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Research Article

Effects of Different Zinc Sources on Growth Performance, Serum Biochemical Indexes and Zinc Metabolism of Pregnant Goats and Their Offspring

Mengli ZHENG [1,a] Xilin LI [2,b] Qiongxian YAN [2,c (*)]
Chuanshe ZHOU [2,d] Zhiliang TAN [2,e] Peihua ZHANG [1,f (*)]

[1] College of Animal Science and Technology, Hunan Agricultural University, Changsha 410128, CHINA
[2] Institute of Subtropical Agriculture, The Chinese Academy of Sciences, Changsha 410125, CHINA
ORCIDs: [a] 0000-0001-6253-3724; [b] 0000-0002-1184-3551; [c] 0000-0003-0035-6819; [d] 0000-0000-0000-0000; [e] 0000-0002-7483-1478
[f] 0000-0003-1408-122X;

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Abstract

This study investigated the effects of different zinc (Zn) sources on body weight, body size, serum biochemical indexes and mineral concentrations in Liuyang pregnant goats and their offspring. Twenty-four two-years-old Liuyang Black goats were randomly allocated to three groups and fed a basal corn-soybean meal diet supplemented respectively with Zn-sulfate (ZnS), Zn-methionine (ZnM), Zn-glycinate (ZnG) at 60 mg/kg Zn for the last 52 days of gestation. The weight and chest circumference of kids in the ZnG group were significantly higher than those in the ZnS group. The concentrations of CHOL and HDL in the serum were significantly higher in the ZnG group than that in the ZnM group 10 days before gestation, but CRPL levels were significantly higher in the ZnS group than in other two groups. The serum ALP activity of 60-day old kid-goats was significantly higher than that of 30-day old and 100-day old ones. The concentrations of potassium and Zn in serum of ZnG group were significantly higher than that of ZnS group. These findings revealed that ZnG as dietary supplementation can improve the performance of kid-goats, while ZnG and ZnM can enhance the immunity of pregnant and postpartum goats, and ZnG supplement is better than ZnM.

Keywords: *Capra, Dietary zinc sources, Growth, Pregnancy, Serum biochemical indices, Zinc*

Farklı Çinko Kaynaklarının Gebe Keçi ve Yavrularında Büyüme Performansı, Serum Biyokimyasal İndeksleri ve Çinko Metabolizması Üzerine Etkileri

Öz

Bu çalışmada, farklı çinko (Zn) kaynaklarının Liuyang gebe keçilerinde ve yavrularında vücut ağırlığı, vücut büyüklüğü, serum biyokimyasal indeksleri ve mineral konsantrasyonları üzerine etkileri araştırıldı. Yirmi dört adet iki yaşlı Liuyang Karası keçi rastgele üç gruba ayrıldı ve gruplar gebeliklerinin son 52 gününde, Zn konsantrasyonu 60 mg/kg olacak şekilde hazırlanan sırasıyla Zn-sülfat (ZnS), Zn-metiyonin (ZnM), Zn-glisinat (ZnG) ilaveli bazal mısır-soya küspesi diyeti ile beslendi. ZnG grubundaki keçi yavrularının ağırlıkları ve göğüs çevresi, ZnS grubundakilerden önemli ölçüde daha yüksek saptandı. Serum CHOL ve HDL konsantrasyonları gebelikten 10 gün önce, ZnG grubunda ZnM grubundakilerden anlamlı derecede daha yüksekti, ancak CRPL seviyeleri diğer iki gruba göre ZnS grubunda anlamlı derecede daha yüksekti. 60 günlük oğlakların serum ALP aktivitesi, 30 günlük ve 100 günlük oğlakların serum ALP aktivitesinden anlamlı derecede daha yüksekti. ZnG grubunun serum potasyum ve çinko konsantrasyonları, ZnS grubuna göre anlamlı derecede daha yüksekti. Bu bulgular, besin takviyesi olarak ZnG'nin oğlakların performansını artırabileceğini, ZnG ve ZnM'nin gebe ve doğum sonrası keçilerin bağışıklığını artırabileceğini ve ZnG takviyesinin ZnM'den daha iyi olduğunu ortaya koydu.

Anahtar sözcükler: *Keçi, Besinsel çinko kaynakları, Büyüme, Gebelik, Serum biyokimyasal indeksleri, Çinko metabolizması*

Introduction

Zinc (Zn) has been demonstrated to be an essential element for ruminants [1,2], and it promotes growth development [3], improves animal's immunity [4] and reproductive performance [5]. The deficiency of Zn is associated with growth

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(*) Corresponding Author
Tel: +86-1354 8638664
E-mail: zhang1970@hunau.edu.cn (P. Zhang), yanqx14@isa.ac.cn (Q. Yan)

retardation [6] and immune dysfunction [7]. In animal production, inorganic Zn (in the form of Zn sulfate), organic Zn (methionine chelated Zn, glycine chelated zinc, Zn gluconate, etc.) and nano-Zn are widely used in diet [8,9]. Studies have shown that organic Zn and nano-Zn could improve the growth performance and immune performance of animals [10-13]. Nano-Zn is superior to organic Zn, but its products are costly. Therefore, organic Zn is widely used in dietary supplementation to improve the productive efficiency of farming animals.

The effects of Zn on the growth performance of ruminants were controversial. It was reported that supplementing lambs, goats and calves with Zn improved growth performance and blood antioxidants regardless of the sources [9,14]. Fadayifar et al.[15] and Garg et al.[16] found that Zn supplementation or methionine chelated zinc (ZnM) improved performance of lambs. Mattioli et al.[17] noted that Zn supplementation could improve daily weight gain of pre-weaning calves. Alimohamady et al.[18] also showed that supplementation of Zn in growing lambs improved growth performance. In addition, Salama et al.[19] reported that ZnM reduced the contents of whey protein and non-protein nitrogen, and increased the apparent absorption of nitrogen and the retention rate of Zn in goats. However, Liu et al.[20] found that Zn sources did not affect the body weight gain in male Liaoning Cashmere goats. Therefore, efficacy of Zn supplementation on ruminants growth performance may be affected by animal species and ages, and the sources of Zn.

Studies on the effects of Zn supplementation on serum biochemical indexes in ruminants are scarce. Previous studies showed that supplementation of Zn improved blood antioxidants and thyroid hormone levels in growing lambs and increased serum alkaline phosphatase activity [18,20]. Mandal et al.[21] indicated that bulls supplemented with Zn propionate had higher cell mediated and humoral immune responses, while there was no alteration in immune response by zinc sulfate (ZnS) supplementation when compared with the unsupplemented control. The serum concentrations of urea and triglycerides increased and total cholesterol and high-density lipoprotein (HDL) cholesterol decreased in pre-partum dairy cows supplemented with Zn [22]. Therefore, the effects of Zn sources on serum biochemical indexes are related to animal species and Zn sources.

Zinc maintains homeostasis through Zn circulation in the blood, excretion of feces and urine, and deposition of bones and organs. The serum Zn concentration increased in cows fed organic Zn [9]. However, Solaiman et al.[23] found that serum Zn did not change and stayed relatively stable regardless of dietary Zn levels in growing Boer-cross goat kids. Zn can interact with other mineral elements, so its effect can vary depending on the statuses of other elements. Copper supplementation causes a significant decrease in serum and tissue Zn [24]. Serum concentration of Ca, Cu, Fe, K, P, Mg, Mo, Ps, Pt, Se, and Zn varied according to days of lactation in dairy cows [25].

In pregnant goats, mineral nutrients including Zn can be transferred to kids through the placenta. Therefore, the objective of the current study was to examine the effects of supplementation of different Zn sources on growth performance of pregnant goats, serum biochemical indexes and Zn metabolism of both the mother and offspring.

Material and Methods

Animal Ethics

The experiments were conducted according to the Animal Care and Use Guidelines of the Animal Care Committee, Institute of Subtropical Agriculture, the Chinese Academy of Sciences, Changsha, China.

Animal Management and Dietary Treatments

Oestrus synchronization of a flock of Liuyang Black goats (a local breed) was carried out with the administration of progestogen followed by equine chorionic gonadotropin, and then artificial insemination was performed. The goats underwent ultrasound test at 40 days after the insemination to ensure pregnancy. Pregnant goats were grazed until about 90 days of gestation. Then, goats were selected (with an initial body weight [BW] of 38.1±9.7 kg and similar pregnancy dates [90-100]), transported into the animal house, and individually fed with corn and soybean meal as basic diet (the concentrate) and fresh awn feed.

Miscanthus forage was harvested and cut into small pieces and then mixed with the concentrate before feeding. The diet prepared with reference to the NRC (2007) nutritional requirements of the diets are presented in *Table1*. Goats were divided into three groups with eight goats in each group. Three forms of Zn in the premix were used as the Zn treatments: Zn sulfate (ZnS), Zn methionine chelates (ZnM) and Zn glycine chelates (ZnG), and the dose was controlled at 60 mg/kg Zn dry matter for each animals. ZnS was purchased from Tanke Co. (China); ZnM was purchased from Noves Co. (China) contained 16% Zn; and ZnG was purchased from Tanke Co. (China) contained 29% Zn.

The selected goats were transported into an animal house at about 90 days of pregnancy, kept in individual pens, and fed the basal diet. After two weeks acclimation, three groups of goats were fed the diet supplemented with the different Zn sources from day 105 of gestation until the kidding. Feed consumption was recorded daily, and body weight was recorded at the beginning and end of the experimental period to calculate the body weight change of the goats over the period. The basal diets for both pregnancy goats and their offspring *(Table 1, Table 3)* were prepared to meet the nutrient requirements of pregnant goats in the late gestation period as recommended by NRC

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

Item	ZnS	ZnM	ZnG
Ingredients, %			
Miscanthus	40.00	40.00	40.00
Corn	34.66	34.66	34.66
Soybean meal	11.74	11.74	11.74
Fat powder	4.49	4.49	4.49
Soy protein concentrate	5.03	5.03	5.03
$Ca(HCO_3)_2$	0.50	0.50	0.50
$CaCO_3$	0.84	0.84	0.84
Premix[1)]	2.34	2.34	2.34
NaCl	0.40	0.40	0.40
Nutrient levels			
DM	91.79	92.36	92.17
CP	17.76	16.74	18.72
EE	2.50	3.04	3.14
ADF	29.30	27.85	31.24
NDF	45.42	43.78	47.64
Ash	10.47	10.58	10.65
Basic dietary zinc (mg/kg)	22.00	22.00	22.00
The total content of zinc (mg/kg)	82.00	82.00	82.00

** **ZnS,** Zinc-sulfate; **ZnM,** Zinc-methionine; **ZnG,** Zinc-glycinate chalates; **ADF,** Acid detergent fiber; **ADFI,** Average daily feed intake; **ADG,** Average daily gain; **CP,** Crude protein; **DM,** Dry matter; **EE,** Ether extract; **NDF,** Neutral detergent fiber*

(2007). All goats were fed in two equal portions of the diet at 08:00 and 18:00, and had free access to fresh drinking water. Samples of the ration were collected weekly, pooled at the end of the experimental period, and sub-sampled for the determination of nutrients levels.

After giving birth, all the lactating goats were fed the same basal diet without adding Zn to address the carry-over effect of Zn supplements during the pregnancy on the growth and development of the offspring. Lactating goats and their offspring were fed separately, the offspring were only placed in the parent house when they are breastfed. The kids were weaned at 60 days of age. Their birth weights (before suckling), and body weights at 30 days, 60 days and 100 days of age were recorded. At 100 day of age all kids, after overnight fasting, were slaughtered for taking liver samples. The kids did not eat the feed of the goats before weaning and the weaning diet of the kids after weaning.

Sampling and Laboratory Analysis

Blood samples were collected by the jugular vein into tubes with heparin sodium from each of the pregnant goats 10 days before kidding, and the kids at 30 days, 60 days and 100 days of age. Blood samples were kept for 2 h at room temperature and then centrifuged at 3000xg for 10 min at 4°C to harvest serum for determination of the biochemical indexes. After blood sampling, the kids were weighed, euthanized with over-dosed barbital, and bled. The liver was immediately dissected for taking samples. The liver samplers were stored at -20°C for mineral elements determination later on.

Goat feces were collected twice a day before feeding (08:00 and 18:00) for 7 days. Subsamples (2% of total weight) of fecal samples were acidified with 10% H_2SO_4 and stored at -20°C for determination of dry matter and mineral elements. Fecal samples were dried at 65°C for 48 h and stored in plastic bags until laboratory analysis.

Dietary samples were collected in the trial period, and the contents of dry matter, Ash, crude protein, crude fat and crude fiber were determined after mixing using the procedures of Jackson et al.[26]. In short, the samples of diets and feces were dried at 105°C overnight and ignited at 550°C for 6 h for measuring dry matter and Ash. Crude protein content was determined as 6.25xN. The concentration of serum biochemical indexes, including total protein (TP), albumin (ALB), alanine transaminase (ALT), AST, alkaline phosphatase (ALP), blood urea nitrogen (BUN), CREA, glucose (GLU), total glycerides (TG), CHOL, HDL, LDL, C-reactive protein (CRPL3) were determined by automatic biochemical analyzer (Cobas c311 Switzerland). The concentrations of P, Zn, Fe, Cu and K in feed, serum, feces and liver samples were determined by inductively coupled serum spectrometer (Agilent Technologies 5110 ICP-OES, American) as described by Salama et al.[19]. The samples were digested with nitric acid-perchloric acid (4:1) and filtered to volume, and then sampled on ICP-OES.

Statistical Analysis

The data were analyzed by SAS software, version 9.2 of the SAS.1, using the General Linear Model (GLM) procedure. For the pregnant goats, Zn source was considered as a factor. For data from kids, Zn source, age and sex of the kids were included as the factors, and the interactions between Zn source and age and between Zn source and sex were also considered. However, the kid sex was not attribute from the Zn treatment (supplemented during the late stage of gestation), the statistical effect of sex on the measurements are not shown in this paper. The least squares means are presented and Duncan's multiple range tests were used to compare the differences between the means. P values <0.05 are declared as statistically significant.

Results

Effects of different Zn sources on body weight (BW) and body size of the offspring are presented in *Table 2*. The BW of kid goats was affected by Zn sources, with greater BW in the ZnG group than that of the ZnS and ZnM groups ($P<0.05$). BW was also affected by the age ($P<0.01$) and sex ($P<0.01$) of kid goats. The BW was increased from birth to weaning ($P<0.05$), meanwhile BW of female kid goats

Table 2. *Body weight and body size of kid goats**

Item	Treatment	Age				SEM	P Value				
		Birth	d30	d60	d100		Treatment	Age	Sex	Treatment x Age	Treatment x Sex
Weight (kg)	ZnS	1.58	3.90	6.09	6.63	0.32	<0.001	<0.001	0.007	0.837	0.020
	ZnM	2.16	4.08	5.86	6.37	0.40					
	ZnG	2.60	5.08	7.15	7.72	0.35					
Body slanting length (cm)	ZnS	—	28.63	30.85	32.85	0.97	0.015	0.001	0.026	0.916	0.092
	ZnM	—	30.83	31.97	33.54	1.26					
	ZnG	—	31.90	33.83	34.65	1.07					
Height at withers (cm)	ZnS	—	23.42	25.86	29.97	0.82	0.055	<0.001	0.419	0.216	0.519
	ZnM	—	23.80	25.66	27.37	1.05					
	ZnG	—	25.94	28.19	29.19	0.89					
Chest circumference (cm)	ZnS	—	39.64	43.44	45.61	0.97	0.003	<0.001	0.058	0.643	0.175
	ZnM	—	42.48	44.95	47.38	1.25					
	ZnG	—	44.33	46.36	47.34	1.06					

** **ZnS,** Zinc-sulfate; **ZnM,** Zinc-methionine; **ZnG,** Zinc-glycinate chalates*

Table 3. *The blood biochemical indexes of pregnant goats**

Item	ZnS	ZnM	ZnG	SEM	P Value
TP, g/L	65.93	69.74	77.88	4.466	0.274
ALB, g/L	24.32	23.92	26.48	1.828	0.672
ALT, U/L	15.05	19.22	14.90	1.767	0.243
AST, U/L	66.00	81.40	72.50	9.348	0.556
ALP, U/L	61.67	57.00	78.00	12.673	0.828
BUN, mmol/L	6.98	7.68	7.33	0.611	0.749
CREA, μmol/L	48.17	48.00	58.50	3.411	0.145
GLU, mmol/L	1.68	1.01	1.53	0.260	0.286
TG, mmol/L	0.56	0.53	0.54	0.083	0.976
CHOL, mmol/L	3.22	2.79	3.78	0.207	0.041
HDL, mmol/L	1.53	1.28	1.84	0.118	0.043
LDL, mmol/l	1.51	1.29	1.87	0.138	0.072
CRPL3, mg/L	4.02	3.99	3.97	0.007	0.006

** **ZnS,** Zinc-sulfate; **ZnM,** Zinc-methionine; **ZnG,** Zinc-glycinate chalates*

was higher than that of males (P<0.05). And there was an interaction of Zn source and sex on the BW of kid goats, and male BW was higher than that of female under the same zinc source (P<0.05).

At 30 and 60 days of age, body slanting length of the ZnG group was greater than that of the ZnS group (P<0.05), but the difference was not significant at 100 days of age among groups (P>0.05), and the sex did not affect the body slanting length (P>0.05). Height at withers and chest circumference at 100 days were higher than that at 60 days and 30 days, and these two indexes at 60 days were higher than that at 30 days (P<0.05). The chest circumference of the ZnG group was higher than that of the ZnS group, while the difference between the ZnM group and the other two groups was not significant (P>0.05).

As shown in *Table 3*, the serum CHOL concentration of the ZnG group of pregnant goats was higher than that of the ZnM group (P<0.05). Compared to other groups, the concentration of HDL of the ZnG group increased (P<0.05). However, there were no differences between ZnM and ZnS groups (P>0.05). Moreover, the concentration of CRPL3 in ZnG and ZnM groups were higher than that of ZnS group (P<0.05). No significant differences in TP, ALB, ALT, AST, ALP, BUN, CREA, GLU, TG and LDL-C3 concentrations were observed among treatment groups (P>0.05).

The effects of the Zn sources on the serum biochemical indexes of the offspring are shown in *Table 4*. On 30 days, 60 days and 100 days of offspring in this experiment, the activities of ALT in the ZnG group were higher than that of the ZnS group (P<0.05). However, there was no

Table 4. *The blood biochemical indexes of kid goats**

Item	Treatment	Age				SEM	P Value				
		Birth	d30	d60	d100		Treatment	Age	Sex	Treatment × Age	Treatment × Sex
TP, g/L	ZnS	—	67.89	64.85	66.45	4.57	0.127	0.769	0.460	0.389	0.979
	ZnM	—	68.02	78.42	72.73	5.90					
	ZnG	—	80.58	73.69	69.88	5.02					
ALB, g/L	ZnS	—	23.90	24.86	26.19	1.87	0.029	0.293	0.703	0.80	0.648
	ZnM	—	24.39	24.86	29.22	2.41					
	ZnG	—	29.19	30.17	29.72	2.05					
ALT U/L	ZnS	—	7.69	12.86	12.85	1.30	0.058	0.664	0.713	0.003	0.080
	ZnM	—	10.46	12.43	9.28	1.67					
	ZnG	—	16.42	12.09	12.77	1.43					
AST, U/L	ZnS	—	57.67	86.44	92.22	9.57	0.227	0.532	0.918	0.131	0.687
	ZnM	—	56.49	68.06	58.20	12.34					
	ZnG	—	79.26	63.04	68.37	11.72					
ALP, U/L	ZnS	—	161.16	210.82	96.95	36.04	0.325	0.040	0.532	0.157	0.314
	ZnM	—	150.73	110.30	113.08	46.51					
	ZnG	—	138.29	287.50	143.30	39.87					
BUN, mmol/L	ZnS	—	4.60	5.27	10.16	0.84	0.318	0.010	0.232	<0.001	0.568
	ZnM	—	4.88	5.70	5.20	1.09					
	ZnG	—	8.39	4.93	5.43	0.93					
CREA, µumol/L	ZnS	—	39.38	45.27	49.94	4.59	0.010	0.236	0.354	0.849	0.324
	ZnM	—	44.37	52.79	49.51	5.91					
	ZnG	—	56.90	57.13	61.10	5.04					
GLU, mmol/L	ZnS	—	4.01	3.14	2.34	0.45	0.021	0.181	0.843	0.005	0.883
	ZnM	—	5.48	3.26	5.04	0.59					
	ZnG	—	3.07	4.10	3.47	0.50					
TG, mmol/L	ZnS	—	0.62	0.49	0.57	0.08	0.686	0.223	0.233	0.160	0.776
	ZnM	—	0.70	0.53	0.43	0.10					
	ZnG	—	0.58	0.74	0.53	0.08					
CHOL, mmol/L	ZnS	—	4.63	5.80	2.96	0.59	0.882	0.126	0.756	0.029	0.936
	ZnM	—	5.03	4.53	4.72	0.76					
	ZnG	—	3.23	5.19	4.88	0.65					
HDL, mmol/L	ZnS	—	2.12	2.29	1.47	0.23	0.222	0.485	0.770	0.022	0.930
	ZnM	—	2.31	2.08	2.23	0.30					
	ZnG	—	1.80	2.55	2.65	0.25					
LDL, mmol/L	ZnS	—	2.42	3.46	1.26	0.42	0.889	0.081	0.531	0.025	0.954
	ZnM	—	2.67	2.46	2.45	0.55					
	ZnG	—	1.41	2.74	2.69	0.47					
CRPL3, mg/L	ZnS	—	3.99	3.98	3.98	0.01	0.504	0.965	0.547	0.751	0.863
	ZnM	—	3.99	3.99	4.00	0.01					
	ZnG	—	3.99	4.00	3.99	0.01					

** **ZnS,** Zinc-sulfate; **ZnM,** Zinc-methionine; **ZnG,** Zinc-glycinate chalates*

difference in the activity of ALT between ZnM and ZnS groups (P>0.05). Moreover, the concentration of ALP on 60 days was higher than that of the 30 days and the 100 days (P<0.05). The concentration of BUN in ZnG group was higher than ZnS group on 30 days, while ZnG group was lower than that of the ZnS group on 100 days (P<0.05). The levels of BUN on ZnM were higher than ZnS group on 30 days. The concentration of CREA in the ZnG group

Table 5. *Mineral concentrations in the serum of pregnant goats**					
Item	**ZnS**	**ZnM**	**ZnG**	**SEM**	**P Value**
Cu (mg/kg)	0.17	0.17	0.20	0.017	0.439
Fe (mg/kg)	0.25	0.32	0.15	0.048	0.109
K (mg/kg)	23.63	24.06	26.20	2.729	0.784
P (mg/kg)	15.00	12.88	17.74	2.382	0.407
Zn (mg/kg)	0.20	0.78	0.05	0.286	0.240

*** ZnS,** *Zinc-sulfate;* ***ZnM,*** *Zinc-methionine;* ***ZnG,*** *Zinc-glycinate chalates*

Table 6. *Mineral concentrations in the feces of pregnant goats**					
Item	**ZnS**	**ZnM**	**ZnG**	**SEM**	**P Value**
Cu (mg/kg)	6.33	5.63	6.55	0.557	0.373
Fe (mg/kg)	127.93	94.80	119.97	5.299	0.144
K (mg/kg)	523.23	463.20	543.50	25.436	0.141
P (mg/kg)	812.70 ab	506.77b	1079.52 a	86.638	0.023
Zn (mg/kg)	15.04	15.32	15.60	1.358	0.978

*** ZnS,** *Zinc-sulfate;* ***ZnM,*** *Zinc-methionine;* ***ZnG,*** *Zinc-glycinate chalates*

was higher than that of the ZnS group (P<0.05), however, there was no difference between ZnM and ZnS groups (P>0.05). The concentration of GLU in the ZnM group was higher than that of the ZnS group on 30 days and 100 days (P<0.05). The concentrations of HDL and LDL in the ZnG group were higher than that of the ZnS group (P<0.05). However, the serum biochemical indexes of TP, ALB, AST, TG and CRPL3 were not different among these three groups (P>0.05). There was an interactive effect of Zn sources and age on the ALT, BUN, GLU, CHOL, HDL and LDL of offspring (P<0.05), and the concentrations of these indicators at d100 were higher than that of d30 and d60 under the same Zn sources (P<0.05).

The effects of the different Zn sources on the mineral (copper, iron, potassium, phosphorus and Zn) concentrations in the serum and feces of the pregnant goats are shown in *Table 5* and *Table 6,* respectively. The source of Zn had no effect on the concentrations of Zn, Cu, K, P in the serum of the pregnant goats (P>0.05). The concentration of phosphorus in the feces of the ZnG group was higher than that of the ZnM group (P<0.05), but there was no difference between the ZnG and ZnS groups (P>0.05). The source of Zn had no effect on the concentrations of copper, iron, potassium and Zn in the feces of pregnant goats (P>0.05).

The concentrations of copper, iron, potassium, phosphorus and Zn in the offspring serum and livers are shown in *Table 7*. The potassium and Zn concentrations in the serum of ZnG group were higher than that of the ZnS group (P<0.05), but there was no difference between the ZnM and ZnS groups (P>0.05). The concentration of phosphorus on 30 days was higher than that of 100 days (P<0.05), but there was no difference in serum phosphorus concentration between 60 days and 100 days (P>0.05). The concentration of iron in male goats was higher than that in female goats. There was an interaction of Zn source and age on the serum copper concentration of offspring (P<0.05). In ZnS and ZnM groups, the serum copper content of 30-day goats was significantly higher than that of 60 and 100-day, while in ZnG group, the serum copper content of 100-day goats was significantly higher than that of 30 and 60-day. The concentration of phosphorus in the liver of the female kid goats was higher than that of the males at 100 days (P<0.05), but other mineral elements were not changed by treatment, age and sex of kid goats (P>0.05).

Discussion

The aim of this experiment was to compare the different Zn sources on the productive performances, blood bio-chemical indexes and mineral concentrations in pregnant goats and their offspring, with a particular focus on the carry-over effects of the offspring. The umbilical cord and placenta are important tissues connecting the mother and the fetus. Nutrients digested and absorbed by the pregnant goats can be transferred to the fetus through the placenta, so theoretically, Zn supplemented to pregnant goats can be transferred to their fetuses to maintain the Zn status. However, the Zn utilization efficiency does differ among Zn sources, which can affect the Zn status of the offspring. This was supported by significant differences in the Zn concentration in the kids aged 30 days, where ZnG and ZnM had the high serum Zn concentration in the present study. Previous studies have shown that Zn sources, especially organic Zn, can increase daily weight gain of ruminants [6,20]. Our previous results also shown that the total and average daily weight gain of pregnant goats were increased by supplementing organic Zn at 42 days before delivery. In contrast, Niu et al.[27], and Mandal et al.[28], found that there were no significant differences

Table 7. *Mineral concentrations (mg/kg) in the serum and liver of kid goats**

Item	Treatment	Age				SEM	P Value				
		Birth	d30	d60	d100		Treatment	Age	Sex	Treatment x Age	Treatment x Sex
Serum											
Cu	ZnS	—	0.17	0.14	0.15	0.021	0.359	0.200	0.942	0.026	0.909
	ZnM	—	0.21	0.14	0.18	0.020					
	ZnG	—	0.11	0.15	0.18	0.020					
Fe	ZnS	—	0.17	0.19	0.23	0.088	0.148	0.911	0.027	0.301	0.325
	ZnM	—	0.28	0.13	0.34	0.085					
	ZnG	—	0.35	0.50	0.31	0.093					
K	ZnS	—	21.54	17.83	15.45	2.709	0.029	0.619	0.332	0.264	0.472
	ZnM	—	22.68	19.61	22.40	2.746					
	ZnG	—	24.72	30.77	25.40	2.833					
P	ZnS	—	21.01	20.55	14.38	2.010	0.279	0.027	0.163	0.580	0.473
	ZnM	—	19.66	16.40	17.10	2.038					
	ZnG	—	22.67	21.85	19.00	2.102					
Zn	ZnS	—	0.14	0.23	0.23	0.102	0.002	0.367	0.987	0.460	0.485
	ZnM	—	0.32	0.17	0.09	0.120					
	ZnG	—	0.63	0.73	0.45	0.102					
Liver											
Cu	ZnS	—	—	—	10.49	1.475	0.186	-	0.557	-	0.209
	ZnM	—	—	—	5.90	1.904					
	ZnG	—	—	—	9.85	1.971					
Fe	ZnS	—	—	—	6.08	0.574	0.554	-	0.232	-	0.261
	ZnM	—	—	—	6.18	0.741					
	ZnG	—	—	—	5.13	0.767					
K	ZnS	—	—	—	297.52	8.769	0.774	-	0.338	-	0.605
	ZnM	—	—	—	288.26	11.320					
	ZnG	—	—	—	289.66	11.718					
P	ZnS	—	—	—	370.45	7.475	0.470	-	0.045	-	0.594
	ZnM	—	—	—	376.64	9.650					
	ZnG	—	—	—	386.22	9.988					
Zn	ZnS	—	—	—	5.25	1.072	0.344	-	0.882	-	0.689
	ZnM	—	—	—	7.60	1.403					
	ZnG	—	—	—	4.81	1.479					

*** ZnS,** *Zinc-sulfate;* ***ZnM,*** *Zinc-methionine;* ***ZnG,*** *Zinc-glycinate chalates*

on average daily gain weight, average daily feed intake of growing-finishing pigs with different Zn sources.

Blood indices were used to evaluate the physiological, nutritional and pathological status of livestock. Serum TP and ALB concentrations are indicators of ruminant protein intake, and inadequate dietary protein intake leads to a decrease in TP and ALB [29]. Our results showed that ALB concentration increased in the blood of goats at the age of weaning may be due to the change from breast-feeding to feeding miscanthus and feeds, which increased the protein intake of goats. The main function of HDL was to transport excess cholesterol from the extra hepatic tissues to the liver for metabolism, so as to prevent cholesterol accumulation in these tissues. And we found that the blood total cholesterol and HDL levels of pregnant goats increased in ZnG group, and the blood contents of high density and low density lipoprotein were also increased in kid goats. The reason is that goats feeding organic Zn increased maternal or energy intake, which is conducive to the increase of body weight and body measurements. Urea is a good indicator of energy or protein imbalance and a sensitive indicator of protein utilization efficiency [30]. CRPL3 is an important inflammatory marker. It is produced in the liver under the transcriptional control of interleukin-6. CRP is produced in response to inflammation, infection, and tissue damage. It is produced in the liver and under the transcriptional control of interleukin-6 CRP. The concentrations of ALT and creatinine in blood of glycine and Zn goats increased, which indicated that liver and kidney function of goats were enhanced. Conversely, El-Hack [31] established that Zn supplementation could significantly affect serum triglyceride, total cholesterol, and LDL cholesterol (low-density lipoprotein), while HDL is not affected. Consistent with our results, Váradyová [32] demonstrated that serum concentration of CRP was significantly higher in ZnS group compared with ZnG group.

Animal body's digestion and metabolism of Zn affects the other mineral elements of digestion and metabolism of maternal intakes. Zinc can be passed to the offspring through the placenta and breast milk. Replacing ZnM with ZnS increased the concentration of potassium and zinc in the blood and liver of offspring. Pal et al.[33] found that goats fed ZnM increased the concentration of Zn in liver, which was inconsistent with our results. Váradyová et al.[32], also found that the serum concentration of Zn was higher fed a diet supplemented with organic Zn. We also found that the iron concentration in male goats was higher than that in female. The concentration of phosphorus in liver of female kid goats was higher than that of male kid goats at the 100th day, but other mineral elements did not change in treatment age and gender. In conclusion, the digestion and metabolism of Zn affect the changes of phosphorus, Zn, potassium and iron in the maternal body and its offspring.

The findings in the present study indicated that using ZnM and ZnG supplements in diets could improve the performance, and serum biochemical indexes in pregnant goats and the offspring. Moreover, based on the results of this trial, we recommend a dietary supplementation of 60 mg/kg Zn from ZnM and ZnG as practical nutrition for pregnant goats. ZnM and ZnG can be used as suitable sources Zn to replace inorganic Zn in diet to improve the production performance and immune function of gestation goats. In a nutshell, ZnG supplement is better than ZnM in this experiment.

Conflict of Interest

There is no conflict of interest.

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Author Contributions

Peihua ZHANG designed the study**.** Mengli ZHENG drafted and wrote the manuscript. Xilin LI collected and analyzed the data. Mengli ZHENG and Xilin LI performed the animal trial and laboratory analysis. Qiongxian YAN, Chuanshe ZHOU and Zhiliang TAN revised the manuscript. All authors gave intellectual input to the study and approved the final version of the manuscript.

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