# Effects of Three Zinc Sources on Growth Performance and Milk Composition, Amino Acid and Fatty Acid Contents in Xiangdong Black Goats (Postprint)

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## Abstract

This experiment aimed to investigate the effects of different zinc sources (zinc sulfate, zinc methionine chelate, and zinc glycine chelate) on the growth performance of Xiangdong black goats and the composition, amino acid, and fatty acid contents of goat milk. Twenty-one pregnant Xiangdong black goats carrying twins (gestation day 90–100 d) with similar body weight (38.1±9.7 kg) and parity were randomly divided into three groups: zinc sulfate group (control group), zinc methionine chelate group, and zinc glycine chelate group. The basal diet composition was identical across all groups (zinc content 22.00 mg/kg DM), and the zinc supplementation level was 60 mg/kg DM for each group. The preliminary period was 7 d, and the formal experimental period was 42 d. During the formal experimental period, the three groups of does were fed diets with different zinc sources, while postpartum does were fed diets without zinc supplementation. Milk samples were collected on day 15 postpartum. The results showed that: 1) Compared with the control group, the total weight gain and average daily gain of does in the zinc methionine chelate and zinc glycine chelate groups were significantly increased ($P<0.05$); 2) Compared with the control group, there were no significant differences in somatic cell count, milk fat, milk protein, lactose, urea nitrogen, and fat-free dry matter content of goat milk in the zinc methionine chelate and zinc glycine chelate groups ($P>0.05$), but the total dry matter content of goat milk in the zinc methionine chelate group was significantly increased ($P<0.05$); 3) Compared with the control group, there were no significant differences in amino acid content of goat milk in the zinc methionine chelate and zinc glycine chelate groups ($P>0.05$); 4) Compared with the control group, the contents of caproic acid, caprylic acid, lauric acid, tridecylic acid, and -linolenic acid in goat milk of the zinc methionine chelate group were significantly increased (P<0.05), while the contents of lignoceric acid, cis-11-eicosenoic acid, and -linolenic acid in goat milk of the zinc glycine chelate group were significantly increased (P<0.05). In conclusion, zinc methionine chelate can increase the total dry matter content in goat milk, zinc glycine chelate can decrease the contents of monounsaturated fatty acids and polyunsaturated fatty acids in goat milk, and both can increase the total weight gain and average daily gain of pregnant does, indicating that supplementary feeding with zinc methionine chelate and zinc glycine chelate can both improve the growth performance of pregnant does and alter goat milk quality.

## Full Text

## Effects of Three Zinc Sources on Growth Performance of Xiangdong Black Goats and Composition, Amino Acid, and Fatty Acid Contents of Goat Milk

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### Abstract

This experiment was conducted to investigate the effects of different zinc sources (zinc sulfate, methionine chelated zinc, and glycine chelated zinc) on growth performance of pregnant Xiangdong black goats and the composition, amino acid, and fatty acid contents of goat milk. Twenty-one pregnant Xiangdong black goats carrying twins, with similar parity and body weight (38.1±9.7) kg, were randomly divided into three groups: zinc sulfate group (control), methionine chelated zinc group, and glycine chelated zinc group. All groups received the same basal diet (containing 22.00 mg/kg DM zinc) with an additional 60 mg/kg DM zinc supplementation, resulting in a total dietary zinc content of 82 mg/kg DM. The pre-trial period lasted 7 days, followed by a 42-day formal trial period.

During the formal trial, the three groups of pregnant goats were fed diets with different zinc sources. After parturition, all lactating goats were fed the same basal diet without zinc supplementation to exclude the influence of zinc sources on lactating goats and their offspring. Milk samples were collected on day 15 postpartum. The results showed: 1) Compared with the control group, total weight gain and average daily gain in both the methionine chelated zinc and glycine chelated zinc groups were significantly increased ($P<0.05$). 2) No significant differences were observed in somatic cell count, milk fat, milk protein, lactose, urea nitrogen, or fat-free dry matter content between the organic zinc groups and the control group ($P>0.05$), but the total dry matter content in the methionine chelated zinc group was significantly higher ($P<0.05$). 3) The amino acid contents in goat milk did not differ significantly among groups ($P>0.05$). 4) Compared with the control group, the methionine chelated zinc group showed significantly increased contents of n-hexanoic acid, caprylic acid, lauric acid, tridecanoic acid, and  -linolenic acid ($P<0.05$), while the glycine chelated zinc group had significantly increased contents of lignoceric acid, cis-11-eicosenoic acid, and  -linolenic acid ($P<0.05$). In conclusion, methionine chelated zinc supplementation can increase total dry matter content in goat milk, while glycine chelated zinc can reduce monounsaturated and polyunsaturated fatty acid contents. Both organic zinc sources can significantly increase total weight gain and average daily gain of pregnant goats, indicating that supplementation with methionine chelated zinc and glycine chelated zinc can improve maternal growth performance and modify goat milk quality.

**Keywords:** zinc source; growth performance; goat milk; amino acid; fatty acid; Xiangdong black goat

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## Introduction

Zinc is an indispensable trace element in animal organisms, essential for DNA replication, protein transcription, and translation. Approximately 70% of pregnant ewes suffer from zinc deficiency, which can lead to low birth weight and decreased survival rates in lambs [1-2]. Since fetal growth and development depend on maternal nutrient supply, zinc supplementation to the mother is necessary to meet normal fetal development requirements. Research indicates that fetal nerve cells require zinc, which participates in the development and function of brain regions controlling cardiac function, such as the brainstem and hypothalamus [3]. Additionally, zinc serves as a cofactor for folate conjugase, interfering with the binding of natural folate to polyglutamyl chains in food, thereby promoting the digestion and absorption of natural folate by the organism.

When zinc sulfate enters the intestine in ionic form, intestinal pH and other factors cause it to react with phytic acid, calcium, and other components, forming insoluble compounds that affect digestion and absorption. Furthermore, zinc sulfate is absorbed in ionic form, which strongly stimulates the intestinal wall, and the body stores relatively little zinc, thereby reducing zinc absorption and utilization. Methionine is an essential amino acid for ruminants and the first limiting amino acid. Supplementing ruminants with zinc methionine primarily reduces the degradation rate of zinc methionine in the rumen, facilitating better intestinal digestion and absorption of zinc. Glycine is a non-essential amino acid for ruminants, and supplementing glycine zinc functions similarly to zinc methionine, but compared with zinc sulfate, glycine is absorbed more rapidly by the organism. Zinc is taken up from the intestinal lumen by brush border cells, enters the cellular zinc pool, crosses the basement membrane into the bloodstream, and a portion of blood zinc eventually becomes milk zinc. Wang et al. [4] found that dairy goats supplemented with the same level of zinc showed higher digestibility of amino acid zinc compared with zinc sulfate. Aliarabi et al. [5] reported that zinc supplementation increased average daily gain and feed conversion rate in lambs. Many studies suggest that zinc primarily functions in organic form within the body, with organic zinc generally showing higher bioavailability than inorganic zinc, increasing serum total protein, globulin, and glucose contents, as well as alkaline phosphatase activity [6-14]. Zinc sulfate, zinc methionine, and glycine zinc are commonly used feed additives in animal production, with organic zinc demonstrating higher utilization rates than inorganic zinc. Research indicates that zinc source and dosage can affect goat weight gain but not feed intake [15]. Nayeri et al. [16] reported that supplementing Holstein cows with zinc methionine during pregnancy increased milk yield. Formigoni et al. [17] found that replacing sulfates with organic trace minerals during the dry and lactation periods increased immunoglobulin and milk fat content in colostrum and reduced calf mortality. Zinc methionine chelate supplementation can enhance dairy goats' resistance to mammary gland stress [18], but few studies have focused on local breeds such as Xiangdong black goats. Therefore, this experiment aimed to compare the effects of three different zinc sources on growth performance and the composition, amino acid, and fatty acid contents of goat milk in Xiangdong black goats.

## Materials and Methods

### 1.1 Experimental Design

Twenty-one pregnant Xiangdong black goats carrying twins, with similar parity and body weight (38.1±9.7) kg at 90-100 days of gestation, were randomly divided into three groups: zinc sulfate group (control), methionine chelated zinc group, and glycine chelated zinc group, with seven replicates per group. The pre-trial period lasted 7 days, followed by a 45-day formal trial period (from day 106 of gestation to parturition).

### 1.2 Experimental Diets

The basal diet was formulated according to NRC (2007) nutrient requirements for late-pregnancy ewes (30 kg body weight, twin pregnancy, dry matter intake

1.05 kg/d). Zinc sulfate, methionine chelated zinc, or glycine chelated zinc were added to the basal diet (containing 22.00 mg/kg DM zinc) at a supplementation level of 60 mg/kg DM, resulting in a total dietary zinc content of 82 mg/kg DM for all treatment diets. The forage was fresh Dongmang grass. Diet composition and nutrient levels are shown in Table 1 . The concentrate-to-forage ratio was 60:40.

**Table 1 Composition and nutrient levels of experimental diets (DM basis)**

| Items | $ZnSO_4$ group | Zn-Met group | Zn-Gly group |
|---|---|---|---|
| **Ingredients** | | | |
| Dongmang | | | |
| Corn | | | |
| Soybean meal | | | |
| Fat powder | | | |
| Soy protein concentrate | | | |
| $Ca(HCO_3)_2$ | | | |
| Stone powder | | | |
| Premix[1] | | | |
| NaCl | | | |
| **Total** | | | |
| **Nutrient levels[2]** | | | |
| DM | | | |
| CP | | | |
| EE | | | |
| ADF | | | |
| NDF | | | |
| Ash | | | |
| Zn (mg/kg) | | | |

[1]One kg of premix contained: VA 100,000 IU, VD3 15,000 IU, VE 300 IU, 1% I (as potassium iodide) 0.1996 g, 1% Se (as sodium selenite) 0.02 g, $CuSO_4 \cdot 5H_2O$ 0.04 g, $FeSO_4 \cdot H_2O$ 0.14 g, $MnSO_4 \cdot H_2O$ 0.38 g.
[2]Nutrient levels were measured values.

### 1.3 Animal Management

Experimental ewes were housed individually with ad libitum access to water. Daily feed intake was recorded during the formal trial period. Immunization and disinfection procedures for pregnant ewes and newborn lambs followed conventional farm practices. Diets were fed at 08:00 and 06:00 daily. After parturition, all lactating ewes were fed the same basal diet without zinc supplementation to exclude the influence of zinc sources on lactating ewes and their offspring.

### 1.4 Diet Composition Analysis

During the formal trial period, diet samples were collected, mixed thoroughly, and analyzed for dry matter, ash, crude protein, crude fat, and crude fiber contents using conventional methods as described by Zhang [19].

### 1.5 Milk Sample Collection and Analysis

**1.5.1 Milk Sample Collection** Milk samples were collected on day 15 postpartum, one hour after feeding. Teats were disinfected with alcohol, the first milk stream was discarded, and then milk samples were collected. Morning and afternoon milk samples were mixed, preservatives were added, and samples were stored at 4°C and sent for analysis within 3 days.

**1.5.2 Routine Milk Composition Analysis** Routine milk composition was determined using a Basic Unit MilkoScan FT+ Type-76150 instrument, including somatic cell count, milk fat, milk protein, lactose, urea nitrogen, fat-free dry matter, and total dry matter content.

**1.5.3 Milk Amino Acid Content Analysis** Amino acid content was determined using an amino acid analyzer (Hitachi L8900). The procedure was as follows: 5 mL of milk sample was placed in a hydrolysis tube with 10 mL of 6 mol/L HCl, heated at 110°C for 24 hours. After cooling, the solution was transferred to a 100 mL volumetric flask. One mL was evaporated to dryness in a 65°C water bath, reconstituted with 0.01 mol/L HCl, filtered, diluted 5-fold, and analyzed.

**1.5.4 Milk Fatty Acid Content Analysis** Fatty acid content was determined by gas chromatography according to GB 5009.168-2016 using a gas chromatograph equipped with a flame ionization detector (FID).

### 1.6 Statistical Analysis

Experimental data were organized using Excel 2007 and analyzed using SPSS 19.0 software for one-way ANOVA. Duncan' s multiple comparison test was used for post-hoc analysis. Results are expressed as "mean ± standard error" (mean±SE). $P<0.05$ was considered statistically significant, while $P>0.05$ indicated no significant difference.

## Results

### 2.1 Effects of Different Zinc Sources on Growth Performance of Pregnant Ewes

As shown in Table 2 , compared with the control group, total weight gain and average daily gain in both the methionine chelated zinc and glycine chelated zinc groups were significantly increased ($P<0.05$), with no significant differences between the two organic zinc groups (P>0.05). No significant differences were observed in dry matter intake, initial body weight, or final body weight among groups (P>0.05).

**Table 2 Effects of different zinc sources on growth performance of pregnant ewes**

| Items | ZnSO4 group | Zn-Met group | Zn-Gly group |
|---|---|---|---|
| DMI (kg/d) | 1.30±0.17 | 1.26±0.11 | 1.29±0.16 |
| Initial body weight (kg) | 36.10±2.27 | 39.68±2.23 | 40.75±3.13 |
| Final body weight (kg) | 39.42±3.10 | 46.00±1.97 | 46.86±3.87 |
| Total weight gain (kg) | 3.27±0.49 | 6.32±0.91 | 7.45±0.34 |
| ADG (g/d) | 78.00±11.88 | 150.60±11.76 | 177.40±8.28 |

In the same row, values with different small letter superscripts mean significant difference (P<0.05), while with the same or no letter superscript mean no significant difference (P>0.05). The same as below.

### 2.2 Effects of Different Zinc Sources on Goat Milk Composition

As shown in Table 3 , compared with the control group, the methionine chelated zinc group showed significantly increased total dry matter content (P<0.05), while somatic cell count, milk fat, milk protein, lactose, urea nitrogen, and fat-free dry matter content showed no significant differences (P>0.05). The glycine chelated zinc group showed no significant differences in any milk composition parameters (P>0.05).

**Table 3 Effects of different zinc sources on goat milk composition**

| Items | ZnSO4 group | Zn-Met group | Zn-Gly group |
|---|---|---|---|
| Somatic cell count ($\times 10^3$/mL) | 69.60±29.11 | 57.00±48.01 | 99.40±24.92 |
| Milk fat (%) | 6.91±0.34 | 8.13±0.39 | 7.15±0.64 |
| Milk protein (%) | 4.65±0.45 | 4.62±0.47 | 3.97±0.21 |
| Lactose (%) | 5.23±0.19 | 5.04±0.20 | 5.21±0.08 |
| Urea nitrogen (mg/dL) | 35.93±0.77 | 37.80±2.62 | 35.82±1.08 |

| Items | ZnSO4 group | Zn-Met group | Zn-Gly group |
|---|---|---|---|
| Fat-free dry matter (%) | 10.58±0.29 | 11.53±1.15 | 9.91±0.18 |
| Total dry matter (%) | 16.83±0.28 | 18.98±1.12 | 16.39±0.60 |

### 2.3 Effects of Different Zinc Sources on Amino Acid Contents of Goat Milk

As shown in Table 4 , compared with the control group, no significant differences were observed in essential amino acids, non-essential amino acids, total essential amino acids, total non-essential amino acids, or total amino acid contents in either the methionine chelated zinc or glycine chelated zinc groups (P>0.05).

**Table 4 Effects of different zinc sources on amino acid contents of goat milk**

| Items | ZnSO4 group | Zn-Met group | Zn-Gly group |
|---|---|---|---|
| **Essential amino acids (EAA)** | | | |
| Thr | 0.14±0.01 | 0.13±0.01 | 0.14±0.04 |
| Val | 0.09±0.01 | 0.09±0.01 | 0.09±0.01 |
| Ile | 0.12±0.01 | 0.13±0.01 | 0.12±0.01 |
| Leu | 0.06±0.01 | 0.07±0.01 | 0.06±0.01 |
| Lys | 0.08±0.01 | 0.08±0.01 | 0.08±0.01 |
| Tyr+Phe | 0.28±0.02 | 0.28±0.03 | 0.28±0.03 |
| Met+Cys | 0.34±0.02 | 0.34±0.03 | 0.34±0.10 |
| **Non-essential amino acids (NEAA)** | | | |
| Asp | 0.09±0.01 | 0.09±0.01 | 0.09±0.01 |
| Ser | 0.13±0.01 | 0.13±0.01 | 0.13±0.02 |
| Glu | 0.04±0.01 | 0.04±0.01 | 0.04±0.01 |
| Gly | 0.34±0.03 | 0.32±0.02 | 0.31±0.04 |
| Ala | 0.32±0.04 | 0.32±0.02 | 0.31±0.04 |
| His | 0.19±0.01 | 0.18±0.02 | 0.18±0.02 |
| Arg | 0.24±0.01 | 0.24±0.02 | 0.24±0.02 |

| Items | ZnSO4 group | Zn-Met group | Zn-Gly group |
|---|---|---|---|
| Pro | 0.22±0.02 | 0.21±0.02 | 0.22±0.03 |
| **Total essential amino acids (TEAA)** | 1.20±0.08 | 1.18±0.11 | 1.18±0.14 |
| **Total non-essential amino acids (TNEAA)** | 1.28±0.08 | 1.26±0.11 | 1.27±0.15 |
| **Total amino acids (TAA)** | 2.39±0.15 | 2.37±0.21 | 2.37±0.27 |

### 2.4 Effects of Different Zinc Sources on Fatty Acid Contents of Goat Milk

As shown in Table 5 , compared with the control group, the methionine chelated zinc group showed no significant differences in saturated fatty acids (SFA), monounsaturated fatty acids (MUFA), or polyunsaturated fatty acids (PUFA) ($P>0.05$), but significantly increased contents of n-hexanoic acid, caprylic acid, lauric acid, tridecanoic acid, and  -linolenic acid ($P<0.05$). The glycine chelated zinc group showed significantly decreased MUFA and PUFA contents ($P<0.05$), with no significant difference in SFA content ($P>0.05$), but significantly increased contents of cis-11-eicosenoic acid,  -linolenic acid, and lignoceric acid ($P<0.05$).

**Table 5 Effects of different zinc sources on fatty acid contents of goat milk (mg/kg)**

| Items | ZnSO4 group | Zn-Met group | Zn-Gly group |
|---|---|---|---|
| Butyric acid | 978.00±49.31 | 1,283.83±111.91 | 1,101.40±147.63 |
| n-Hexanoic acid | 1,065.66±34.14 | 1,548.00±52.47 | 1,104.50±177.47 |
| Caprylic acid | 1,258.33±49.55 | 1,806.00±58.87 | 1,169.25±170.94 |
| Decanoic acid | 4,098.33±274.12 | 5,500.60±240.87 | 4,177.50±873.85 |

| Items | ZnSO4 group | Zn-Met group | Zn-Gly group |
|---|---|---|---|
| Undecanoic acid | 57.50±12.42 | 64.01±6.11 | 41.76±6.26 |
| Lauric acid | 1,853.50±165.86 | 2,606.66±198.74 | 1,742.33±277.26 |
| Tridecanoic acid | 52.16±7.79 | 58.15±4.90 | 40.06±3.60 |
| Pentamethylfuran bromate acid | 3,981.66±288.94 | 3,881.66±793.10 | 3,619.50±559.37 |
| Myristoleic acid | 50.11±6.41 | 80.50±23.91 | 55.72±8.81 |
| Pentadecanoic acid | 485.40±53.87 | 491.80±49.17 | 362.83±36.86 |
| Palmitic acid | 10,776.66±573.49 | 14,460.00±1,735.10 | 11,456.00±953.27 |
| Palmitoleic acid | 222.50±28.25 | 327.00±76.87 | 326.80±28.38 |
| Heptadecanoic acid | 425.66±50.26 | 506.57±42.88 | 615.00±4.72 |
| Stearic acid | 7,670.00±566.39 | 7,786.00±344.04 | 6,740.00±598.58 |
| Oils acid | 10,885.00±1,194.57 | 13,933.33±1,959.02 | 16,096.00±1,882.07 |
| Linolelaidic acid | 46.16±4.39 | 50.45±4.81 | 57.08±6.43 |
| Linoleic acid | 1,147.50±82.04 | 1,290.33±86.84 | 1,001.00±77.00 |
| Arachidic acid | 131.26±13.75 | 165.10±24.58 | 114.03±10.35 |
| - Linolenic acid | 12.56±0.93 | 18.74±1.25 | 19.12±3.02 |
| cis-11-Eicosenoic acid | 101.55±10.82 | 133.50±8.40 | 228.12±19.07 |
| Linolenic acid | 25.38±1.35 | 28.31±3.02 | 23.45±2.66 |
| Heneicosanoic acid | 23.78±1.45 | 29.16±2.16 | 22.88±1.72 |
| 11,14-Eicosadienoic acid | 24.38±2.42 | 28.03±6.62 | 28.62±2.83 |
| Behenic acid | 37.04±2.02 | 48.26±6.52 | 31.72±3.41 |

| Items | ZnSO4 group | Zn-Met group | Zn-Gly group |
|---|---|---|---|
| cis-8,11,14-Octadecenoic acid | 12.30±1.07 | 16.12±3.17 | 16.90±2.62 |
| 11,14,17-cis-Icotrienoic acid | 41.80±7.72 | 31.00±8.06 | 27.33±8.71 |
| Triclosanic acid | 169.76±13.39 | 226.60±20.66 | 197.80±22.92 |
| Arachidonic acid | 21.50±3.33 | 22.92±1.60 | 15.76±1.40 |
| Lignoceric acid | 23.92±3.00 | 31.60±7.49 | 69.43±11.92 |
| Timnodonic acid | 8.65±1.23 | 8.98±1.18 | 6.54±0.69 |
| cis-15-Myristic acid | 8.39±1.53 | 13.32±2.82 | 15.05±6.83 |
| Docosahexaenoic acid | 27.25±4.59 | 36.86±3.47 | 36.28±10.60 |
| **SFA** | 1,769.82±52.16 | 2,011.86±310.48 | 1,532.38±129.48 |
| **MUFA** | 1,909.56±78.70 | 2,084.44±135.50 | 1,311.80±146.91 |
| **PUFA** | 4,004.07±152.55 | 4,367.42±303.09 | 3,155.00±273.50 |

## Discussion

### 3.1 Effects of Zinc Sulfate, Methionine Chelated Zinc, and Glycine Chelated Zinc on Growth Performance of Pregnant Ewes

No significant differences in dry matter intake were observed among the zinc sulfate, methionine chelated zinc, and glycine chelated zinc groups, which is consistent with the findings of Wu et al. [20] in lactating sows and indicates similar palatability among diets. In this experiment, total weight gain and average daily gain in both the methionine chelated zinc and glycine chelated zinc groups were significantly higher than in the control group, demonstrating that organic zinc sources are superior to inorganic zinc in promoting growth performance of pregnant ewes. However, Ren et al. [21] reported that adding 60 mg/kg zinc sulfate or 60 mg/kg zinc methionine to the diet of male mink during the growing period had no significant effect on daily weight gain, which contradicts our findings.

### 3.2 Effects of Zinc Sulfate, Methionine Chelated Zinc, and Glycine Chelated Zinc on Routine Milk Composition

Zinc sulfate, zinc methionine, and glycine zinc are all feed additives for zinc supplementation in animals. Amino acid absorption during late pregnancy is primarily used for milk protein synthesis. Over 90% of milk protein is synthesized de novo in mammary tissue from absorbed amino acids, and milk protein synthesis is mainly limited by two factors: available amino acids and energy. Methionine is the first limiting amino acid for ruminants fed corn and soybean meal-based diets. This study found that the methionine zinc group had 2.15 percentage points higher total dry matter content than the control group, with a non-significant increase in milk fat content. This may be explained by two mechanisms: first, methionine chelated zinc may increase intestinal absorption efficiency of methionine, thereby increasing the total pool of available amino acids in mammary tissue; second, rumen-protected methionine may promote amino acid metabolism in the liver and mammary gland, where amino acids can be metabolized into acetyl-CoA for fatty acid synthesis and subsequent conversion to milk fat. Our results differ somewhat from previous studies. For instance, intra-arterial amino acid infusion in Chinese Holstein cows significantly increased milk fat percentage by 5.92% compared with the control group, though milk yield and other milk components did not differ significantly [22]. Faulkner and Weiss [23] reported that feeding organic chelated zinc, manganese, and copper to dairy cows increased immunoglobulin content in colostrum and milk fat content by 4.4%, while milk yield, protein content, and somatic cell count were unaffected. Bi et al. [24] found that adding 60 g/d rumen-protected methionine to the diet of lactating cows producing 19 kg/d had no significant effects on milk protein, milk fat percentage, milk yield, somatic cell count, 4% fat-corrected milk, or milk non-fat solids content. Wang et al. [25] reported that supplementing lactating cows with zinc amino acid chelate had no significant effects on feed intake, milk composition, or somatic cell count, though milk yield was significantly increased in the lowest and highest supplementation groups compared with the control. Griffiths et al. [26] found that supplementing complexed zinc, manganese, copper, and cobalt significantly increased milk yield, energy, milk fat percentage, milk crude protein, and milk non-fat solids content, though milk composition and somatic cell count did not differ significantly. Sobhanirad et al. [27] observed numerical increases in milk and fat-corrected milk yield in dairy cows, though these were independent of zinc source; milk protein, lactose, milk fat, total milk non-fat solids content, and milk density percentage did not differ significantly, but somatic cell count and fat-corrected milk were lower in the zinc methionine group. In this experiment, the significant increase in total dry matter content in the methionine zinc group may be due to increased ash content and decreased water content in goat milk, while other components remained unchanged, possibly because of increased trace elements such as zinc, iron, and phosphorus in milk. These results indicate that supplementing zinc methionine during late pregnancy in Xiangdong black goats can increase total dry matter content in goat milk.

### 3.3 Effects of Zinc Sulfate, Methionine Chelated Zinc, and Glycine Chelated Zinc on Milk Amino Acid Content

This study demonstrated that different zinc sources during late pregnancy in Xiangdong black goats had no significant effects on milk amino acid content. Milk protein formation involves two pathways: transfer from serum proteins and synthesis from amino acids absorbed by mammary epithelial cells from blood, with the latter accounting for over 90% of milk protein. This experiment found no significant differences in milk protein and lactose contents between the organic zinc groups and the control group. Therefore, the lack of significant differences in milk amino acid content may be related to the absence of significant differences in milk protein and lactose contents, as some glucogenic amino acids in the mammary gland, including methionine and glycine, can be used for lactose synthesis while the remainder exists as milk protein. Bi et al. [24] reported that adding 60 g/d rumen-protected methionine to dairy cow diets had no significant effect on milk amino acid composition, which is consistent with our findings.

### 3.4 Effects of Zinc Sulfate, Methionine Chelated Zinc, and Glycine Chelated Zinc on Milk Fatty Acid Content

Changes in milk fatty acids may reflect dairy cow health and energy status [28]. The material basis for milk fat synthesis consists of milk component precursors (acetic acid, -hydroxybutyric acid, free fatty acids, etc.). Dietary digestion and conversion form milk fat synthesis precursors through rumen fermentation, intestinal absorption, and liver metabolism, ultimately being utilized for milk fat synthesis in the mammary gland. The main component of milk fat is triglyceride, which is synthesized from fatty acids and -glycerophosphate in mammary epithelial cells. Fatty acids are absorbed by small intestinal epithelial cells and transported to various tissues for utilization, directly affecting the material and energy metabolism of nursing offspring. Research indicates that n-hexanoic acid, caprylic acid, and decanoic acid are the main sources of goat milk flavor. In this experiment, the methionine chelated zinc group had significantly higher n-hexanoic acid and caprylic acid contents than the control group, with a trend toward higher decanoic acid content, suggesting that dietary methionine chelated zinc supplementation can regulate goat milk flavor. Compared with the control group, the methionine chelated zinc group showed no significant difference in SFA composition, while the glycine chelated zinc group showed a significant reduction. Supplementing goat diets with amino acid chelated zinc may reduce SFA content in goat milk, thereby reducing energy content and consequently decreasing cholesterol and neutral fat content in milk. The glycine chelated zinc group had significantly lower MUFA and PUFA contents than the control group, while the methionine chelated zinc group showed no significant difference from the control group. Therefore, supplementing goats with methionine chelated zinc and zinc sulfate may reduce cholesterol while making goat milk more susceptible to rancidity. In this experiment, the methionine chelated zinc group had higher contents of lauric acid and tridecanoic acid in SFA, and higher -linolenic acid content, with trends toward higher decanoic acid, palmitic acid, heneicosanoic acid, and behenic acid contents. These results demonstrate that different zinc sources can affect medium- and long-chain fatty acid contents, with more pronounced effects from dietary methionine chelated zinc and glycine chelated zinc supplementation.

## Conclusion

Supplementing methionine chelated zinc during late pregnancy in Xiangdong black goats increased total dry matter, n-hexanoic acid, caprylic acid, lauric acid, tridecanoic acid, and -linolenic acid contents in goat milk. Glycine chelated zinc supplementation increased cis-11-eicosenoic acid and -linolenic acid contents while decreasing monounsaturated and polyunsaturated fatty acid contents. Both organic zinc sources significantly increased total weight gain and average daily gain of pregnant ewes. These results indicate that supplementation with methionine chelated zinc and glycine chelated zinc can improve maternal growth performance and modify goat milk quality.

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*Note: Figure translations are in progress. See original paper for figures.*