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The Effect of Maternal Supplementation of Zinc, Selenium, and Cobalt as Slow-Release Ruminal Bolus in Late Pregnancy on Some Blood Metabolites and Performance of Ewes and Their Lambs

Hassan Aliarabi [1] · Amir Fadayifar [2] · Reza Alimohamady [1] · Amir Hossein Dezfoulian [1]

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Abstract

The aim of this study was to determine the effect of the supplementation of a slow-release bolus of zinc (Zn), selenium (Se), and cobalt (Co) at late gestation (6 week prepartum) on performance and some blood metabolites of Mehraban ewes and their lambs until weaning. Seventy pregnant ewes, 6 weeks prior to expected lambing, were randomly divided into two groups (35 heads each) including (1) control group and (2) slow-release bolus group. Blood samples of ewes were obtained on day 10 prepartum and 45 and 90 days postpartum, and milk samples were collected on day 45. Blood samples of lambs were collected on days 10, 45, and 90. Body weight at birth and weaning and average daily gain were higher and percentage of mortality and white muscle disease rate were lower in lambs whose mothers were given a bolus ($P < 0.05$). Slow-release bolus administration increased serum alkaline phosphatase and whole blood glutathione peroxidase activity, plasma concentrations of Zn, Se, and vitamin B_{12} in ewes and their lambs ($P < 0.05$). In addition, serum creatine phosphokinase activity of lambs whose mothers were given bolus was lower ($P < 0.05$). Serum concentration of T_3 in bolus given ewes and their lambs was higher ($P < 0.05$) and serum T_4 concentration was lower ($P < 0.05$). Zinc, Se, and vitamin B_{12} concentrations in milk were significantly higher in treated ewes ($P < 0.05$). Obtained results showed that maternal supplementation of zinc, selenium, and cobalt as slow-release ruminal bolus in late pregnancy improved some mineral status of ewes and their lambs until weaning and led to higher body weights of lambs at weaning.

Keywords Sheep · Trace minerals · Controlled release bolus · Vitamin B_{12} · Serum enzymes

Introduction

Nutrient provision during gestation not only has an effect on maternal status and reproductive performance [1] but also affects prenatal and postnatal litter growth and health [2]. Although trace elements are needed by the body in small amounts, they are essential nutrients for several metabolic functions such as growth, development, reproduction, and immunity [3]. Furthermore, newborn animals are dependent upon their dams for transfer of these nutrients via the placenta and the mammary gland [4].

✉ Hassan Aliarabi
h_aliarabi@yahoo.com

1 Department of Animal Science, Faculty of Agriculture, Bu-Ali Sina University, Hamedan, Islamic Republic of Iran

2 Department of Animal science, Faculty of Agriculture, Lorestan University, Khorramabad, Islamic Republic of Iran

It has been reported that supplementation of zinc (Zn) [5], selenium (Se) [4, 6], and cobalt (Co) [7] improved indices of reproductive performance, lamb production, and health. Soils and feeds in many regions of Iran are deficient in Zn [8, 9], Se [10, 11], and Co [12, 13], and deficiency symptoms have been observed in several flocks. In extensive production systems, supplementing animals with trace elements can be difficult. Using supplemental feed as a trace element carrier incurs the costs of both feed and labor, if additional feed is not required [14]. Free access minerals, mineral licks and blocks are subject to variable intakes with animals consuming between nothing and many times the required intake [15]. Oral dosing with trace element drenches is another possible alternative. Although this ensures that each animal receives a dose, it may need regular handling, storage mechanisms for the element and/or a high animal tolerance to the levels of element given for long-term administration [14]. Previous work has shown oral drenches to be effective for only short periods in the correction of clinical copper deficiency (1–2 weeks) [16]. The controlled release bolus route should provide each animal with a consistent dose in line with its requirements sustained over a long period of time, such that one treatment of the animals should ensure adequate trace element cover for a number of months [14, 16–18]. Abdelrahman et al. [19] indicated that trace minerals slow-release bolus supplementation in Najdi ewes, raised under intensive system, improved Se, Zn, Cu, and Co status at parturition and Co, Zn, Cu, P, and Se in their newborns at birth. Additionally, the higher colostrum yield and the body weight of the newborns show positive effects of the trace mineral supplementation. However, to our knowledge, there are no studies on the mother's supplementation with slow-release trace elements ruminal bolus at late gestation and its effect on the status of the elements in the mother and the lamb until weaning. Furthermore, given that slow-release trace elements ruminal bolus should not be used for newborn lambs until weaning, the aim of this study was to determine the effect of the supplementation of slow-release bolus of Zn, Se, and Co at late gestation (6 weeks prepartum) on performance and status of mineral profile in milk and plasma of Mehraban ewes and their lambs until weaning.

Materials and Methods

Seventy pregnant Mehraban ewes (58 ± 4 kg) were randomly assigned into two groups. In the first group, 35 ewes, 6 weeks prior to the expected lambing date, were given glass boluses containing Zn, Co, and Se via a bolus gun, while animals in another group (control), were not given boluses. The boluses used in this experiment had an average weight of 18.82 g containing 20% zinc, 0.50% cobalt, and 0.23% selenium. Their average release rate in the rumen was 103.55 mg per day, and the daily supply was 23.01 mg zinc, 0.535 mg cobalt, and 0.258 mg selenium. The ewes were kept indoors as a single flock from 42 days prepartum to 30 days postpartum and fed with the same base diet (Table 1). Thirty days after parturition ewes and their lambs were turned out to medium-quality pasture. Lambs were kept together with their mothers from birth until weaning at 120 days after birth. They were weighed to determine average birth and weaning weights. Lamb mortality and white muscle disease symptoms were also recorded.

Sample Collection

Blood samples were collected from ewes (10 days prepartum, 45 and 90 days postpartum) and lambs (10, 45, and 90 days old). Blood samples were collected in two tubes in the morning (8:00 am) via the jugular vein, one containing heparin to obtain plasma and the other without heparin to obtain serum by centrifuging at 3000 rpm for 15 min. In addition, 5 mL of blood was collected into a heparinized vacutainer tube to estimate glutathione peroxidase (GSH-Px) activity. All samples were stored at − 80 °C until further analysis. Plasma samples were used to determine concentrations of Zn, Se, and vitamin B_{12} and serum samples to determine activity of alkaline phosphatase (ALP), tetraiodothyronine (T_4), and triiodothyronine (T_3) concentrations in ewes and their lambs. Also, serum creatine phosphokinase (CPK) activity was determined in lambs. Milk samples were collected from ewes on day 45 postpartum, stored at − 20 °C and finally used to determine milk Zn, Se, and vitamin B_{12} concentrations.

Minerals and Vitamin B_{12} Determination

The concentrations of Zn and Se in plasma, milk, and feeds were determined in an air-acetylene flame on an atomic absorption spectrophotometer (Varian SpectrAA220, Australia). Cobalt concentration in feeds was determined using an atomic absorption spectrophotometer (PHILIPS Model PU9100, single beam) according to the procedures of [20]. Plasma and milk concentrations of vitamin B_{12} were analyzed using a competitive binding radioimmunoassay kit, in which the non-specific vitamin B-binding R-protein was removed by affinity chromatography (ICN, Costa Mesa, CA, USA).

Enzymes and Thyroid Hormone Determination

Serum ALP and CPK activity were estimated according to the recommendations of German Society of Clinical Chemistry by available commercial kits (Pars Azmon, Tehran, Iran) and GSH-Px was measured by the method [21] of using the Ransel kit (cat. no. RS 504, Randox Laboratories Ltd., UK) by a spectrophotometer (Varian SpectrAA220, Australia). Total amounts of T_3 and T_4 were determined by enzyme-linked immunosorbent assay (ELISA) methods as explained by the commercial kit (PadtanGostar, Tehran, Iran) using an ELISA reader (ELX808, Bio-Tek, USA). Sensitivity and intra-assay coefficients of variation of the T_3 assay were 0.3 nmol/L and 7.4%, respectively. Also, sensitivity and intra-assay coefficients of variation of the T_4 assay were 12 nmol/L and 5.4%, respectively.

Statistical Analysis

The GLM procedure of SAS [22] was used for analysis of data. Birth weights, weaning weights, and average daily gain of lambs were analyzed with least squares means (LSM) using *t* test. Because the interaction between gender (male or female) and type of birth (single or twin) was not significant, their interaction was excluded from the model:

$$Y_{ijkl} = \mu + T_i + A_j + B_k + e_{ijkl}$$

where μ is the overall mean, T_i is the effect of treatment, A_j is the effect of sex (male or female), B_k is the effect of birth (single or twin), and e_{ijkl} is the effect of error.

Table 1 Ingredients and nutrient composition of the basal diet

Item	Feedstuff				Basal diet
	Alfalfa hay (35%)[a]	Corn silage (10%)	Wheat straw (23%)	Barley grain (32%)	
Dry matter (%)	92	33	94	92.5	86.72
Organic matter (%DM)	91.6	96	92.4	97.1	93.98
Crude protein (%DM)	15.8	8.5	3	12	10.91
Ether extract (%DM)	3	3	2	2	2.45
Neutral detergent fiber (%DM)	46	46	85	28	49.21
Acid detergent fiber (%DM)	35.78	28	49.4	9.69	29.78
Ash (%DM)	8.4	4	7.6	2.9	8.18
Metabolizable energy (Mcal/kg)	2.2	2.6	1.5	3.1	2.36
Calcium (%DM)	1.2	0.28	0.31	0.05	0.53
Phosphorus (%DM)	0.24	0.25	0.10	0.34	0.24
Zinc (mg/kg DM)	16.04	18.12	12.02	22.12	17.26
Selenium (mg/kg DM)	0.11	0.015	0.02	0.29	0.053
Cobalt (mg/kg DM)	0.17	0.012	0.011	0.12	0.101

[a] Percentage of ingredients in the basal diet (DM)

All factors in milk and blood were analyzed according to a completely randomized design. The model used for analysis was as follows:

$$Y_{ij} = \mu + c_i + e_{ij}$$

where μ is overall mean, c_i is the effect of treatments, and e_{ij} is the residual effects.

Duncan's multiple range tests was used for comparison of means, considering $P \leq 0.05$ as the significant level.

Number and percentage of healthy, with white muscle disease (WMD) signs and lambs alive at weaning were compared by chi-square test.

Results and Discussion

Number and percentage of lambs with WMD signs until weaning were significantly lower ($P < 0.05$), and lambs alive at weaning were significantly higher ($P < 0.05$) in lambs whose mothers were given bolus compared to animals in control group (Table 2). There were 4 dead lambs and 7 lambs with clinical signs of WMD in control group while no mortality and WMD incidence was observed in the treated group. Nutritional myopathy commonly known as "white muscle disease" is the most understood Se-responsive disease [3]. The present study showed that the boluses, by releasing selenium, ensured a substantial supply of selenium for the lambs. Similarly, Zervas [18] reported that boluses containing selenium, copper, and cobalt before pregnancy significantly decreased WMD incidence in newborn lambs.

Table 2 Number and percentage of WMD sign and dead until weaning in lambs

	Control No. (%)	Bolus No. (%)	X^2	*P* value
Pregnant ewes	35 (100)	35 (100)	0.00	1.00
Non-pregnant ewes	0.0 (0.0)	0.0(0.0)	0.00	1.00
Lambs born alive	39 (100)	38 (97.44)	2.01	0.364
Lambs with WMD signs	7 (17.95)[a]	0.0 (0.0)[b]	7.50	0.006
Lambs alive at weaning	35 (89.74)[b]	38 (100)[a]	4.11	0.042

Different superscript letters in rows represent statistical differences

Body weight at birth and weaning and average daily gain were significantly higher ($P < 0.01$) in lambs whose mothers were given bolus compared to animals in control group (Table 3). Kendall et al. [17] reported that growing lambs receiving slow-release bolus containing Zn, Se, and Co had higher daily gains. In the present experiment, three trace elements were supplemented simultaneously which may cause difficulty in determining which element is responsible for growth response. However, individual supplementation of Zn [5, 23], Se [24], and Co [12] have been reported to improve performance.

Plasma Zn concentrations in bolus given animals and their lambs were higher ($P < 0.01$) at all sampling times compared

Table 3 Birth weight, weaning weight, and average daily gain in lambs

	Control	Bolus	SEM	*P* value
Birth weight (kg)	3.32[b]	4.63[a]	0.032	>0.0001
Weaning weight (kg)	27.49[b]	33.87[a]	0.353	>0.0001
Average daily gain (kg)	0.201[b]	0.243[a]	0.037	>0.0001

Different superscript letters in rows represent statistical differences. Least squares means (LSM) corrected on the basis of gender (male or female) and type of birth (single or twin)

Table 4 Zinc concentration (mg/L) in plasma and milk of ewes and their lambs

		Time	Control	Bolus	SEM	*P* value
Ewe	Plasma					
		10 days before lambing	0.983[b]	1.394[a]	0.037	0.0005
		45 days after lambing	0.909[b]	1.425[a]	0.034	0.0001
		90 days after lambing	0.971[b]	1.402[a]	0.026	0.0001
	Milk					
		45 days after lambing	4.533[b]	6.566[a]	0.133	0.0001
Lamb	Plasma					
		10 days old	1.053[b]	1.536[a]	0.038	0.0003
		45 days old	0.957[b]	1.444[a]	0.033	0.0001
		90 days old	0.840[b]	1.427[a]	0.072	0.0022

Different superscript letters in rows represent statistical differences

to control group (Table 4). Considering plasma zinc concentration in a quoted normal range from 0.8 to1.4 mg/L [3], all ewes and their lambs had normal plasma zinc concentration; however, zinc supplementation as slow-release bolus could increase plasma zinc concentration. Similar to our findings, Kendall et al. [17, 25] reported that administration of a slow-release bolus (Zn, Co, and Se) to sheep increased plasma Zn level in animals receiving bolus compared to control group. Similar to our findings, Abdelrahman et al. [19] reported that administration of a slow-release bolus of selenium (Se), copper, zinc (Zn), cobalt (Co), phosphorous (P), manganese [26], and iodine (I) at late gestation (60 days prepartum) to ewes increased serum Zn level in newborn lambs that were born from animals receiving bolus compared to control group.

Significant correlations were reported for plasma and milk Zn concentration [27]. Hence, the higher level of plasma Zn of lambs seen in the present study (Table 4) may be a reflection of higher Zn concentration of milk in the bolus-treated group. Our result is consistent with White et al. [28] and Zali and Ganjkhanlou [29] who indicated that Zn supplementation to ewes increased milk and plasma Zn concentrations.

Table 5 Serum alkaline phosphatase activity of ewes and their lambs (U/L)

	Control	Bolus	SEM	*P* value
Ewe				
10 days before lambing	166.33[b]	184.23[a]	2.916	0.0074
45 days after lambing	169.52[b]	210.47[a]	2.973	>0.0001
Lamb				
10 days old	201.34[b]	246.18[a]	3.097	0.0002
45 days old	192.56[b]	245.82[a]	2.973	>0.0001
90 days old	169.95[b]	231.87[a]	2.897	>0.0001

Different superscript letters in rows represent statistical differences

Table 6 Selenium concentration in milk and plasma of ewes and their lambs (μg/L)

			Control	Bolus	SEM	*P* value
Ewe	Plasma					
		10 days before lambing	80[b]	163[a]	2.28	>0.0001
		45 days after lambing	91[b]	171[a]	1.82	>0.0001
		90 days after lambing	97[b]	169[a]	2.33	>0.0001
	Milk					
		45 days after lambing	21[b]	45[a]	1.87	>0.0001
Lamb	Plasma					
		10 days old	55[b]	115[a]	1.43	>0.0001
		45 days old	66[b]	121[a]	1.23	>0.0001
		90 days old	73[b]	102[a]	1.71	>0.0001

Different superscript letters in rows represent statistical differences

Alkaline phosphatase activity was higher in bolus-treated ewes, and their lamb's at all sampling times as compared to animals in control group (Table 5). The activities of enzymes which have Zn as a cofactor are indicators of Zn status in the body [3] and changes in the rates of plasma ALP may reflect changes in concentration of Zn in plasma among animals [30]. Several reports indicate that ALP activity increases at higher levels of Zn supplementation [9, 31]. Probably level of Zn in the basal diet (17.26 mg/kg DM) was not sufficient for an adequate ALP activity in ewes and their lambs, so that the administration of a slow release bolus, containing Zn, can improve the ALP activity.

Selenium concentrations in plasma and milk of bolus given ewes during the course of the study were significantly higher than those of control animals (Table 6). Our results are consistent with findings of Zervas [18], who reported that administration of slow-release bolus (Se, Cu, and Co) enhanced plasma Se level of pregnant ewes at 3 months prepartum until 3 months postpartum. Abdelrahman et al. [19] also reported that administration of a slow-release bolus of Se, Cu, Zn, Co, P, Mn, and I at late gestation (60 days prepartum) to ewes

Table 7 Whole blood glutathione peroxidase activity of ewes and their lambs (μkat/L)

	Control	Bolus	SEM	*P* value
Ewe				
10 days before lambing	217.3[b]	960.5[a]	56.18	0.0002
45 days after lambing	205.0[b]	1043.1[a]	41.98	>0.0001
Lamb				
10 days old	221.8[b]	1033.8[a]	36.72	>0.0001
45 days old	265.5[b]	1047.1[a]	58.30	0.0002
90 days old	294.5[b]	997.5[a]	59.71	0.0004

Different superscript letters in rows represent statistical differences

Table 8 Serum T_3 concentration of ewes and their lambs (nmol/L)

		Control	Bolus	SEM	*P* value
Ewe	T_3				
	10 days before lambing	1.61[b]	1.86[a]	0.037	0.0002
	45 days after lambing	1.41[b]	1.84[a]	0.047	>0.0001
Lamb	T_3				
	10 days old	1.57[b]	1.86[a]	0.044	0.0057
	45 days old	1.49[b]	1.81[a]	0.029	0.0006
	90 days old	1.52[b]	1.85[a]	0.040	0.0021

Different superscript letters in rows represent statistical differences

increased serum Se level in newborn lambs. Furthermore, addition of Se to the maternal diet increased Se concentration in serum of newborn calves [32], kids [33], and lambs [34].

Concentration of Se in milk depends on the selenium status of sheep [35] and increase in plasma Se concentration can increase its concentration in milk. The concentrations of selenium in colostrum and main milk can both be raised by inorganic selenium supplements in sheep [4] and goats [36], but selenomethionine is by far the more effective [37–39].

Glutathione peroxidase activity of lambs born from Se-treated ewes (Table 7) was higher than those born from the control ewes, and these differences were sustained to weaning ($P > 0.05$). The glutathione peroxidase has been used as an indicator of Se status in animals. Misurova et al. [40] reported a significant correlation between activity of GSH-Px and blood selenium concentrations in newborn kids. Increased activity of GSH-Px as a result of Se supplementation in the present, is in agreement with the results of Lacetera et al. [41] who reported that injections of selenium at 30 days before parturition increased the activity of glutathione peroxidase before and after parturition in pregnant ewes. Also, Zervas [18] indicated that administration of a slow release bolus (Cu, Co, and Se), 3 months prepartum to ewes, increased the glutathione peroxidase activity until 3 months postpartum. The antioxidant system of living organisms includes enzymes such as superoxide dismutase, glutathione peroxidase, and catalase. Cooperation of all the different antioxidants provides greater protection against attack by reactive oxygen, than any single compound alone. In earlier research, the greater SOD and GSH-Px activity observed in Zn supplemented lambs and ewes [31] indicated that at least 15 mg Zn/kg DM supplementation was required for obtaining higher antioxidant enzyme activities.

Table 9 Serum T_4 concentration of ewes and their lambs (nmol/L)

		Control	Bolus	SEM	*P* value
Ewe	T_4				
	10 days before lambing	85.73[b]	72.30[a]	0.451	>0.0001
	45 days after lambing	85.45[b]	72.33[a]	0.608	>0.0001
Lamb	T_4				
	10 days old	77.99[b]	64.01[a]	1.425	0.0010
	45 days old	81.23[b]	68.36[a]	1.940	0.0054
	90 days old	80.78[b]	68.61[a]	0.678	>0.0001

Different superscript letters in rows represent statistical differences

Table 10 Serum creatine phosphokinase activity of lambs (U/dL)

	Control	Bolus	SEM	*P* value
Lamb				
10 days old	284.57[b]	77.98[a]	39.04	0.0134
45 days old	488.32[b]	78.01[a]	29.21	0.0002
90 days old	279.02[b]	77.36[a]	28.02	0.0038

Different superscript letters in rows represent statistical differences

Serum T_3 concentration (Table 8) was significantly higher and serum T_4 concentration (Table 9) was significantly lower in bolus given ewes and their lambs as compared to animals in control group ($P > 0.01$). Similar to our findings, the increased serum T_3 and the decreased serum T_4 has been reported in growing male lambs supplemented with 0.2 mg Se/kg DM [11]. Normal thyroid status is dependent on the presence of some trace elements (I, Se, Zn, and Fe) for both the synthesis and metabolism of thyroid hormones [42]. Selenium has a critical role in the synthesis and homoeostatic control of the thyroid hormones. About 80% of T_3 in serum is produced in the liver, kidney, and muscle, and all these tissues contain the selenium dependent enzyme deiodinases that convert T_4 to T_3 [43]. Positive correlations were also reported between plasma selenium level of ewes and T_3 level of their lambs ($r = 0.72$) and between milk Se concentration and lamb plasma Se concentration ($r = 0.84$) [35]. Probably, consumption of milk containing higher concentration of selenium by lambs born from ewes which received bolus is one of the reasons for the results obtained in the present study.

This result was in agreement with the finding of Abou-Zeina et al. [44] who reported that zinc supplementation increased total T_3. In addition to its participation in protein synthesis, Zn is essential for proper thyroid function. It is involved in T_3 binding to its nuclear receptor [45]. Also, Zn participates in synthesis and action of thyrotropin-releasing hormone (TRH). Pekary et al. [46] reported that the processing of prepro-TRH to form TRH is Zn dependant via post-translational processing enzymes such as carboxypeptidase. El-Tohamy [47] indicated that Zn alone or combined with Se deficiencies resulted in a decrease in thyroid function. Zinc deficiency can also indirectly affect thyroid hormone status by decreasing energy intake [48].

Serum CPK in lambs, whose mothers received bolus, was significantly lower at all sampling times as compared to lambs born in control group (Table 10). Creatine phosphokinase is a muscle enzyme that is strictly related to muscular damage. So, serum activities of CPK were measured as an indicator of muscle injury [49]. Due to selenium deficiency in plants grown in several parts of Iran and low level of selenium in

Table 11 Vitamin B_{12} concentration in milk and plasma of ewes and their lambs

		Time	Control	Bolus	SEM	*P* value
Ewe						
	Plasma (nmol/L)					
		10 days before lambing	432.53^{b}	737.47^{a}	14.34	>0.0001
		45 days after lambing	361.39^{b}	839.35^{a}	12.88	>0.0001
	Milk (mg/L)					
		45 days after lambing	2325^{b}	3640^{a}	44.68	>0.0001
Lamb						
	Plasma (nmol/L)					
		10 days old	175.03^{b}	305.14^{a}	12.81	0.0008
		45 days old	203.88^{b}	349.75^{a}	13.64	0.0006
		90 days old	303.89^{b}	561.78^{a}	40.29	0.0069

Different superscript letters in rows represent statistical differences

the basal diet, increased activity of CPK in the lambs born in the control group was expected. This could also be correlated with the higher level of WMD seen in this group. Similar to our findings, there are some reports on effect of Se supplementation [50] and Se injection [10] on CPK activity in sheep fed a basal diet deficient in Se. In contrast, there was no significant difference for CPK activity in fattening lambs fed a basal diet containing 0.06 mg Se/kg DM (control group) or basal diet + 0.2 mg Se/kg DM [11]. This difference may be related to the type of diet used, since it has been demonstrated that selenium absorption in forage based diets (present study) is less than diets with high levels of concentrate [51].

Plasma concentration of vitamin B_{12} in bolus-treated ewes and their lambs was significantly higher as compared to control (Table 11). In addition, milk concentration of vitamin B_{12} in treated ewes was significantly higher than that of animals in the control group. The only known animal requirement for cobalt is as a constituent of vitamin B_{12}, which has about 4% cobalt in its chemical structure. This means that a cobalt deficiency is really a vitamin B_{12} deficiency [52]. Microorganisms in the rumen are able to synthesize vitamin B_{12} needs of ruminants, if the diet is adequate in cobalt. In lambs, until the rumen becomes functional, the only vitamin B_{12} supply is their mother's milk. However, at birth, the rumen is not yet functional and becomes functional when the lambs are older. The lambs start to produce their own vitamin B_{12} from about 1 month of age, when the rumen becomes functional. It is believed that the concentration of vitamin B_{12} in the milk is a reliable index of cobalt sufficiency in ruminants [53]. Higher concentrations of vitamin B_{12} in blood of the lambs born from ewes receiving bolus on day 10 may be associated with higher vitamin B_{12} levels in milk. Considering increasing trend in both groups from d 10 to d 90 in plasma vitamin B_{12} which should be duo to cobalt supplied from the feed to the rumen microorganisms, the significant difference between the two groups may be related to the higher vitamin B_{12} content of the bolus group. Similarly, Zervas [18] indicated that administration of a slow-release bolus (Cu, Co, and Se) at 3 months prepartum to ewes increased the plasma concentrations of vitamin B_{12} until 3 months postpartum. Furthermore, Andrews and Stephenson [54] reported that cobalt supplementation of pregnant ewes enhanced vitamin B_{12} status of their lambs due to increases in the fetal reserves of the vitamin and supply of vitamin B_{12} from milk.

Conclusion

Obtained results showed that maternal supplementation of Zn, Se, and Co as slow-release ruminal bolus in late pregnancy improved some mineral status of ewes and their lambs until weaning and led to higher body weights of lambs at weaning.

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