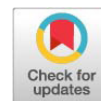


Research Article



The Role of Micro-Organic Minerals (Zn, Cu, Se, and Cr-lysinate) in Enhancing Feed Utilization and Productive Performance of Etawa Goats

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Abstract | The use of micro-organic minerals in ruminant nutrition has gained attention due to their higher bioavailability and potential to improve animal performance and nutrient utilization. This study aimed to determine the effects of micro-organic mineral supplementation zinc (Zn-lysinate), copper (Cu-lysinate), selenium (Se-lysinate), and chromium (Cr-lysinate) on growth performance and nutrient digestibility in Etawa crossbreed goats. Fifteen male goats (body weight 17–33 kg) were randomly assigned to five dietary treatments: R0 (basal ration), R1 (basal + 40 ppm Zn-lysinate), R2 (basal + 10 ppm Cu-lysinate), R3 (basal + 0.1 ppm Se-lysinate), and R4 (basal + 0.3 ppm Cr-lysinate). The measured parameters included average daily gain (ADG), feed intake, feed conversion ratio (FCR), and digestibility of dry matter (DMD), organic matter (OMD), crude protein (CPD), crude fiber (CFD), and total digestible nutrients (TDN). Nutrient digestibility was assessed using the total fecal collection method. The results demonstrated that supplementation with micro-organic minerals had a significant ($P < 0.05$) effect on ADG, FCR, OMD, and CFD, while there was no significant effect ($P > 0.05$) on feed intake, DMD, CPD, fat digestibility, or TDN. Among all treatments, the group receiving Cr-lysinate (R4) exhibited the best performance, indicated by the highest ADG, lowest FCR, and superior OMD and CFD values compared to the other treatments. Supplementation of 0.3 ppm Cr-lysinate in the ration improves growth performance and enhances fiber and organic matter digestibility in Etawa crossbreed goats.

Keywords | Performance, Nutrient digestibility, Microorganic minerals, Etawa Goats, Feed utilization, Supplementation

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INTRODUCTION

Previous studies have shown that various factors, both internal and external, influence livestock productivity. The feed factor cannot be denied to be an important factor in supporting livestock productivity. Feed is needed by

livestock for basal needs, for growth, and for production. The quality of feed, of course, must meet the needs of livestock. Therefore, the nutrient content in feed must meet the needs of livestock in order to be able to support basic needs, growth, and production. Feeding for ruminants ranges from 3% to 4% of body weight in order to meet their

daily needs (Ahmad *et al.*, 2020). Goats are small ruminants that are widely available in Indonesia. Utilization of goats in Indonesia as a source of animal protein food for the community. This is of course what needs to be a concern so that the fulfillment of feed needs for goats must be met. Nutrients needed by livestock consist of carbohydrates, proteins, fats, vitamins, and minerals. The balance of these components must be considered so that the feed given to livestock is able to support livestock productivity. Akinmoladun *et al.* (2021) state that the amount of nutrient content in the feed will mutually affect the performance of other nutrients in the body of the livestock that consumes it. This means that all nutrient components must be met, even though it is necessary to add supplementary feed.

Minerals are essential nutrients for livestock as well as for goats. Minerals consist of macro and micro minerals. Macro minerals are needed in large amounts, while micro minerals are needed in small amounts. Al-Arif *et al.* (2017) stated that the mineral is very important for goats that are lactating and pregnant. Organic minerals can be grouped into a form called "protein minerals". Protein minerals can be defined as minerals that have undergone a chemical process into mineral chelates and amino acids, so that they can increase the production of ruminants. Free forms of macro and micro minerals in the digestive tract of livestock can interact positively or negatively with fat, protein, or other organic materials, so that these minerals will be excreted with feces. This causes the animal's body to lack minerals in the body. Microminerals consist of Zn, Cr, Cu, and Se (Cunniff and Washington, 1997; Silva *et al.*, 2021). This mineral may also be needed in the mechanism of absorption of food substances in the digestive tract. Therefore, using minerals in the form of organic minerals is expected to increase the digestibility of food substances and the implications for the performance of Etawa crossbreed goats which include average daily gain (ADG), consumption of ration, and feed conversion. Provision of minerals in inorganic form due to the interaction of minerals with materials in the digestive tract can cause insufficient mineral needs in the body of livestock. This interaction can be avoided if minerals and organic binders bind first before being consumed by livestock and entering the body of livestock. Giving organic minerals will increase mineral absorption so that mineral availability can be maintained.

Minerals play an important role in the metabolic process of the livestock body. The micro mineral that plays a role in the formation of hemoglobin is iron ion (Fe). Another mineral that is no less important is the copper ion (Cu), which plays a role in the formation of hemoglobin, pigment, and as a coenzyme. Other micro minerals, such as cobalt ion (Co) help absorb vitamin B12 and are important

for microbial growth in the rumen. Zn minerals also play a role for rumen microbes by increasing rumen microbial activity. The addition of Zn in feed also helps activate rumen microbial enzymes so that it can accelerate protein synthesis. Cu minerals also have an important role as a catalyst for metalloprotein enzymes because these enzymes contain Cu. The mineral Cr has an important role in the process of fat synthesis, protein metabolism, and nucleic acid. With the addition of organic minerals in the ration, it is hoped that it will affect average daily gain (ADG), so that it can produce high meat production. The amount of mineral supply must be appropriate and sufficient, excessive mineral supply will interfere with livestock health.

Micro-minerals such as Zn, Cu, Se, and Cr are particularly important for ruminants. Zinc plays a key role in enzyme activation and rumen microbial function (Lima *et al.*, 2019), copper is involved in hemoglobin synthesis and oxidative metabolism (Yanuartono *et al.*, 2016), selenium functions as an antioxidant component of glutathione peroxidase (Hendawy *et al.*, 2022), and chromium enhances insulin activity and nutrient metabolism (Spears *et al.*, 2017). Supplementation with these minerals in organic form has been shown to improve growth performance, feed efficiency, and nutrient digestibility in goats (Raguati, 2012; Yulianti *et al.*, 2019).

Therefore, this study aimed to determine the effects of micro-organic mineral supplementation zinc (Zn-lysinate), copper (Cu-lysinate), selenium (Se-lysinate), and chromium (Cr-lysinate) on growth performance and nutrient digestibility in Etawa crossbreed goats.

MATERIALS AND METHODS

RESEARCH IMPLEMENTATION PROCEDURES

ANIMALS

A total of 15 male Etawa Crossbreed goats with different body weights were divided into three categories, namely five goats with low weight (14–20 kg), medium weight (21–28 kg), and heavy weight (29–38 kg) were used in this experiment. The rations used consisted of cassava leaf silage (from the east Lampung area), corn leaf silage, coconut cake, cassava, fine bran, soybean meal, organic minerals (Zn, Cu, Se, and Cr), and lysine.

FEEDS

Goats are given a basal ration with the composition of the ration consisting of silage from cassava leaves, corn leaves, soybean meal, cassava, fine bran, and oil palm cake. The nutrient content of the feed ingredients can be seen in Table 1. The nutrient content of feed ingredients and rations was analyzed using the proximate method (Cunniff and Washington, 1997).

Table 1: Content of ingredients for basal ration.

Feed Stuff	Nutrient content (%)*					
	DM	CP	EE	CF	Ash	NFE
Cassava leaf silage	95.17	20.52	12.25	13.61	10.91	37.89
Corn leaf silage	96.17	13.27	7.75	15.66	17.83	41.66
Cassava pulp	87.41	1.25	1.04	14.53	6.32	76.86
Rice bran	84.49	10.00	10.51	12.08	5.95	61.46
Soybean meal	86.00	36.87	3.08	14.06	8.18	37.81
Palm oil meal	93.03	16.7	14.64	22.82	4.03	41.81
Molasses	43.69	3.94	0.30	0.40	11.00	84.36

*Results of analysis at the Nutrition and Animal Feed Laboratory. DM: Dry Matter, CP: Crude Protein, EE: Ether Extract, CF: Crude Fiber, NFE: Nitrogen Free Extract.

At the preparation stage of cassava leaf silage, what must be done is to prepare cassava leaves to be made into silage. First, the cassava leaves in the chopper are then dried to reduce the water content. After the ingredients are ready then mix the with EM4. EM4 is a microorganism fermented from organic materials that are yellowish brown in color in liquid form. After being mixed with EM4, it is stored anaerobically by compacting and tightly closed in a silo so that no air enters and good fermentation results are obtained. The fermentation process lasts for 21 days, after which it can be used for animal feed. The rations are arranged according to the nutritional needs of the Etawa crossbreed goats. Feed nutritional requirements refer to Atmojo and Indarto (2019) and Silva *et al.* (2021). The table of the composition of the ration used and the nutrient content of the ration can be seen in Table 2.

Table 2: Composition and nutrient content of basal ration.

Feed stuff	Com- position %	DM	CP	EE	CF	Ash	NFE
Cassava leaf silage	15	14.28	3.08	1.84	2.04	1.64	5.68
Corn leaf silage	15	14.43	1.99	1.16	2.35	2.67	6.25
Cassava pulp	32	27.97	0.40	0.33	4.65	2.02	24.60
Rice bran	8	6.76	0.80	0.84	0.97	0.48	4.92
Soybean meal	10	8.60	3.69	0.31	1.41	0.82	3.78
Palm oil meal	15	13.95	2.51	2.20	3.42	0.60	6.27
Molasses	5	2.18	0.20	0.02	0.02	0.55	4.22
Total	100	88.17	12.66	6.69	14.86	8.78	55.72

*Results of analysis at the Nutrition and Animal Feed Laboratory. DM: Dry Matter, CP: Crude Protein, EE: Ether Extract, CF: Crude Fiber, NFE: Nitrogen Free Extract.

EXPERIMENTAL DESIGN

Research preparation was carried out by preparing the feed and preparing the cages. Before taking the research data, the feed adaptation was carried out for 7 days. The

maintenance system is carried out in individual cages. Feeding is done twice a day, in the morning and evening.

The feeding treatments in this study were:

R0: Basal Ration

R1: Basal Ration + 40 ppm Organic Mineral Zn lysinate

R2: Basal Ration + 10 ppm Organic Mineral Cu lysinate

R3: Basal Ration + 0.1 ppm Organic Mineral Se lysinate

R4: Basal Ration + 0.30 ppm Organic Mineral Cr lysinate

DATA RETRIEVAL

The variables studied included average daily gain (ADG), feed consumption, feed conversion, dry matter digestibility, organic matter digestibility, crude protein digestibility, and crude fiber digestibility. Average daily gain (ADG) was obtained from the difference between the final body weight and the initial body weight. The consumption of ration was obtained by calculating the amount of feed given minus the remaining feed the next day. Feed conversion is the amount of feed consumed per day divided by the daily live weight gain. The method of determining the digestibility used is the total collection method (Van Emon *et al.*, 2020; Akhadiarto *et al.*, 2025). Stool collection was carried out every day for 7 days by taking and separating the feces according to the treatment and weighing the amount of feces produced. Stool collection was taken for 24 hours within 7 days.

STATISTICAL ANALYSIS

The data generated from this study were analyzed using analysis of variance (ANOVA) in IBM SPSS statistics 2021 version. The analytical design used was a randomized block design with grouping based on body weight. Livestock is considered a random factor in the model. The results obtained if significantly different will be continued with further testing. Further analysis using the Least Significant Difference (LSD) test was applied to evaluate the differences between the three groups tested for ANOVA. $P = 0.05$ and 95% confidence intervals were used to reveal statistical significance.

RESULTS AND DISCUSSION

AVERAGE DAILY GAIN

The quality of feed consumed by livestock is evident from the increase in average daily gain (ADG) (Ahmad *et al.*, 2020). Feed that is digested in the body of livestock is utilized by the body for basic needs, growth, and production. ADG refers to the daily increase in weight of livestock, resulting from the consumption of food substances (Al-Arif *et al.*, 2017). The results of analysis of variance showed that feed ingredients with the addition of different organic micro-minerals in male PE goats had a significant effect on ADG ($P < 0.05$), which can be seen in Table 3.

Table 3: Feed intake, average daily gain, feed conversion, and nutrient digestibility of Etawa crossbreed goats fed with and without the addition of minerals Zn, Cu, Se and Cr.

Parameters	Treatments				
	R0	R1	R2	R3	R4
Feed intake (g/head/day)	1506.67±87.37	1403.33±136.14	1620±95.39	1480±72.11	1676.67±111.51
Average daily gain (g/head/day)	133.33±25.17 ^a	66.67±25.17 ^a	123.33±57.74 ^a	96.67±28.87 ^a	176.67±45.09 ^b
Feed conversion	11.49±1.49 ^a	22.91±7.48 ^b	14.86±5.63 ^a	16.10±4.04 ^a	9.83±1.92 ^a
Dry matter digestibility (%)	71.87±3.30 ^a	70.72±4.32 ^a	71.16±2.99 ^a	71.00±5.88 ^a	72.51±4.99 ^a
Organic matter digestibility (%)	75.63±4.02 ^{bc}	73.71±4.57 ^{ab}	75.57±3.11 ^c	73.63±4.80 ^a	75.99±4.12 ^c
Crude fiber digestibility (%)	33.23±1.09 ^a	45.66±9.48 ^b	40.60±7.77 ^a	41.42±12.51 ^a	45.62±9.84 ^b
Crude protein digestibility (%)	73.33±4.01	74.55±3.97	73.29±3.89	74.21±4.12	74.86±4.07
Ether extract digestibility (%)	42.42 ± 12.16 ^a	43.79 ± 2.05 ^a	39.20 ± 8.23 ^a	49.33 ± 1.38 ^a	48.65 ± 1.19 ^a
Total digestible nutrients (TDN, %)	68.37 ± 3.89 ^a	65.29 ± 2.17 ^a	67.12 ± 1.40 ^a	66.38 ± 1.82 ^a	66.84 ± 2.20 ^a

^{a,b,c} Different superscripts in the same row showed significant differences ($P<0.05$). R0: Basal Ration; R1: Basal Ration + 40 ppm organic mineral Zn lysinate; R2: Basal Ration+ 10 ppm organic mineral Cu lysinate; R3: Basal Ration + 0.1 ppm organic mineral Se lysinate; R4: Basal Ration + 0.30 ppm organic mineral Cr lysinate.

Table 3 shows that there is a significant effect of giving minerals Zn, Cu, Se, and Cr to the ADG of Etawa crossbreed without the addition of minerals and with the addition of minerals. Based on the least significant difference (LSD) analysis of the four treatments in this study, the R4 treatment ratio, namely the addition of Cr minerals, gave a good response compared to the R0, R1, R2, and R3 treatments. This is because the palatability level in the R4 treatment was higher, and the ration consumed could be digested properly, so as to increase the ADG of the goats. According to [Kenny *et al.* \(2018\)](#), the treatment R2 supplemented with organic chromium yielded significantly better results in average daily gain was caused by reducing energy loss during methanogenesis through the presence of allicin, an anti-methanogenic compound. Organic chromium supplementation increased ruminal NH_3 production, total VFA, and the proportion of propionate ([Rodríguez-Rodríguez *et al.*, 2022](#)), as well as enhanced microbial energy utilization efficiency, thereby improving feed digestibility ([Tahuk *et al.*, 2023](#)). Furthermore, rumen fermentation was shifted toward greater propionate production ([Rodjan *et al.*, 2018](#)). Organic chromium, in the form of a glucose tolerance factor, activates insulin, which facilitates the transport of glucose and amino acids into cells, serving as precursors for protein (meat) synthesis ([Moreira *et al.*, 2020](#); [Mattos Pereira and Neir, 2024](#)).

In the R4 treatment, there was an increase in consumption of ration so that the weight gain of the R4 treatment goats also increased. This is based on the opinion of [Hendawy *et al.* \(2021\)](#) and [Makkar \(2016\)](#) that the large amount of rations consumed indicates an increase in the amount of nutrients absorbed for basic life needs, production, and reproduction, which in turn causes increased growth. According to ADG is influenced by several factors ([Kenny *et al.*, 2018](#)), namely the total protein obtained every day,

gender, age, genetic conditions, environment, individual conditions, and management.

CONSUMPTION OF RATION

The results of the analysis of variance in this study showed that the administration of micro-organic minerals had no significant effect ($P>0.05$) on ration consumption ([Table 3](#)). This is because the livestock obtains the required nutrients sufficiently from the rations given in the same amount, so that micro-organic mineral supplements have no significant effect on the amount of livestock consumption in each treatment. The results showed that the addition of 0.30 ppm of Cr mineral in the ration had a high consumption rate compared to other treatments. Consumption of rations is the amount of food consumed by livestock when given ad libitum within a certain period of time. Livestock consume rations to meet the needs of nutrients for production and reproduction ([Makkar, 2016](#); [Davis and White, 2020](#)). Feed palatability is one of the factors that affect the amount of feed consumption and the ability of livestock to consume crude protein contained in feed ingredients, related to the physical capacity of the stomach and the condition of the digestive tract, so that the level of feed consumption in ruminants is strongly influenced by environmental factors, livestock conditions, and feed factors. The palatability of the ration is determined by the taste, smell, and color of the forage ([Lima *et al.*, 2019](#)).

FEED CONVERSION RATIO

Based on the results of the calculation of the analysis of variance in this study, it was found that the provision of organic micro minerals had a significant effect ($P<0.05$) on feed conversion ratio (FCR). The R1 treatment had the highest feed conversion value, while the lowest conversion value was in the R4 treatment. The high and low rates of

FCR are due to a higher or lower difference in the ratio of feed consumption and ADG. The R4 treatment had the lowest conversion value of 9.83 ± 1.92 , accompanied by an increase in ADG of 16.8 (Table 3).

The lower the FCR value, the higher the efficiency level of ration utilization by livestock because FCR is calculated based on the ratio of the dry matter of the ration consumed to the daily weight gain. The most efficient feed in the utilization of rations by livestock was characterized by the lowest FCR (Nathaniel *et al.*, 2021; Mayulu and Topan, 2022). The R4 treatment had the lowest conversion value. Feed conversion is strongly influenced by livestock conditions, livestock digestibility, gender, nation, quality and quantity of feed, as well as environmental factors. FCR is influenced by feed quality, so that the increase in digestibility value and the efficiency of nutrient utilization in metabolic processes in the animal's body tissues are influenced by the better quality of feed consumed by livestock (Empel *et al.*, 2016; Cantalapiedra-Hijar *et al.*, 2018).

NUTRIENT DIGESTIBILITY

Digestibility of feed ingredients depends on the rate of movement of food in the digestive tract, while the rate of food is influenced by the type of food consumed. Digestibility of feed that can be observed includes the digestibility of dry matter, organic matter, crude protein, ether extract, and crude fiber (NRC, 2007; Gurung, 2020).

DRY MATTER DIGESTIBILITY

As shown in Table 3, the analysis of variance showed that the treatment rations had no significant effect ($P > 0.05$) on dry matter digestibility (DMD). The highest DMD was observed in the R4 treatment (72.42%), slightly higher than the control R0 (72.18%) and other treatments. Overall, DMD values for both the basal and treatment rations ranged from 70.72% to 72.51%, which is comparable to previous findings (Jiwuba *et al.*, 2021; Khejornsart *et al.*, 2022). According to Phesatcha *et al.* (2021), average DMD values for diets supplemented with forage protein sources range from 69.69% to 76.91%. This indicates that the basal ration used in this study already had good digestibility (71.87%), even without supplementation of organic trace minerals (Zn lysinate, Cu lysinate, Se lysinate, and Cr lysinate).

The results showed that there was no difference in the treatment results between R0 and R1, R2, R3, and R4 against DMD. This indicates that the organic micro-minerals in the ration have met the needs of livestock before and after addition. This could also be caused by the lack of mineral administration of Zn lysinate, Ce lysinate, and Cr lysinate (40 ppm, 0.1 ppm, and 0.3 ppm) in accordance with the opinion (Katongole and Yan, 2020), which states

that the provision of Zn minerals needs to be carried out with consideration to meet requirements for ruminants. The addition of organic micro minerals (Zn, Cu, Cr, and Se) in the diet resulted in higher dry matter and organic matter digestibility values compared to the diet without microorganic minerals. This can also be suspected because the mineral Cr lysinate gave a good effect on the ration feed, so that the R4 treatment (72.42%) gave a higher dry matter digestibility than the other treatments. These results indicate that the dose of microorganic minerals can still be used properly by livestock to increase the growth and activity of rumen microbes, so that the dry matter digestibility of the ration can increase (Gendley, 2015; Mion *et al.*, 2022).

ORGANIC MATTER DIGESTIBILITY

The analysis of variance revealed a significant effect ($P < 0.05$) of the treatment rations on organic matter digestibility (OMD), which ranged from 73.63% to 75.99% (Table 3). The highest OMD was recorded in the R4 treatment (75.99%), followed by R2 (75.57%), both of which were higher than the control R0 (75.34%). Several studies have demonstrated that Cr supplementation can positively modulate OMD under specific conditions. Arief *et al.* (2021) and Rezapour *et al.* (2024) reported that the combination of probiotics with organic chromium significantly improved OMD (51.96%) compared to the control (48.98%), accompanied by a shift in volatile fatty acid (VFA) profile towards higher propionate proportion. Similarly, Kenny *et al.* (2018) observed that chromium-methionine supplementation enhanced dry matter digestibility in Tan sheep, which is typically associated with improved organic matter utilization.

This shows that the increase in dry matter digestibility of the ration is always accompanied by the organic matter digestibility of the ration. Iqbal and Iqbal (2015) stated that organic matter is part of dry matter, so that when dry matter increases, organic matter increases and vice versa. Therefore, this will also apply to the digestibility value if the dry matter digestibility increases, of course, the organic matter digestibility also increases. Widiyono and Anggraini (2019) which states that the ability to digest food is determined by several factors, such as the type of livestock, the chemical composition of the feed, and the storage of the feed. The digestibility of a feed ingredient depends on the compatibility of the food substances contained therein (Spears *et al.*, 2017).

CRUDE PROTEIN DIGESTIBILITY

The results of the analysis of variance showed that the treatment ration had no significant effect ($P > 0.05$) on crude protein digestibility (CPD; Table 3). CPD has a range of 73.29% to 74.86% with a protein ratio of 13.97%. Warly and Kawamura (2019) and Rodríguez-Rodríguez

et al. (2022) explain that the digestibility of crude protein can be seen from the amount of crude protein lost in the digestive process, which can also indicate the amount of crude protein that is digested and absorbed for metabolism. The greater the digestibility of crude protein, the more nutrients are absorbed and utilized by livestock. An increase in crude protein consumption is the same as an increase in nitrogen consumption, because nitrogen is a constituent of crude protein (Tahuk *et al.*, 2023). However, in the research conducted, consumption of ration did not significantly affect the digestibility value of crude protein. This is presumably because organic mineral supplements did not significantly affect the amount of livestock consumption in each treatment, so that the consumption of crude protein also did not have a significant effect on the digestibility of crude protein. Zn supplementation can accelerate protein synthesis by microbes by activating microbial enzymes. Zn is absorbed through the mucosal surface of the rumen tissue (Katongole and Yan, 2020; Abdullah and Cakrawati, 2023). Similarly, Kenny *et al.* (2018) observed that supplementation with chromium-methionine significantly enhanced nitrogen retention and digestibility in Tan sheep, supporting the role of organic Cr in improving protein metabolism.

ETHER EXTRACT DIGESTIBILITY

The results of the analysis of variance showed that the treatment ration had no significant effect ($P > 0.05$) on ether extract digestibility (EED; Table 3). The digestibility of a feed ingredient also depends on the compatibility of the food substances contained in it, which is known as the association effect. If the EE value is low, the EED value is high (Barbosa *et al.*, 2017). Fat is an important component of animal feed and is often added to increase the density obtained by livestock without increasing the acid load in the rumen. The addition of vegetable and fish oil or high-fat ingredients can sometimes cause problems in the rumen, including: toxicity of fatty acids to some rumen bacteria, formation of trans fatty acids and suppression of milk production, and binding of minerals, thereby reducing the availability of minerals for bacterial growth and rumen function (Kumar *et al.*, 2020; Abdullah and Cakrawati, 2023). Minerals play an important role in the physiological processes of livestock, both for growth and maintenance of health. Zn deficiency due to low content in feed is often classified as severe, moderate, and mild deficiency. Zn deficiency in animals causes delayed growth due to a lack of use of protein and mineral S. The low availability of Zn in feed was also caused by the high content of other minerals that were antagonistic, such as Ca, P, and Cu (Yi *et al.*, 2018). Ruminant goats (beef goats or dairy goats) given forage containing Zn (18 to 23 mg/kg) were deficient in Zn, meaning that forage containing 23 ppm Zn, the availability of Zn was low, so it was

suggested that the demand for beef goats and dairy goats would be low. Zn was 30 and 40 mg/kg ration, respectively (Katongole and Yan, 2020).

Mayulu and Topan (2022) said that supplementation of trace minerals such as Zn, Cu, Fe, Se, Mn, Co, and Cr in organic form enhances their bioavailability, thereby supporting ruminal and post-ruminal metabolic processes. Adequate mineral supply is crucial for optimizing microbial activity and nutrient utilization. Organic mineral supplementation, particularly Zn and Cr, has been shown to improve microbial metabolism and population in the rumen, which subsequently enhances overall nutrient digestibility, including crude fat digestibility

CRUDE FIBER DIGESTIBILITY

The effect of giving organic micro-minerals in the rumen to crude fiber digestibility (CFD) had a significant effect ($P < 0.05$) on the CFD of male PE goats (Table 3). CFD of goats feed R0 (33.23%) treatment increased R2 (40.60%), R3 (41.42%), R4 (45.62%), and R1 (45.66%). Several studies have reported positive responses. Rodríguez-Rodríguez *et al.* (2022) found that supplementation of chromium-methionine (Cr-Met) in Tan sheep improved nutrient digestibility, including crude fiber, when fed on a basal roughage diet. The increase in CFD was accompanied by improved dry matter and protein digestibility, suggesting that Cr enhanced microbial utilization of structural carbohydrates. Similarly, Yanuarianto *et al.* (2021) reported that the addition of probiotics combined with organic Cr increased fiber degradability in vitro compared to the control, supported by a shift in ruminal fermentation toward higher propionate production.

Supplementation of Zn in the diet, both in organic and inorganic compounds, is to activate several hormones and enzymes related to metabolism and reproductive function of livestock. Improving the quality of feed and Zn supplementation can increase the pH of the rumen fluid from 7 to 8 (alkaline), with the highest pH found in improving the quality of feed supplemented with Zn-acetate (Al-Arif *et al.*, 2017). The main absorption of Zn occurs in the small intestine. In ruminants, one-third of oral Zn is absorbed in the abomasum, but the major absorption site is the small intestine, and the most active in the duodenum. Zn absorption is influenced by the amount and balance of other minerals as well as the content of Zn in the ration and the form of Zn absorbed (Katongole and Yan, 2020). Selenium (Se) is a trace mineral commonly used as a supplement to regulate animal metabolism. Administration of Se to goats during late gestation improves antioxidant status and immune response after calving (Arief *et al.*, 2021).

CONFLICT OF INTEREST

The authors have declared no conflict of interest.

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Based on the results of this study, it can be concluded that supplementation of organic trace minerals (Zn, Cu, Se, and Cr) in the diet had a significant effect on ADG, FCR, OMD, and CFD of male Etawa crossbred goats. However, it had no significant effect on feed intake, DMD, and CPD.

Supplementation of 0.03 ppm Cr-based organic mineral in the ration (R4) produced the best performance in male Etawa crossbred goats, yielding the highest ADG and the lowest feed conversion ratio compared to other organic trace minerals (Zn, Cu, and Se). It also resulted in higher OMD and CFD than other treatments.

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NOVELTY STATEMENT

This study provides updated insights into the bioavailability of organic trace minerals compared to conventional inorganic forms in tropical forage or waste-based feeds. The novelty lies in demonstrating that precision dosing of Zn, Cu, Se, and Cr-lysinate supplementation significantly reduces the feed conversion ratio (FCR) and enhances nutrient digestibility in Etawa goats.

AUTHOR'S CONTRIBUTION

All authors are equally sharing.

ETHICAL APPROVAL

All experimental procedures involving animals were conducted in accordance with the guidelines for the care and use of laboratory/experimental animals established by the Government Regulation of the Republic of Indonesia. The experimental protocol was reviewed and approved by the Animal Ethics Committee of the Faculty of Agriculture, Universitas Lampung, Indonesia (Approval No.: [001/UNILA/KEH/EC/2018]).

GENERATIVE AI AND AI ASSISTED TECHNOLOGY STATEMENT

The authors declare that no generative AI and AI assisted technology was used in the creation of this manuscript.

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