Postprint on Trace Element Requirements for Weaned Lambs of Northern Shaanxi White Cashmere Goats

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Abstract

This experiment aimed to investigate the effects of different levels of trace elements on growth performance, nutrient digestion and metabolism, and trace element deposition in tissues of weaned Shaanbei white cashmere goat kids. Twenty-four 6-month-old Shaanbei white cashmere goats with a body weight of approximately 20 kg were selected and randomly divided into 4 groups, with 3 replicates per group and 2 goats per replicate. Different levels of trace elements were added to each group: Group I had dietary iron, copper, zinc, manganese, and cobalt contents of 279.30, 15.35, 63.41, 68.51, and 0.22 mg/kg, respectively; Group II had 290.14, 18.19, 81.62, and 94.10 mg/kg, respectively; Group III had 302.23, 28.20, 103.28, 133.85, and 0.43 mg/kg, respectively; Group IV had 319.74, 31.60, 126.64, 167.07, and 0.67 mg/kg, respectively. The feeding trial lasted for 65 days, including a 5-day preliminary period and a 60-day formal experimental period. On day 30 of the formal experimental period, one goat was randomly selected from each replicate (12 goats total) and placed in individual metabolic cages for a digestion and metabolism trial, with a 7-day preliminary period and a 7-day formal collection period. On the final day of the feeding trial, the remaining 12 goats were slaughtered to collect heart, liver, spleen, kidney, and longissimus dorsi muscle samples for determination of trace element deposition. The results showed: 1) The average daily gain and feed-to-gain ratio of Group II were significantly higher and lower than those of Group I ($P<0.05$), respectively, with no significant differences from Groups III and IV ($P>0.05$); the dry matter intake of Group II was significantly higher than that of other groups ($P<0.05$). 2) The fecal energy and urinary energy of Groups I and II were significantly lower than those of Groups III and IV ($P<0.05$), and the total energy digestibility was significantly higher than that of Groups III and IV ($P<0.05$). 3) Group III had the highest nitrogen retention rate, nitrogen intake, digestible nitrogen, and retained nitrogen, which were significantly higher than those of Groups I and IV (P<0.05), with no significant difference from Group II (P>0.05). 4) The apparent metabolism rates of each trace element showed a trend of first increasing and then decreasing with increasing trace element supplementation levels, with Group II having the highest apparent metabolism rates for copper, iron, manganese, zinc, and cobalt. 5) Group II had the highest manganese deposition in longissimus dorsi muscle and heart, and the highest iron, iodine, copper, and manganese deposition in liver; in spleen, Group II had the highest iron deposition, while Group IV had the highest iodine deposition; in kidney, Group II had the highest zinc deposition, and Group I had the highest iodine deposition. Under the conditions of this experiment, the optimal combination of trace element requirements for Shaanbei white cashmere goats was: iron 290.14 mg/kg, copper 18.19 mg/kg, zinc 81.62 mg/kg, manganese 94.10 mg/kg, and cobalt 0.31 mg/kg.

Full Text

Trace Element Requirements of Weaned Lambs of Shaanbei White Cashmere Goats

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Abstract

This study was conducted to evaluate the effects of different dietary trace element levels on performance, nutrient digestion and metabolism, and trace element deposition in tissues of weaned Shaanbei white cashmere goat lambs. Twenty-four healthy 6-month-old lambs with an average body weight of approximately 20 kg were selected and randomly assigned to four groups, with three replicates per group and two lambs per replicate. Each group received diets supplemented with different trace element levels: Group I contained 279.30 mg/kg iron, 15.35 mg/kg copper, 63.41 mg/kg zinc, 68.51 mg/kg manganese, and 0.22 mg/kg cobalt; Group II contained 290.14 mg/kg iron, 18.19 mg/kg copper, 81.62 mg/kg zinc, and 94.10 mg/kg manganese; Group III contained 302.23 mg/kg iron, 28.20 mg/kg copper, 103.28 mg/kg zinc, 133.85 mg/kg manganese, and 0.43 mg/kg cobalt; and Group IV contained 319.74 mg/kg iron, 31.60 mg/kg copper, 126.64 mg/kg zinc, 167.07 mg/kg manganese, and 0.67 mg/kg cobalt. The feeding trial lasted 65 days, including a 5-day preliminary period and a 60-day experimental period.

On day 30 of the experimental period, one lamb from each replicate (12 total) was randomly selected and placed in individual metabolic cages for a digestion and metabolism trial consisting of a 7-day preliminary period followed by a 7-day collection period. At the conclusion of the feeding trial, the remaining 12 lambs were slaughtered to collect heart, liver, spleen, kidney, and longissimus dorsi muscle samples for trace element deposition analysis. The results showed:

(1) Group II exhibited significantly higher average daily gain and significantly lower feed-to-gain ratio compared to Group I ($P<0.05$), with no significant differences from Groups III and IV ($P>0.05$); Group II also showed significantly higher dry matter intake than all other groups ($P<0.05$). (2) Fecal energy and urinary energy in Groups I and II were significantly lower than in Groups III and IV ($P<0.05$), while gross energy digestibility was significantly higher ($P<0.05$). (3) Group III achieved the highest nitrogen retention rate, nitrogen intake, digestible nitrogen, and retained nitrogen, which were significantly higher than Groups I and IV ($P<0.05$) but not significantly different from Group II ($P>0.05$). (4) The apparent metabolic rate of trace elements increased initially and then decreased with increasing supplementation levels, with Group II showing the highest apparent metabolic rates for copper, iron, manganese, zinc, and cobalt. (5) Group II demonstrated the highest manganese deposition in longissimus dorsi muscle and heart, and the highest iron, iodine, copper, and manganese deposition in liver; in spleen, Group II showed the highest iron deposition while Group IV showed the highest iodine deposition; in kidney, Group II exhibited the highest zinc deposition and Group I the highest iodine deposition. Under the conditions of this experiment, the optimal combination of trace element requirements for Shaanbei white cashmere goats was determined to be: iron 290.14 mg/kg, copper 18.19 mg/kg, zinc 81.62 mg/kg, manganese 94.10 mg/kg, and cobalt 0.31 mg/kg.

Keywords: Shaanbei white cashmere goats; trace elements; performance; tissue deposition

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Introduction

The Shaanbei white cashmere goat is a new breed developed primarily for cashmere production with dual-purpose utility for meat and wool, serving as an important economic resource for people in the Shaanbei region and playing an increasingly vital role in local economic development. Therefore, maximizing the production capacity and improving the production efficiency of Shaanbei white cashmere goats is crucial for promoting regional economic growth and increasing farmers' income. Although dietary trace elements do not directly participate in physiological processes such as animal growth and fat deposition, they are involved in regulating these processes and play a critical role in improving animal health and performance. Inappropriate trace element supplementation not only affects livestock growth and development but can also cause conditions such as anemia and skeletal deformities.

While NRC (1981) and AFRC (1997) have provided recommended nutrient requirements for goats, these standards lack specificity for particular breeds and their unique physiological characteristics. Notably, NRC (1981) goat feeding standards and NRC (1985) sheep feeding standards recommend identical trace element levels, and these standards have not been revised since. However, animal feeding levels and environmental conditions have changed dramatically in recent years, rendering these standards inadequate for current requirements. For example, NRC (1981) recommends a copper supplementation level of 7-11 mg/kg DM in daily goat diets, yet Lü et al. found that Small-tailed Han sheep require 25 mg/kg DM of copper. Additionally, Solaiman et al. demonstrated significant differences in copper requirements between goats and sheep, with goats requiring higher levels than sheep. Consequently, AFRC (1997) and NRC (2007) recommend conducting breed-specific studies under local ecological conditions when establishing nutritional standards.

Current research on Shaanbei white cashmere goat nutrition has progressed in protein, energy, and calcium-phosphorus requirements, but no studies have reported on copper, iron, manganese, zinc, and cobalt requirements. In practice, inappropriate trace element supplementation levels have caused urinary calculi, anemia, and skeletal deformities in Shaanbei white cashmere goats, severely affecting their health and performance. Therefore, timely research on trace element requirements is of great significance. This study investigated the effects of different dietary trace element levels on production performance, nutrient digestion and metabolism, and trace element deposition in tissues to determine the trace element requirements of Shaanbei white cashmere goats and provide a basis for dietary formulation.

1.1 Experimental Animals and Methods

Twenty-four healthy 6-month-old Shaanbei white cashmere goat lambs with similar age, body weight, and body condition were selected from the Shaanbei White Cashmere Goat Breeding Farm in Hengshan County, Yulin City, Shaanxi Province. The lambs were randomly divided into four groups with three replicates per group and two lambs per replicate, with each group receiving diets supplemented with different trace element levels. The basal diet was formulated according to NRC (2007) guidelines, with composition and nutrient levels shown in Table 1 . Supplemental forms and purity of trace elements are presented in Table 2 , while dietary trace element supplementation levels and measured values are shown in Table 3 .

1.2 Feeding Management

Lambs were housed individually in indoor pens to prevent ingestion of foreign materials other than the experimental diets. Feeding occurred at 08:00 and 16:00 daily, with 1 kg of diet provided each time to ensure ad libitum intake. Feed offered and refusals were recorded accurately each day. The feeding trial lasted 65 days (5-day preliminary period, 60-day experimental period), with free access to water throughout.

1.3 Measurements

1.3.1 Performance Lambs were weighed in replicate units after overnight fasting at the beginning and end of the trial. Daily feed intake was recorded to calculate average daily gain (ADG) and feed-to-gain ratio (F/G = dry matter intake / average daily gain).

1.3.2 Nutrient Digestion and Metabolism On day 30 of the experimental period, one lamb from each replicate (12 total) was randomly selected and placed in individual metabolic cages for a digestion and metabolism trial. After a 7-day preliminary period, total feces and urine were collected for 7 days. Feces were weighed and 10% of fresh feces were sampled daily, with 10 mL of 10% sulfuric acid added per 100 g fresh feces for nitrogen preservation. Total daily urine volume was recorded, with 10% sampled and 5 mL of concentrated sulfuric acid added per 1000 mL urine for nitrogen preservation. The 7-day fecal samples were pooled, dried at 65°C for 48 hours, re-equilibrated to air temperature, and weighed to obtain analytical samples, which were then frozen after determining initial moisture content. The 7-day urine samples were pooled and stored at -20°C for later analysis.

Routine dietary components were analyzed using conventional methods with a Kjeldahl nitrogen analyzer, bomb calorimeter, and atomic absorption spectrophotometer. Dry matter content in feces and urine, as well as fecal and urinary energy, were determined using the same instruments following methods described by He. Methane energy was estimated using the method of Blaxter et al.:

Methane energy = 3.67 + 0.062D

Where methane energy is expressed as percentage of gross energy (%GE) and D is the digestibility of gross energy intake by ewes (%).

Based on measurements of gross energy, fecal energy, and urinary energy for the four dietary groups, combined with estimated methane energy, energy metabolism indices were calculated as follows:

Gross energy digestibility (%) = [(Gross energy - Fecal energy) / Gross energy] × 100
Gross energy metabolic rate (%) = [(Gross energy - Fecal energy - Urine energy - Methane energy) / Gross energy] × 100
Digestible energy metabolic rate (%) = [(Gross energy - Fecal energy - Urine energy - Methane energy) / (Gross energy - Fecal energy)] × 100

1.3.3 Trace Elements On the final day of the experimental period, the remaining 12 lambs were slaughtered according to NY/T 1340-2007 and NY/T 1341-2007 standards. The carcasses were processed to remove unnecessary organs and fat, retaining heart, liver, spleen, kidney, and longissimus dorsi muscle.

Collected tissue samples were homogenized and stored for trace element analysis. Trace element contents (iron, manganese, copper, zinc, cobalt, iodine) were determined following GB/T 5009.90-2003, GB/T 5009.13-2003, and GB/T 5009.14-2003 methods, with each sample analyzed in duplicate.

Apparent metabolic rate of trace elements was calculated as:
Apparent metabolic rate (%) = (Trace element intake - Trace element excretion) / Trace element intake $\times$ 100

1.4 Statistical Analysis

Experimental data were initially processed using Excel 2007 and analyzed using one-way ANOVA in SPSS 19.0. Multiple comparisons were performed using LSD method, with $P<0.05$ as the significance threshold. Results are expressed as "mean $\pm$ standard deviation".

2.1 Performance

The effects of different trace element levels on performance of Shaanbei white cashmere goats are shown in Table 4 . Average daily gain increased initially and then decreased with increasing dietary trace element levels, with Group II showing the highest value, significantly higher than Group I ($P<0.05$) but not significantly different from Groups III and IV ($P>0.05$). Dry matter intake differed significantly among all groups except between Groups I and IV ($P>0.05$), with Group II significantly higher than other groups ($P<0.05$). Feed-to-gain ratio in Group II was significantly lower than in Group I ($P<0.05$) but not significantly different from Groups III and IV ($P>0.05$).

2.2 Energy Metabolism

The effects of different trace element levels on energy metabolism are presented in Table 5 . No significant differences were observed in gross energy intake among the four groups ($P>0.05$). However, fecal energy and urinary energy differed significantly between low supplementation groups (I, II) and high supplementation groups (III, IV) ($P<0.05$), showing an increasing trend with elevated trace element levels. Gross energy digestibility in low supplementation groups (I, II) was significantly higher than in high supplementation groups (III, IV) ($P<0.05$). Although methane energy, digestible energy, metabolizable energy, and gross energy metabolic rate showed no significant differences among groups ($P>0.05$), they generally exhibited an initial increase followed by a decrease with rising trace element levels.

2.3 Nitrogen Metabolism

Effects of different trace element levels on nitrogen metabolism are shown in Table 6 . Group III achieved the highest nitrogen retention rate, significantly higher than Groups I and IV ($P<0.05$) but not significantly different from Group II ($P>0.05$). Group III also had the highest nitrogen intake, significantly higher than Groups I and IV ($P<0.05$) but not significantly different from Group II ($P>0.05$). Fecal nitrogen was highest in Group I, significantly higher than Groups II and IV ($P<0.05$) but not significantly different from Group III ($P>0.05$). Urinary nitrogen was highest in Group IV, not significantly different from Group II ($P>0.05$) but significantly higher than Groups I and III ($P<0.05$). Digestible nitrogen and retained nitrogen showed the same pattern as nitrogen intake.

2.4 Trace Element Metabolism

The effects of different trace element levels on trace element metabolism are presented in Table 7 . Group II showed the highest apparent metabolic rate for copper, not significantly different from Groups I and III ($P>0.05$) but significantly higher than Group IV ($P<0.05$). Group II also had the highest apparent metabolic rate for iron, significantly higher than Group I ($P<0.05$) but not significantly different from Groups III and IV ($P>0.05$). Manganese apparent metabolic rate was highest in Group II, significantly higher than Groups III and IV ($P<0.05$) but not significantly different from Group I ($P>0.05$). Zinc apparent metabolic rate was highest in Group II, significantly higher than all other groups ($P<0.05$), with no significant difference between Groups I and III ($P>0.05$). Cobalt apparent metabolic rate was highest in Group II, significantly higher than Group IV ($P<0.05$) but not significantly different from Groups I and III ($P>0.05$). Overall, apparent metabolic rates of all trace elements increased initially and then decreased with increasing supplementation levels.

2.5 Trace Element Deposition in Tissues

Trace element deposition in various tissues is shown in Table 8 . In longissimus dorsi muscle, manganese deposition in Group II was significantly higher than in Groups I and III ($P<0.05$), with no significant differences among groups for the other five trace elements ($P>0.05$).

In heart, manganese deposition in Group III was significantly higher than in Group II ($P<0.05$), with no significant differences among groups for the other five trace elements ($P>0.05$).

In liver, iron and copper deposition in Group II were significantly higher than in Groups I, III, and IV ($P<0.05$), with Group III significantly higher than Group IV ($P<0.05$). Manganese deposition in Groups II and III was significantly higher than in Group I ($P<0.05$) but not significantly different from Group IV ($P>0.05$). Iodine deposition in Group II was significantly higher than in Groups I and IV ($P<0.05$), with no significant differences for the other two trace elements ($P>0.05$).

In spleen, iron deposition in Group II was significantly higher than in Groups I, III, and IV ($P<0.05$), with Group III significantly higher than Groups I and

IV ($P<0.05$). Iodine deposition in Group IV was significantly higher than in Groups I and III ($P<0.05$), with no significant differences for the other four trace elements ($P>0.05$).

In kidney, zinc deposition in Group II was significantly higher than in Groups I and III ($P<0.05$), while iodine deposition in Group I was significantly higher than in Groups II and III ($P<0.05$). No significant differences were observed for the other four trace elements ($P>0.05$).

Discussion

3.1 Effects of Trace Elements on Performance, Energy Metabolism, and Nutrient Metabolism

The results indicate that under the same basal dietary conditions, different trace element supplementation levels significantly affected dry matter intake in Shaanbei white cashmere goats. Yang et al. reported significant improvements in feed intake after trace element supplementation in Jinzhong sheep, while Yang et al. found no significant changes in feed intake in grazing sheep supplemented with trace elements. These discrepancies may be related to baseline trace element levels in the diet; when dietary trace elements meet animal requirements, supplementation has minimal impact on intake, whereas supplementation improves intake when requirements are not met. Feed-to-gain ratio showed an initial improvement followed by deterioration with increasing trace element levels, suggesting that trace element levels can alter dietary digestibility. The overall feed-to-gain ratios in this study were relatively high compared to previous research, likely due to breed differences. Liu reported feed-to-gain ratios of 6.10-7.50 for Hu sheep, while Li reported 9.17-11.74 for Inner Mongolian wether sheep. Since Shaanbei white cashmere goats are primarily selected for cashmere rather than meat production, their feed efficiency is inherently lower.

The gross energy digestibility and metabolic rates in all four groups were substantially lower than those reported by Wang, who found gross energy digestibility of 62.45-69.66% in Shaanbei white cashmere goats compared to 50.16-60.73% in this study. However, dry matter intake in the current study (0.97-1.03 kg/d) was considerably higher than in Wang' s study (683.54-754.00 g/d), though dietary digestible energy was similar between studies. The lower energy digestibility and metabolic rates may be attributed to age differences, as Wang used 1.5-year-old non-pregnant ewes while this study used 6-month-old lambs, in addition to differences in dietary composition. Further research is needed on the effects of different trace element levels on energy metabolism.

Currently, few studies have reported on the effects of different trace element supplementation levels on nitrogen metabolism in animals. Jia reported nitrogen retention rates of 51.12-61.12% in meat sheep under different feeding regimes, similar to the current results, though Groups II and III in this study exceeded

61.12%, indicating that these trace element levels had greater effects on nitrogen metabolism. The trends of digestible nitrogen and retained nitrogen showed initial increases followed by decreases, suggesting that trace element levels affect nitrogen utilization in Shaanbei white cashmere goats, with Group II levels approaching the optimal requirement.

Although no significant differences were observed in gross energy among groups, fecal energy, urinary energy, and methane energy tended to increase with higher trace element supplementation, indicating that excessive trace element levels increase energy loss in excreta and waste energy. Metabolizable energy and gross energy digestibility also showed initial increases followed by decreases, suggesting that trace element supplementation levels should not be excessively high.

Tian reported that supplementing Tibetan sheep with 10 mg/kg copper resulted in significantly better average daily gain and feed-to-gain ratio compared to 5 or 15 mg/kg, consistent with the current findings. Li found that appropriate copper sulfate levels in rumen fluid improved digestion of roughages like wheat straw and alfalfa by rumen microorganisms. Liu reported that different zinc levels in Liaoning cashmere goat diets did not significantly affect cashmere growth or fineness, though fineness and coarse hair length increased with higher zinc levels. Wang found that supplementing 0.25-0.50 mg/kg cobalt in meat sheep diets effectively enhanced vitamin B12 synthesis by rumen microorganisms and increased total volatile fatty acid production, particularly propionate, in the rumen. Biswas reported that manganese supplementation significantly improved rumen digestibility in cattle, while Salamone found that increasing ferrous sulfate levels did not significantly affect feed intake or average daily gain in lambs.

The apparent metabolic rates of trace elements were generally low in this study, indicating poor utilization efficiency by Shaanbei white cashmere goats. As dietary trace element levels increased from Group I to IV, the metabolic rates of copper, iron, manganese, zinc, and cobalt initially increased then decreased, consistent with findings by Zhang et al. Group II showed relatively high metabolic rates for all trace elements.

3.2 Trace Element Deposition in Tissues

Trace element deposition in tissues is influenced by multiple factors including growth rate, breed, sex, growth stage, and nutritional level. The distribution of trace elements in animal tissues is related to their metabolic characteristics and varies significantly among different tissues due to differences in physiological function and metabolic activity. Distribution patterns are affected by breed, sex, body weight, and feeding level. Substances in the body such as sugars, proteins, and fats contain hydroxyl and amino groups that can provide lone pair electrons to form coordination bonds with trace elements, promoting their absorption and utilization. Additionally, polysaccharide molecules contain free amino groups (-NH2) with adjacent hydroxyl groups (-OH) that can form cage-like molecular structures through hydrogen or salt bonds, providing stable adsorption capacity for metal ions.

3.2.1 Copper Deposition in Tissues Copper plays crucial roles in various enzyme systems including ferroxidase, cytochrome C oxidase, and copper-zinc superoxide dismutase, participating in biochemical functions such as electron transport, oxidative stress responses, transport and degradation, and superoxide dismutation. The liver regulates trace element content in the body, and hepatic trace element levels reflect both absorption efficiency and whether supplementation meets animal requirements. As the primary site for trace element metabolism and storage, the liver provides the most reliable information about trace element status. Solaiman et al. reported that goat kids fed 252 mg/kg copper showed higher weight gain than those fed 187 or 472 mg/kg, indicating that appropriate copper levels benefit animal growth. In this study, copper deposition in liver followed the same trend as performance changes, while other organs did not show similar patterns, suggesting a relationship between hepatic copper deposition and goat performance. In China' s livestock industry, increased dietary copper has been used to promote growth, but this study indicates an optimal level beyond which growth is impaired and environmental pollution from copper excretion increases. High zinc and iron supplementation may be necessary to maintain normal physiological metabolism when copper is added.

3.2.2 Manganese and Iron Deposition in Tissues Cumming et al. reported that manganese is a component of pyruvate carboxylase and plays an important role in the conversion of fat or pyruvate to oxaloacetate and glucose, improving glucose utilization, promoting adipose tissue breakdown, providing energy for protein synthesis, and enhancing protein synthesis by activating transaminases. Dietary manganese levels affect lactate dehydrogenase (LDH) activity in mink serum, with LDH activity in liver and testes decreasing synchronously when manganese is deficient, related to manganese accumulation in these tissues, indicating that appropriate manganese supplementation can increase serum LDH activity. Iron is an important participant in physiological metabolism, serving as a component of many enzymes and proteins and acting as a catalyst for numerous biochemical reactions. Iron and manganese deposition showed opposite trends in tissues other than liver, and the inhibitory effect of high iron on manganese has been consistently reported in mammals and chickens. Copper and iron also show antagonistic effects, manifested in spleen deposition, consistent with the opposite trends observed in this study.

3.2.3 Zinc and Cobalt Deposition in Tissues Zinc is a component and activator of many enzymes, exerting its effects primarily by regulating enzyme activity. Various animals have strong tolerance to high zinc levels, though tolerance varies by species, growth stage, and dietary antagonists. Ruminants are more sensitive than monogastric animals and are prone to toxicity, tolerating only about 10 times their requirement. The liver and pancreas are the main sites for zinc deposition and metabolism, with their zinc content reflecting metabolic status. In this study, zinc deposition in internal organs showed an initial increase followed by a decrease. Cobalt has a strong correlation with vitamin B12 content in the body, being stored primarily as vitamin B12 and coenzymes in the liver to exert its biological functions. In this study, hepatic cobalt deposition increased gradually with trace element supplementation levels, suggesting that cobalt supplementation had not yet reached the optimal level.

The lack of significant differences in trace element deposition among groups for some elements may be attributed to two factors: (1) dietary trace element levels were designed based on NRC (2007) recommendations, which may not meet the specific requirements of Shaanbei white cashmere goats, and interactions among elements during digestion, absorption, metabolism, and excretion may have obscured differences; and (2) different trace elements have different functions and requirements in different tissues, leading to non-significant deposition differences.

Conclusion

1. Dietary trace element levels significantly affect energy metabolism and nitrogen metabolism in Shaanbei white cashmere goats, thereby influencing performance and trace element deposition in tissues.
2. Under the conditions of this experiment, the optimal combination of trace element requirements for Shaanbei white cashmere goats was: iron 290.14 mg/kg, copper 18.19 mg/kg, zinc 81.62 mg/kg, manganese 94.10 mg/kg, and cobalt 0.31 mg/kg.

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