.87^{b}	506.50^{a}	503.43^{ab}	504.67^{ab}	9.02	0.025
FE (g/g)	7.03 ^{a}	4.83 ^{b}	4.30 ^{b}	4.61 ^{b}	0.20	0.001

CONT: control diet; AZM-0.2: Azomite 0.2%; AZM-0.4: Azomite 0.4%; AZM-0.6: Azomite 0.6%; FLBW: final live body weight; WG: weight gain; ADG: average daily gain; ADDMI: average daily dry matter intake; FE: feed efficiency.

Nutrient digestibility

As indicated in Table 3, AZM supplementation significantly enhanced dry matter (DM), crude protein (CP), and fat digestibility ($P < 0.01$). Ash retention was also significantly affected ($P < 0.05$), with AZM-0.4 showing improved values over the CONT. The highest ($P < 0.05$) acid detergent fiber (ADF), and neutral detergent fiber (NDF) retainability observed in AZM-0.4. The AZM-0.4 group consistently exhibited the highest nutrient retention values.

Table 3: Effect of AZOMITE on nutrient digestibility of male goats (%).

Items (%)	Dietary treatments				SE	P value
	CONT	AZM-0.2	AZM-0.4	AZM-0.6		
DM	70.63^{b}	71.03^{b}	73.35^{a}	69.47^{c}	0.49	0.0001
CP	68.15^{b}	68.90^{b}	71.77^{a}	67.41^{c}	0.49	0.0001
Fat	76.21^{b}	76.76^{b}	79.53^{a}	73.62^{c}	0.62	0.0001
Ash	82.27^{ab}	82.52^{ab}	84.04^{a}	79.70^{b}	1.31	0.027
ADF	42.29^{ab}	43.16^{ab}	44.48^{a}	39.21^{b}	1.50	0.015
NDF	45.20^{b}	45.70^{ab}	47.96^{a}	43.73^{b}	0.82	0.006

CONT: control diet; AZM-0.2: Azomite 0.2%; AZM-0.4: Azomite 0.4%; AZM-0.6: Azomite 0.6%; DM: dry matter; CP: crude protein; ADF: acid detergent fiber; NDF: neutral detergent fiber.

Dressing characteristics

As shown in Table 4, carcass weight ($P < 0.01$), dressing percentage and most primal cut weights including hind leg, front leg, loin, ribs ($P < 0.05$), loin and shoulder were significantly higher ($P < 0.01$) in the AZM-0.4 group compared to the CONT. The weight of neck showed no difference in all treatments. Moreover, organ weights such as heart, liver, and kidney and spleen showed no significant differences among treatments ($P < 0.05$).

Links Researchers

Table 4: Effect of AZOMITE on carcass performance of male goats.

Items	Dietary treatments				SE	P value
	CONT	AZM-0.2	AZM-0.4	AZM-0.6		
CW (kg)	6.06[c]	7.52[b]	8.32[a]	6.50[c]	0.19	<0.001
DP (%)	44.97[b]	45.53[ab]	47.20[a]	44.77[b]	0.75	0.017
Hind Leg (kg)	1.11[b]	1.12[b]	1.37[a]	1.10[b]	0.03	0.021
Front Leg (kg)	0.70[c]	0.76[b]	0.85[a]	0.72[c]	7.92	0.011
Neck (kg)	0.79	0.84	0.89	0.72	0.03	0.092
Ribs (kg)	1.30[b]	1.38[b]	1.73[a]	1.31[b]	0.04	0.0041
Loin (kg)	0.75[c]	0.80[b]	1.09[a]	0.77[bc]	0.01	<0.001
Shoulder (kg)	0.27[b]	0.33[b]	0.56[a]	0.27[b]	0.04	<0.001
Heart (kg)	0.10	0.11	0.13	0.11	0.01	0.069
Liver (kg)	0.30	0.34	0.34	0.30	0.01	0.075
Kidney (kg)	0.09	0.10	0.12	0.10	4.86	0.069
Spleen (kg)	0.04	0.05	0.05	0.04	4.56	0.213

CONT: control diet; AZM-0.2: Azomite 0.2%; AZM-0.4: Azomite 0.4%; AZM-0.6: Azomite 0.6%, CW: carcass weight; DP: dressing percentage.

Physicochemical properties of meat

The effects of AZOMITE on meat quality parameters are presented in Table 5. No significant differences ($P > 0.05$) were observed in moisture content, crude protein, fat, ash, or pH values among the treatments. However, the CL and DL was significantly reduced ($P < 0.05$) in the AZM-0.4 group. However, water-holding capacity (WHC) was significantly improved ($P < 0.05$) in AZM-0.4 group.

Table 5: Effect of AZOMITE on physicochemical propertied of meat of male goats.

Items	Dietary treatments				SE	P value
	CONT	AZM-0.2	AZM-0.4	AZM-0.6		
MOIS (%)	71.24	71.21	71.54	71.55	2.39	0.731
CP (%)	19.86	19.92	20.04	19.74	0.64	0.906
Fat (%)	3.80	3.79	3.62	3.86	0.34	0.910
Ash (%)	1.11	1.15	1.21	1.26	0.13	0.684
pH	5.93	5.75	5.65	5.900	0.24	0.201
CL (%)	30.26[a]	27.67[ab]	26.03[b]	30.26[a]	1.03	0.035
DL (%)	4.84[a]	3.43[ab]	2.42[b]	2.95[b]	0.10	0.021
WHC (%)	69.52[b]	70.68[ab]	71.79[a]	68.77[b]	1.65	0.007

CONT: control diet; AZM-0.2: Azomite 0.2%; AZM-0.4: Azomite 0.4%; AZM-0.6: Azomite 0.6%; MOIS: moisture; CP: crude protein; CL: cooking loss; DL: drip loss; WHC: water holding capacity.

DISCUSSION

The livestock industry is emphasizing increasing goat production through efficient feed utilization and enhanced nutrient digestibility to improve mutton yield (Pirzado *et al*., 2016). Many feed additives are now being used to improve animal efficiency, e.g., prebiotics, probiotics, organic acids, essential oils, enzymes, edible insects and immune enhancers (Qureshi *et al*., 2024; Abbasi, 2024, 2025; Zakria *et al*., 2025). Consequently, trace minerals (organic and inorganic) and rare earth elements have gained more popularity for improving growth performance, nutrient utilization, health status, and immunity in poultry, small ruminants, and other animal species (Sheoran, 2017; Pirzado *et al*., 2021; Samarin *et al*., 2022; Vizcarra-Chávez, 2024).

AZM has been identified as a functional mineral supplement and feed additive that enhances growth performance and nutrient utilization in aquaculture and poultry, primarily through improvements in digestive efficiency (Liu *et al*., 2011; Batool *et al*., 2018; Pirzado *et al*., 2022). The beneficial effects of AZM are likely mediated by multiple mechanisms, which may include the binding of dietary toxins, improved bioavailability of nutrients, and the unique contribution of its complex mineral profile. Specifically, its composition comprising hydrated sodium calcium aluminosilicate, rare earth elements, and diverse trace minerals provides essential cofactors that support metabolic, digestive, and physiological processes in animals. The present study offers novel insights into the application of AZM supplementation in goats. To the best of our knowledge, evidence on the dietary incorporation of AZM in goats remains scarce, and information regarding its effects on growth performance and nutrient utilization is particularly limited.

In the present study, dietary supplementation of 0.4% AZM in goats resulted in improved average dry matter intake (ADMI), average daily gain (ADG), body weight gain (BWG), and feed efficiency. These findings are consistent with earlier reports demonstrating enhanced ADG, average daily feed intake (ADFI), and feed conversion ratio (FCR) in aquatic species such as shrimp, tilapia, and catfish following AZM supplementation (Liu *et al*., 2009, 2011; Musthafa *et al*., 2016). Comparable outcomes were also observed by Pirzado *et al*. (2022), who reported that inclusion of 0.25% and 0.5% AZM in broiler diets significantly improved ADG and FCR in broiler chickens. Moreover, an earlier study reported that dietary supplementation with 4.0 g/kg AZM significantly improved growth performance in koi carp fingerlings (Jaleel *et al*., 2015). Previous studies have attributed improvements in growth performance and feed efficiency to enhanced nutrient digestibility, absorption, and metabolism associated with AZM supplementation (Azam *et al*., 2016). These effects may be linked to the diverse trace minerals in AZM, which act as cofactors for digestive enzymes, stimulate rumen microbial activity, and optimize nutrient absorption, thereby contributing to improved growth efficiency and overall performance (Samarin *et al*., 2022).

Male goats receiving a diet containing 0.4% AZM exhibited a statistically significant increase in the in vivo digestibility of dry matter (DM), crude protein (CP), fat, and the fiber fractions, namely acid and neutral detergent fibre (ADF and NDF). These findings corroborate earlier work in poultry, where broilers receiving identical dosage levels of AZM (0.25 and 0.5%) also demonstrated enhanced digestibility of DM, CP, fat, and fibre (Pirzado *et al*., 2022). Comparable augmentations in DM and CP digestibility were recorded in tilapia following AZM inclusion (Fodge *et al*., 2011), thereby suggesting a potential species-invariant mode of action mediated by the additive. Furthermore, complementary research illustrated that the incorporation of nano zinc oxide into lamb rations elicited marked increases in the digestibility of DM, CP, ADF, and NDF (Abadi, 2024). Notably, supplementation with trace minerals in male goats was recently shown to yield improvements in digestibility metrics for ADF and NDF (Thamizhan *et al*., 2024), underscoring the collective impact of mineral fortification strategies. AZM itself serves as a concentrated reservoir of both ubiquitous and oligoelement minerals including rare earth elements which are speculated to mediate enhancements in microbial and enteric digestibility, absorption kinetics, and overall gastrointestinal function. The incorporation of specific minerals into diets characterized by rumen-degradable protein (RDP) and non-fiber carbohydrates (NFC) significantly improves both feed digestibility and fermentation efficiency in the rumen, as corroborated by Vigh *et al*. (2023). Sulphur, within this cohort, assumes a key positive role in enhancing rumen microbial metabolism because it activates microbial protein synthesis, a process critical for optimal growth and metabolic stability in ruminants, as articulated by Rosmalia *et al*. (2022). Nutritional equilibria, fortified by the judicious inclusion of key minerals, foster amplified microbial proliferation and confer a concurrent rise in digestibility, the effectiveness of which has been documented in the findings of Hao *et al*. (2018) and Lv *et al*. (2020). These empirical observations lend credence to the hypothesis that the administration of AZM may, through an augmentation of gastrointestinal digestive enzyme activity, increase both proteolytic and amylolytic pathways. Such a metabolic up-regulation would, in turn, antagonistically effect protein and carbohydrate fermentation, ultimately translating into heightened nutrient assimilation and, as a corollary, accelerated growth and enhanced weight gain in male goats.

Carcass performance, including all major primal cuts, was significantly improved in goats supplemented with 0.4% AZM in the diet, with the exception of the spleen, which showed no significant difference. To the best of our knowledge, no studies have been published to date that specifically evaluate the effects of AZM supplementation on carcass characteristics in goats. Our findings are inconsistent with those documented by Pirzado *et al*. (2022), who observed that AZM supplementation in broiler diets enhanced carcass traits, including dressing percentage, breast and leg yields, and organ weights. Similarly, several studies have documented that dietary inclusion of 2–4 g/kg AZM in fish significantly improved body mass and overall growth performance (Azam *et al*., 2016; Batool *et al*., 2018). Moreover, selenium yeast supplementation has been shown to improve carcass weight, dressing percentage, and leg muscle yield in goats (Samo *et al*., 2018). Comparable results were reported by Aghwan *et al*. (2016), who demonstrated that dietary supplementation with a combination of selenium and iodine significantly enhanced carcass weight and dressing percentage in goats. The enhancement in carcass cuts observed with AZM supplementation is likely attributable to improved nutrient bioavailability, which enhances nitrogen retention and amino acid utilization. This, in turn, stimulates muscle protein synthesis and promotes lean tissue accretion, particularly in metabolically active, high-yield regions such as the loin, legs, and shoulder muscles (Yao *et al*., 2024).

The findings indicate that AZM supplementation had no discernible effect on the proximate composition of goat meat, including moisture, crude protein, fat, ash, and pH. However, dietary inclusion of AZM at the 0.4% level markedly improved key functional meat quality attributes (WHC, DL and CL). Our findings are in agreement with those of Zhang *et al*. (2024), who indicated that the use of organic mineral chelates lowered cooking loss (CL) in the meat of sheep. Evidence from Verma *et al*. (2025) corroborates these observations, as their findings shown that mineral supplementation concurrently reduced both cooking loss (CL) and drip loss (DL) in goat meat. However, the study led by Huang *et al*. (2014) reported that the addition of trace minerals shown no notable alteration in either cooking loss (CL) and drip loss (DL) in goat meat. Notably, reductions in cooking loss and drip loss suggest enhanced water retention capacity in the muscle tissue, which is a critical determinant of meat quality during processing and storage and reduces the flavor (Huff-Lonergan and Lonergan, 2005). These improvements may be attributed to the mineral-rich composition of AZM, which potentially contributes to better muscle fiber integrity and postmortem water-binding properties, thereby supporting its application as a functional feed additive in meat-producing goats.

CONCLUSION

Supplementation with AZM at a concentration of 0.4% markedly improved the growth performance of male goats, elevated nutrient digestibility, and enhanced the physicochemical attributes of meat. Thus, the results suggest that the moderate incorporation of AZM is capable of conferring considerable productive advantages in goat production. To establish the robustness of these observations, it is advisable that follow-up trials be conducted with expanded cohorts and prolonged experimental periods.

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NOVELTY STATEMENT

The current study investigates the effect of AZM supplementation on the growth performance, nutrient digestibility and meat quality traits of goats. Although AZM has been studied in poultry, fish and lambs, there is no publication on the effect of AZM on goats. Filling such existing gaps, this study seeks to provide new insights regarding the efficacy of mineral complexes for productivity and carcass attributes and meat quality of small ruminants.

AUTHOR CONTRIBUTION

SAB: Investigation, visualization, software and initial draft of manuscript. SAP: Conceptualization, supervision and review and editing the final. RA: Methodology. MCA: Formal analysis. GSB: Data curation.

Data availability

The data will be made available by the corresponding author on reasonable request.

Generative AI and AI-assisted technology statement

The authors declare that no generative AI and AI-assisted technologies were used in the writing, editing, data analysis, and preparation of manuscript.

Conflict of interest

The authors have declared no conflict of interest.

REFERENCES

Abadi E (2024). Dietary supplementation of zinc oxide nanoparticles and yeast culture: Effect on nutrient digestibility, growth performance, and blood metabolites in Ghanduzi male lambs. Iran. J. Appl. Anim. Sci., 14: 581–589.

Abbasi E (2024). A review of cultural aspects and barriers to the consumption of edible insects. Health Sci. Monit., 3: 179–194. https://doi.org/10.61186/hsm.3.3.179

Abbasi E (2025). Edible insects as a sustainable and innovative approach to addressing global food security and environmental challenges: A comprehensive review. J. Insects Food Feed., 1: 1–12.

Aghwan ZA, Sazili AQ, Kadhim KK, Alimon AR, Goh YM and Adeyemi KD (2016). Effects of dietary supplementation of selenium and iodine on growth performance, carcass characteristics and histology of thyroid gland in goats. Anim. Sci. J., 87: 690–696. https://doi.org/10.1111/asj.12484

Antonius A, Pazla R, Putri EM, Negara W, Laia N, Ridla M and Marta Y (2023). Effectiveness of herbal plants on rumen fermentation, methane gas emissions, *in vitro* nutrient digestibility, and population of protozoa. Vet. World, 16: 1477. https://doi.org/10.14202/vetworld.2023.1477-1488

AOAC International (2000). Official methods of analysis (17th ed.). Gaithersburg, MD: AOAC International.

Azam AR, Khan N and Iqbal KJ (2016). Impact of azomite supplemented diets on the growth, body composition and endogenous enzymes in genetically male tilapia. Pak. J. Zool., 48: 1205–1208.

Batool SS, Khan N, Atique U, Azmat H, Iqbal KJ, Mughal DH and Amjad S (2018). Impact of azomite supplemented diets on the growth and body composition of catfish (*Pangasius hypophthalmus*). Pak. J. Zool., 48: 1205–1208.

Azomite International (2023). Azomite in the News. Available online: https://azomite.com/about-azomite-mineral-products/azomite-in-the-news

Byrne L, Murphy RA (2022). Relative bioavailability of trace minerals in production animal nutrition: A review. Animals, 12: 1981. https://doi.org/10.3390/ani12151981

Fodge D, Rattanagulvaron S, Huong NTM (2011). Making strides in aquaculture with natural trace minerals. Aquac. Asia Pac., 7: 24–25.

He ML, Wehr U, Rambeck WA (2010). Effect of low doses of dietary rare earth elements on growth performance of broilers. J. Anim. Physiol. Anim. Nutr., 94: 86–92. https://doi.org/10.1111/j.1439-0396.2008.00884.x

Hao X, Diao X, Yu S, Ding N, Mu C, Zhao J, Zhang J (2018). Nutrient digestibility, rumen microbial protein synthesis, and growth performance in sheep consuming rations containing sea buckthorn pomace. J. Anim. Sci., 96: 3412–3419. https://doi.org/10.1093/jas/sky201

Honikel KO (1998). Reference methods for the assessment of physical characteristics of meat. Meat Sci., 49:447–457. https://doi.org/10.1016/S0309-1740(98)00034-5

Huang Y, Wang Y, Lin X, Guo C (2014). Effects of supplemental copper on the serum lipid profile, meat quality, and carcass composition of goat kids. Biol. Trace Elem. Res., 159: 140–146. https://doi.org/10.1007/s12011-014-9976-9

Huff-Lonergan E, Lonergan SM (2005). Mechanisms of water-holding capacity of meat: The role of postmortem biochemical and structural changes. Meat Sci., 71: 194–204 https://doi.org/10.1016/j.meatsci.2005.04.022.

Jaleel MA, Musthafa MS, Ali AJ, Mohamed MJ, Kumar MA, Natarajan V, Thiagarajan G (2015). Studies on the growth performance and immune response of koi carp fingerlings

(*Cyprinus carpio koi*) fed with azomite supplemented diet. J. Biol. Nat., 4: 160–169.

Kondaiah N, Anjaneyulu ASR, Rao VK, Sharma N, Joshi HB (1985). Effect of salt and phosphate on the quality of buffalo and goat meats. Meat Sci., 15: 183–192. https://doi.org/10.1016/0309-1740(85)90036-1

Lawler TL, Taylor JB, Finley JW, Caton JS (2004). Effect of supranational and organically bound selenium on performance, carcass characteristics, and selenium distribution in finishing beef steers. J. Anim. Sci., 82: 1488–1493. https://doi.org/10.2527/2004.8251488x

Liu Z, Li K, Zhong R, Chen L, Liu L, Zhang H (2021). Effect of dietary fibre and indigestible markers on the apparent total tract digestibility of gross energy and nutrients, and indigestible marker recovery in diets fed to growing pigs. Arch. Anim. Nutr., 75: 465–473. https://doi.org/10.1080/1745039X.2021.2018922

Liu ManZi LM, Leng XiangJun LX, Li XiaoQin LX, Xiao ChangWu XC, Chen DaoRen CD (2011). Effects of Azomite on growth performance, intestinal digestive enzyme activities and serum nonspecific immune of grass carp (*Ctenopharyngodon idella).* Chin. J. Anim. Nutr., 23: 312–318.

Liu AJ, Leng XJ, Li XQ, Wang LP, Luo YX, Zhu RJ (2009). Effects of azomite on growth, intestinal structure and non-specific immunity of tilapia (*Oreochromis niloticus* × *O. aureus*). China J. Anim. Nutr., 21: 1006–1011.

Lv X, Cui K, Qi M, Wang S, Diao Q, Zhang N (2020). Ruminal microbiota and fermentation in response to dietary protein and energy levels in weaned lambs. Animals, 10: 109. https://doi.org/10.3390/ani10010109

McNaughton J (2011). Effect of Azomite feed grit on swine performance. Available at: http://massamllc.com

Ming Y, Xiu Z, Ming H, Yuan L (1995). Production and physiological effect of rare earth complex added to growing pig diet. In: Proc. 3rd Int. Conf. Rare Earth Dev. Appl., 21–25 August 1995, Baotou, China. Metallurgical Industry Press.

Musthafa MS, Ali ARJ, Mohamed MJ, Jaleel MMA, Kumar MSA, Rani KU, Harikrishnan R (2016). Protective efficacy of azomite enriched diet in *Oreochromis mossambicus* against *Aeromonas hydrophila*. Aquaculture, 451: 310–315. https://doi.org/10.1016/j.aquaculture.2015.09.006

Ockerman HW (1985). Quality control of post-mortem muscle tissue. Dept. Anim. Sci., Ohio State University, 3: 65–70.

Ou X, Guo Z, Wang J (2000). The effects of rare earth element additive in feed on piglets. Livest. Poult. Ind., 4: 21–22.

Pazla R, Jamarun N, Zain M, Arief M (2018). Microbial protein synthesis and *in vitro* fermentability of fermented oil palm fronds by phanerochaete chrysosporium in combination with tithonia (*Tithonia diversifolia*) and elephant grass (*Pennisetum purpureum*). Pak. J. Nutr., 17: 462–470. https://doi.org/10.3923/pjn.2018.462.470

Pirzado SA, Zhengke W, Purba A, Cai H, Guilan C, Liu G (2022). Effect of azomite on growth performance, nutrient retention, immunity and bone mineralization of broiler chickens. Pak. J. Zool., 54: 737–744. https://doi.org/10.17582/journal.pjz/20200130040147

Pirzado SA, Arain MA, Huiyi C, Fazlani SA, Alagawany M, Gouhua L (2021). Effect of azomite on growth performance, immune function and tibia breaking strength of broiler chickens during starter period. Anim. Biotechnol., 33: 1539–1544. https://doi.org/10.1080/10495398.2021.1914644

Pirzado SA, Hassan FU, Arain MA, Zhengke W, Huiyi C, Haile TH, Guohua L (2021). Effect of azomite on growth performance, nutrient utilization, serum biochemical index and bone mineralization of broilers fed low protein diet. Ital. J. Anim. Sci., 20: 1282–1291. https://doi.org/10.1080/1828051X.2021.1953409

Pirzado SA, Zhengke W, Jiao L, Zheng A, Guohua L (2020). Effect of azomite with low energy diet on growth, carcass performance and blood biochemical indexes in broiler chickens. J. Aquacult. Livest. Prod., SRC/JALP-105. https://doi.org/10.17957/IJAB/15.1465

Pirzado SA, Zakria M, Tariq M, Baloch MH, Kalhoro DH, Laghari IH, Lagari RA (2016). Effect of different levels of protein diets on growth performance and carcass yield of Pateri male goat kids. Pure Appl. Biol. (PAB*)*, 5: 1200–1206. https://doi.org/10.19045/bspab.2016.50144.

Putri EM, Zain M, Warly L, Hermon H (2021). Effects of rumen-degradable-to-undegradable protein ratio in ruminant diet on *in vitro* digestibility, rumen fermentation, and microbial protein synthesis. Vet. World, 14: 640–648. https://doi.org/10.14202/vetworld.2021.640-648

Qureshi BA, Rajput AUH, Pirzado SA, Baloch ZA, Qureshi MA, Abbas U (2024). Effect of low protein diets with supplementation of *Bacillus pumilus* on growth and carcass performance, haematological and biochemical indices of broiler chicken. Int. J. Biol. Biotechnol., 21: 307–316.

Rosmalia A, Permana IG, Despal D (2022). Synchronization of rumen degradable protein with non-fiber carbohydrate on microbial protein synthesis and dairy ration digestibility. Vet. World, 15: 252. https://doi.org/10.14202/vetworld.2022.252-261

Samarin AA, Norouzian MA, Afzalzadeh A (2022). The effect of trace mineral source on nutrients digestibility and ruminal fermentation parameters. Iran. J. Appl. Anim. Sci., 12: 281–286.

Samo SP, Malhi M, Gadahi J, Kaciwal AB, Soomro SA (2018). Effect of organic selenium supplementation in diet on gastrointestinal tract performance and meat quality of goat. Pak. J. Zool., 50: 995–1001. https://doi.org/10.17582/journal.pjz/2018.50.3.995.1003

Sen AR, Santra A, Karim SA (2004). Carcass yield, composition and meat quality attributes of sheep and goat under semiarid conditions. Meat Sci., 66: 757–763. https://doi.org/10.1016/S0309-1740(03)00035-4

Sharif M, Hanif AR, Shahid MS, Ahmad S, Bilal MQ, Riaz M, Khalid MF (2022). Effects of dietary substitution of canola meal with yeast fermentative biomass on growth performance, blood metabolites, haematological index and serum minerals in buffalo male calves. Res. Square, pp. 1–19 https://doi.org/10.21203/rs.3.rs-1437114/v1.

Sheoran, (2017). Organic minerals in Poultry. Adv. Res., 12(3): 1-10

Tan CG, Li XQ, Leng XJ, Su XG, Chen L, Liu B and Guo T (2014). Effects of supplemental Azomite in diets on growth, immune function and disease resistance of white shrimp (*Litopenaeus vannamei*). Aquacult. Nutr., 20: 324–331. https://doi.org/10.1111/anu.12081

Thamizhan P, Jadhav SE, Jadhav PS, Chaudhary P, Choubey PK, Singh VK, Dutta N (2024). Influence of select dietary trace minerals and their levels on growth performance, nutrient utilization and mineral balance in male goats. Biol. Trace Elem. Res., 202: 3097–3106. https://doi.org/10.1007/s12011-023-03915-6

Van Soest PV, Robertson JB, Lewis BA (1991). Methods for dietary fiber, neutral detergent fiber, and nonstarch polysaccharides in relation to animal nutrition. J. Dairy Sci., 74: 3583–3597. https://doi.org/10.3168/jds.S0022-0302(91)78551-2

Vatankhah S, Ebrahimi M, Taghizadeh A, Asadpour R (2025). Impacts of trace minerals supplementation on reproductive performance and blood parameters of Ghezel ewes. Iran. J. Appl. Anim. Sci., 15: 49–60.

Verma AK, Rajkumar V, Kumar R, Gururaj K, Singh TP, Kushwah T, Chatli MK (2025). Impact of dietary mineral and vitamin supplementation on meat quality and nutritional profile and gene expression in goats. Eur. J. Lipid Sci. Technol., 127: e70005. https://doi.org/10.1002/ejlt.70005

Vigh A, Criste AD, Corcionivoschi N, Gerard C (2023). Rumen solubility of copper, manganese and zinc and the potential link between the source and rumen function: A systematic review. Agriculture, 13: 2198. https://doi.org/10.3390/agriculture13122198

Vizcarra-Chávez CA, Urías-Estrada JD, Ponce-Barraza E, Estrada-Angulo A, Arteaga-Wences YJ, Castro-Pérez BI, 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: 3018. https://doi.org/10.3390/ani14203018

Wan Q, Tian J, Peng H, Zhang X, Lee D, Woo C, Ryu J, Park C (1998). The effects of rare earth on increasing yield, improving quality and reducing agricultural chemical remained in crop production. Proc. 2nd Int. Symp. Trace Ele. Fd. Chain, Wuhan, China, pp. 15–25.

Wardlaw FB, McCaskill LH, Acton JC (1973). Effect of postmortem muscle changes on poultry meat loaf properties. J. Food Sci., 38: 421–423. https://doi.org/10.1111/j.1365-2621.1973.tb01444.x

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 Immunol., 108: 53–62. https://doi.org/10.1016/j.fsi.2020.11.016

Yao M, Chang L, Xu S, Zhang J, Li P, Tian B, Zou X (2024). Comparison of production performance and meat quality characteristics between Guizhou Black goats and F4 generation hybrids of South African Kalahari goats. Sci. Rep., 14: 18608. https://doi.org/10.1038/s41598-024-69174-0

Zain M, Tanuwiria UH, Syamsu JA, Yunilas Y, Pazla R, Putri EM, Bagaskara B (2024). Nutrient digestibility, characteristics of rumen fermentation, and microbial protein synthesis from Pesisir cattle diet containing non-fiber carbohydrate to rumen degradable protein ratio and sulfur supplement. Vet. World, 17: 672. https://doi.org/10.14202/vetworld.2024.672-681

Zakria M, Leghari IH, Rajput N, Soomro SA, Pirzado SA (2025). Assessing the effect of dietary protease supplementation with low amino acid diet on growth, gut enzyme activity, immunity, meat quality and bone morphometry in broiler chicken. J. Anim. Health Prod., 13: 572–582. https://doi.org/10.17582/journal.jahp/2025/13.3.572.582

Zhang Y, Huang H, Chang WT, Li X, Leng X (2023). The combined supplementation of Azomite and citric acid promoted the growth, intestinal health, antioxidant, and resistance against *Aeromonas hydrophila* for largemouth bass (*Micropterus salmoides*). Aquacult. Nutr., 2023: 5022456. https://doi.org/10.2139/ssrn.4512961

Zhang N, Teng Z, Qi Q, Hu G, Lian H, Gao T (2020). Carcass traits, meat quality characteristics, and lipid metabolism-related gene expression pattern of Yaoshan white goats raised in traditional extensive production system: Effects of slaughter age and meat cuts. Small Rumin. Res., 182: 29-36. https://doi.org/10.1016/j.smallrumres.2019.11.004.

Zhang R, Wei M, Zhou J, Yang Z, Xiao M, Du L, Bao H (2024). Effects of organic trace minerals chelated with oligosaccharides on growth performance, blood parameters, slaughter performance and meat quality in sheep. Front. Vet. Sci., 11: 1366314. https://doi.org/10.3389/fvets.2024.1366314