The effects of maternal supplementation of selenium and iodine via slow-release blouses in late pregnancy on milk production of goats and performance of their kids

Mehrshad Rashnoo, Zaman Rahmati, Arash Azarfar and Amir Fadayifar

Faculty of Agriculture, Department of Animal science, Lorestan University, Khorramabad, Iran

ABSTRACT
Forty pregnant dairy goats were used in a 2 × 2 factorial arrangement of treatments to evaluate the effects of prepartum supplementation of selenium (Se) and iodine (I) as slow-release boluses. The boluses were administered four weeks prior to the expected kidding time to supply daily amounts of (1) 0 mg Se and 0 mg I, (2) 0 mg Se and 0.40 mg I, (3) 0.25 mg Se and 0 mg I and (4) 0.25 mg Se and 0.4 mg I. Milk production, milk fat percentage, daily production of milk components, milk selenium and iodine concentrations were greater in goats received 0.25 mg Se/day than no supplemental Se (p < .05). Milk production, daily production of milk compounds, milk iodine concentration, serum T₃ and T₄ concentrations in goats received 0.40 mg I/day were greater than goats received no supplemental I (p < .05). Bodyweight at weaning and average daily gain in kids whose mothers were received 0.25 mg Se/day were greater than zero Se (p < .05). Bodyweight at weaning and average daily gain in kids whose mothers were given 0.40 mg I/day were greater than zero Se (p < .05). Serum Se and T₃ concentration and whole blood glutathione peroxidase activity were significantly greater in goats and their kids received 0.25 mg Se/day than goats received no supplemental Se (p < .05). There was no Se level × I level interaction for all assessed parameters. Results showed that maternal supplementation of Se and I as a slow-release ruminal bolus in late pregnancy improved milk production of grazing goats and the performance of their kids.

HIGHLIGHTS
- Intra-ruminal administration of slow-release boluses containing selenium and iodine improved milk production of grazing goats.
- Kids from goats receiving supplemental selenium and iodine via intra-ruminal boluses perform better.
- Intra-ruminal administration of slow-release boluses containing selenium in late pregnancy improved the antioxidant status of grazing goats and their kids.

Introduction
The transition period from pregnancy to lactation encompasses intense metabolic activities for the dairy ruminant. Nutrient requirements increase drastically as a consequence of the terminal foetus and the imminent start of milk secretion (Conway et al. 1996; NRC 2007; Celi et al. 2008). Like the other ruminants, goats are very sensitive to nutritional deficiency during pregnancy because rapid foetal growth during the last six weeks of pregnancy leads to a metabolic challenge requiring the mobilisation of maternal body tissue (Osuagwuh and Aire 1990). Thus, an inadequate nutrient supply during the late pregnancy may result in weight loss in does and reproductive wastage, including abortion and neonatal death as a result of low birth weight (Osuagwuh 1992; Sibanda et al. 1997; Cappai et al. 2019). Therefore, provision of adequate nutrients during the transition period not only affects maternal status and reproductive performance (Wettemann et al. 2003), but it also affects prenatal and postpartum litter growth and health (Godfrey and Barker 2000; Wu et al. 2006). Among the nutrients, provision of trace elements for ruminants in such a critical period is of great importance as they are necessary for normal foetal growth and lactation.
Among the micronutrients, selenium (Se) and iodine (I) are essential trace elements for animal health, production and reproduction. Principally, the role of Se is in the active site of several antioxidant proteins including glutathione peroxidases (GSH-Px) (Beckett and Arthur 2005). Furthermore, iodothyronine deiodinase type 1 (ID1) is another selenoenzyme which is responsible for peripheral activation of triiodothyronine (T₃) from thyroxine (T₄) in liver and kidneys (Beckett and Arthur 2005). Iodine is involved in the synthesis of the thyroid hormones, namely T₃ and T₄. These hormones have important roles in thermoregulation, increasing cellular respiration and energy generation, and also have widespread effects on intermediary metabolism, growth, development, reproduction, muscle function, immune defence, and circulation (Herdt and Hoff 2011).

Iodine and selenium are elements whose clinical deficiencies are well known in newborn ruminants. Clinical selenium deficiency results in many disorders related to tissue lesion such as white muscle disease (WMD), an illness that causes high mortality in young ruminants (Suttle 2010). Clinical iodine deficiency is characterized by cardinal signs of goitre, whereas subclinical deficiency is difficult to diagnose because clinical signs are not evident (Bhardwaj 2018). Iodine deficiency is a common problem among humans and livestock throughout the world. Prevalence is very high in goats due to less access to soils and browsing habits of goats (Bhardwaj 2018). It is primarily due to deficiency of iodine in soil, feed, fodder, and water or due to the presence of goitrogen in the diets of animals. In ruminants, iodine deficiency has been associated with the late foetal development, early embryonic mortality, abortions, stillbirths and births of weak newborn, prolonged gestation, placental retention (Hetzel and Mano 1989; Ferri et al. 2003) and decreased foetal brain weight (Potter et al. 1986).

Unfortunately, soils and feeds in many regions of Iran are deficient in Se (Mohri et al. 2011; Alimohamady et al. 2013; Zarbalizadeh-Saed et al. 2020) and I (Emami et al. 1969; Masoudi et al. 2010) and deficiency symptoms related to these elements have been reported in several flocks. Therefore, the objective of this study was to investigate the effects of supplementation of dairy goats with either Se or I, or both via intra-ruminal administration of slow-release blouses in the late pregnancy on milk production and milk composition of goats, performance of their kids, and some blood metabolites of goats and their kids.

Materials and methods

Animal care and use were approved by the Ethical Committee of Lorestan University and conducted according to the guidelines of Iranian Council of Animal Care (1995). Among 120 dairy goats that were previously oestrus synchronised, 40 pregnant goats (bodyweight 43.22 ± 2.22 kg) were selected after ultrasound examination, approximately 120 days of pregnancy. Oestrus was synchronised with two intramuscular injections of prostaglandin (250 mg/mL cloprostenol, estroplan, Paranel Laboratories (Australia Pty Ltd, Alexandria, NSW) administered 9 days apart. For each 5 goats, a buck was introduced to the herd. Four weeks prior to the expected kidding, goats were randomly allotted to 4 groups and received intraruminal slow-release blouses with four different formulations of a single bolus to supply: (1) 0 mg Se and 0 mg I (Se₀I₀), (2) 0 mg Se and 0.40 mg I (Se₀I₀.₄₀), (3) 0.25 mg Se and 0 mg I (Se₀₀.₂₅I₀), and (4) 0.25 mg Se and 0.4 mg I (Se₀₀.₂₅I₀.₄₀) daily. The goats were kept indoors as a single flock from mating time to 30 days prepartum, and fed with the same diet (Table 1). Thirty days before parturition goats were brought back to the pasture (Lorestan-Iran province; 46 degrees 51 minutes 50 degrees 3 minutes east and 32 degrees 37 minutes 34 degrees 22 minutes north latitude) where nutritional myopathy was very common and causes great losses in lambs and kids. The goats and their kids remained at the pasture until the end of the experiment. Kids had free access to the same hay and were offered ad libitum a barley grain. The kids were weighed at birth and weaning (day 60 of age) to determine average birth and weaning weights.

Blood sample collection

Blood samples were collected from goats (10 days prepartum, 30 and 60 days postpartum) and kids (10, 30 and 60-days-old). Blood samples were collected in the morning (8:00 am) via the jugular vein into two tubes, one containing heparin to determine whole blood GSH-Px activity and the other one without heparin to obtain serum by centrifuging at 3000 rpm for 15 min. All samples were stored at −20°C pending further
analyses. Serum samples were used to determine creatine phosphokinase (CPK) activity and concentrations of Se, T₃ and T₄ in goats and their kids.

**Estimation of milk production and sample collection**

Milk production was estimated once a week for each goat, from week 5 to 8 of lactation by suckled-hand method (Peniche et al. 2015). Kids were separated from their dams for 12 h beginning at 20:00 h. The day after kids were weighed with a digital weighing scale (5 g/kg of precision) at 8:00 h and at that moment they were allowed to suckle the goat for 10 min, then kids were weighed again immediately to estimate the amount of milk suckled. Additionally, after suckling, the goats were hand milked soon after to get the milk left in their udders and this quantity of milk was recorded. In order to obtain the residual milk in dams an intramuscular injection of three IU of synthetic oxytocin (Aranda Laboratories, Queretaro, Qro., Mexico) was used. During the separation period, kids were located in pens allowing having sight and smelling contact with their dams while avoiding suckling. After measuring the milk production, kids were kept with their dams for the rest of the day.

Daily milk production was calculated by summing up the milk suckled by kids (the difference between kid’s weights) and milk obtained by the hand milking. Then, the result of this calculation was multiplied by two, with the aim to extrapolate the estimation of the milk production in 24 h period. Milk samples were collected on the eighth week and analysed for fat, protein, solids-nonfat and lactose concentration using an automatic Milk-O-Scan 133B analyser (Foss Electric, Denmark).

**Feed analysis and determination of minerals**

Feeds were analysed for dry matter (DM), organic matter (OM), crude protein (CP), ether extract (EE), ash and non-fibre carbohydrates (NFC) using standard procedures of AOAC (2000). Neutral detergent fibre (NDF) and acid detergent fibre (ADF) were analysed according to Van Soest et al. (1991). The Ca contents of feed samples were estimated in an air-acetylene flame on an atomic absorption spectrophotometer (model Varian spectra AA220, Australia). Selenium was measured in the serum, feed and milk using the hydride generation atomic absorption spectrophotometry method, after wet digestion of samples in a closed nitric acid and hydrogen peroxide system and subsequent hydrogen chloride reduction (Pechova et al. 2005). Milk and feed samples were analysed for iodine concentration by inductively coupled plasma mass spectrometry (PerkinElmer-SCIEX, Model Elan DRC II, Thornhill, Canada) conducted in the isotope dilution mode with ¹²⁹I – as the isotopic tracer (Dyke et al. 2009). Feed samples were homogenised using a Retch Grindomix GM200 knife mill (Verder Scientific, Inc., Newtown, PA). Samples of 1 g for feeds and 2 g for milk were weighed and placed into 50 mL BD Falcon centrifuge tubes (BD Biosciences, Bedford, MA). After addition of 10 mL of 5% Tetramethylammonium hydroxide (electronic grade, purity > 99.9999%, Ward Hill, MA), the samples were vortexed for 1 min followed by a heating step at 85 °C for 3 h. After cooling, the tubes were vortexed and gravimetrically diluted to approximately 50 g with water. The samples were mixed again by vortexing and centrifuged at 3000 rpm for 10 min. 20 mL aliquots of the samples were poured in 50-mL capacity centrifuge tubes (BD Biosciences, Bedford, MA). After addition of 10 mL of 5% Tetramethylammonium hydroxide (electronic grade, purity > 99.9999%, Ward Hill, MA), the samples were vortexed for 1 min followed by a heating step at 85 °C for 3 h. After cooling, the tubes were vortexed and gravimetrically diluted to approximately 50 g with water. The samples were mixed again by vortexing and centrifuged at 3000 rpm for 10 min. 20 mL aliquots of the samples were poured in 50-mL capacity centrifuge tubes and centrifuged at 16,000 rpm at 15 °C for 30 min (Sorvall RC-6+, www.thermo.com; Fiberlite F-13-14X50CY rotor, www.piramoon.com). The liquid portion of the resulting sample was decanted to the top of a pre-washed PL-10 Centricon Plus-20 centrifugal filter device (UFC2 LGC 24, www.millipore.com) and centrifuged at 5000 rpm at 15 °C for 90 min. A 0.5 g aliquot of pre-washed Amberlyst 15 macroreticular cation exchange resin (www.sial.com) was added to the dialyzate; the sample was vortexed for 5 min and allowed to stand for

| Table 1. Ingredients and nutrient composition of the pre-experimental diet. |
|-----------------|-----------------|-----------------|-----------------|
| **Item**       | Alfalfa hay (35%) | Wheat straw (40%) | Barley grain (25%) | Basal diet |
| Dry matter (DM), % | 92              | 94              | 93.5            | 92.92       |
| Organic matter (%DM) | 91.60         | 92.40           | 97.10           | 93.29       |
| Crude protein, %DM | 15.70          | 3.30            | 11.70           | 9.74        |
| Ether extract, %DM | 3.10           | 2.10            | 2.30            | 2.50        |
| Neutral detergent fibre, %DM | 46.60       | 85.40           | 28.10           | 57.50       |
| Acid detergent fibre, %DM | 36.90       | 50.40           | 10.20           | 39.02       |
| Ash, %DM | 8.4            | 7.6             | 2.9             | 6.71        |
| Metabolizable energy, Mcal/Kg | 2.2          | 1.5             | 3.1             | 2.11        |
| Calcium, %DM | 1.10           | 0.31            | 0.05            | 0.52        |
| Phosphorus, %DM | 0.24           | 0.10            | 0.34            | 0.21        |
| Iodine, mg/kg DM | 0.23           | 0.17            | 0.28            | 0.22        |
| Selenium, mg/kg DM | 0.15          | 0.02            | 0.12            | 0.09        |

*Percentage of ingredients in the pre-experimental diet (DM)
10 min. The samples were then taken into a prewashed 10-mL disposable syringe and passed through a prewashed 25 mm, 0.45 μm pore size nylon membrane syringe filter prior to analysis. The resulting samples were diluted $10^3$ with water for ICP-MS analysis, and spiked to a concentration of 10 μg/L of $^{129}$I – prior to analysis.

**Enzymes determination**

Serum CPK activity was determined according to the recommendations of German Society of Clinical Chemistry by the available commercial kit (Pars Azmon, Tehran, Iran) and GSH-Px was measured using the Ransel kit (cat. no. RS 504, Randox Laboratories Ltd., UK) by a spectrophotometer (Varian SpectrAA220, Australia) (Paglia and Valentine 1967).

**Thyroid hormones determination**

Total concentrations of T3 and T4 were determined by enzyme-linked immunosorbent assay (ELISA) using a commercial kit (PadtanGostar, Tehran, Iran) by an ELISA reader (ELX808, Bio-Tek, USA). Sensitivity and intra-assay coefficients of variation of the T3 assay were 0.3 nmol/L and 7.4%, respectively. Also, sensitivity and intra-assay coefficients of variation of the T4 assay were 12 nmol/L and 5.4%, respectively.

**Statistical analysis**

Birth weights, weaning weights, an average daily gain of kids and all factors in milk were analysed as a $2 \times 2$ factorial arrangement of treatments based on a completely randomised design using the GLM procedure of (SAS. 2004). The model used was:

$$Y_{ijk} = \mu + A_i + B_j + AB_{ij} + e_{ijk}$$

where $\mu$ is overall mean, $A_i$ is the effect of $i$th level of Se supplement; $B_j$ is the effect of $j$th level of I supplement; $AB_{ij}$ is the interaction of $A_i$ and $B_j$ and $e_{ijk}$ is the residual effect.

Other traits including whole blood GSH-Px activity and the serum concentrations of Se, CPK, T3 and T4 were analysed as repeated measures using the following model:

$$Y_{ijklm} = \mu + A_i + B_j + AB_{ij} + T_l + AT_{jl} + BT_{jl} + ABT_{ijl} + e_{ijklm}$$

where $\mu$ is the overall mean, $A_i$ is the effect of $i$th level of Se supplement; $B_j$ is the effect of $j$th level of I supplement; $AB_{ij}$ is the interaction of $A_i$ and $B_j$; $T_l$ is the effect of time; $AT_{jl}$ is the interaction of $A_i$ and $T_l$; $BT_{jl}$ is the interaction of $B_j$ and $T_l$; $ABT_{ijl}$ is the interaction between $A_i$, $B_j$ and $T_l$; and $e_{ijklm}$ is the residual effect.

Duncan’s multiple range tests was used for comparison of means, considering $p \leq .05$ as the significant level.

**Results**

**Production performance of goats and their kids**

Milk production, milk composition and performance of kids are presented in Table 2. The interaction effect of Se $\times$ I had no effect on milk production, percentage of milk composition, daily production of milk compounds and performance of kids. Regardless of I level, milk production, milk fat percentage, daily production of milk compounds, milk selenium and iodine concentration in goats received 0.25 mg Se per day were greater than those received no supplemental Se ($p < .05$). Selenium supplementation had no effect on percentage of protein, lactose and solids-nonfat in milk ($p > .05$). Regardless of Se level, milk production, daily production of milk compounds, milk iodine concentration in goats received 0.40 mg I per day were greater than those not supplemented with I ($p < .05$). Iodine supplementation had no effect on percentage of fat, protein, lactose and solids-nonfat in milk ($p > .05$). Regardless of I level, body weight at weaning and average daily gain in kids whose mothers received 0.25 mg Se per day via an intra-ruminal bolus were greater than in those whose mothers were not given intra-ruminal Se boluses ($p < .05$). Regardless of Se supplementation level, body weight at weaning and average daily gain in kids whose mothers were received 0.40 mg Se per day as intra-ruminal bolus were greater than zero I ($p < .05$).

**Selenium status and activities of GSH-Px and CPK**

Serum concentrations of Se, CPK activity, and activity of whole blood GSH-Px in different days are presented in Table 3. The interactions of Se $\times$ I and treatment $\times$ time did not influence serum Se concentration and activities of GSH-Px and CPK in goats and their kids. Regardless of I supplementation, serum Se concentration and whole blood GSH-Px activity were significantly greater in goats received 0.25 mg Se per day than in not-supplemented goats ($p < .05$). Selenium Se supplementation had no effect on serum CPK activity of goats ($p > .05$). Regardless of Se status, I supplementation had no effects on serum Se concentration, whole blood GSH-Px activity and serum CPK activity of
goats (p > .05). Regardless of I status, serum Se concentration and activity of GSH-Px were significantly greater, while serum CPK activity was significantly lower in kids whose mothers received 0.25 mg Se per day as intra-ruminal bolus than those received no Se containing bolus (p < .05). Maternal supplementation of I had no significant effects on serum Se concentrations and activities of GSH-Px and CPK of kids.

### Serum concentrations of thyroid hormones in goats and their kids

Serum T₃ and T₄ concentrations and T₄/T₃ of goats and their kids at different sampling days are presented in Table 4. No interaction was detected between Se and I supplementation for serum T₃, T₄ concentrations and T₄/T₃ in goats and their kids. Serum T₃ concentration was significantly greater, while serum T₄ concentration and T₄/T₃ were significantly lower in goats and their kids received 0.25 mg Se daily via intra-ruminal administration of a slow-release bolus than those received no supplemental Se (p < .05). Serum T₃ and T₄ concentration was significantly greater and T₄/T₃ was significantly lower in goats and their kids received 0.40 mg I per day than those received no supplemental I via a slow-release bolus containing I (p < .05).

### Discussion

#### Production performance of goats and their kids

Similar to our findings, Tufarelli and Laudadio (2011) observed that dietary supplementation of dairy goats with 0.20 mg/day Se as Na-selenite along with 20 mg/day vitamin E increased milk production of dairy goats compared with control group. Meyer et al. (2014) demonstrated that colostrum and milk production were greater in lactating cows fed the high Se level diets (0.44 mg Se/kg DM) during gestation compared with those fed with diets containing adequate level of Se (0.28 mg Se/kg DM). Moreover, Wang et al. (2009) and Bagnicka et al. (2017) also showed that Se supplementation increased milk yields of dairy cow. Colostrum production during the first 3 days and the daily milk productions during the first 4 weeks of lactation did not increase in treated goats compared with the controls (Kachuee et al. 2014).

Our result confirms the findings of previous works where dietary Se supplementation improved both milk fat content and yield in dairy cows (Liu et al. 2008; Calamari et al. 2010), goats (Pechova et al. 2008; Tufarelli et al. 2011) and ewes (Lacetera et al. 1999). A number of studies also confirmed that Se
supplementation can affect lipid metabolism in ruminants (Netto et al. 2014). It has been reported that Se supplementation increases the content of polyunsaturated fatty acids, especially conjugated linoleic acid isomers in lambs' meat and liver (Gabryszuk et al. 2007) as well as in cow's (Ran et al. 2010) and goat's (Pechova et al. 2008) milk.

The results of the current study support the general idea that Se supplementation does not markedly affect milk concentrations of protein, lactose and solids-nonfat (Charmley et al. 1993; Juniper et al. 2006). In contrast, Khalifa et al. (2016) observed that milk protein content in dairy cows was significantly increased when diets supplemented with Se. Also, dietary supplementation of dairy goats with 0.20 mg/head/day Se as Na-selenite and 20 mg/head/day vitamin E increased milk protein content compared with not-supplemented goats (Tufarelli et al. 2011).

Our result confirms the previous findings that dietary supplementation of dairy goats (Pechova et al. 2008) with Se increased milk selenium concentration. It has been shown that milk Se concentration depends on the selenium status of sheep (Hefnawy et al. 2014), and that an increase in plasma Se concentration may lead to increased milk Se concentration. Pechova et al. (2008) reported that in white shorthaired goats fed a diet based on hay containing 0.1 mg Se/kg DM, milk Se content was 12.5 µg/L. In the present study, average milk concentration of selenium was 7 µg/L, which was increased to 11.5 µg/L after Se supplementation.

In our study, I supplementation through the slow-release boluses increased milk fat content of goats compared with not-supplemented animals, which agrees with the previous findings (Pechova et al. 2008; Nudda et al. 2009). However, in the other studies

### Table 3. Serum selenium (Se, µg/L), whole blood glucose peroxidase activity (GSH-Px, µkat/L) and serum creatine phosphokinase activity (CPK, U/dL) of goats and their kids.

|                  | Se     | GSH-Px | CPK  | Se     | GSH-Px | CPK  |
|------------------|--------|--------|------|--------|--------|------|
| **Goats**        |        |        |      |        |        |      |
| Treatment¹       |        |        |      |        |        |      |
| Se0I0            | 69.50b | 77.56b | 170.58| 39.18b | 68.50b | 198.32a|
| Se0I0.40         | 69.54b | 77.48b | 203.53| 38.90b | 69.28b | 200.00a|
| Se0.25I0         | 94.52a | 230.25a| 182.28| 69.89 a| 263.12 a| 157.14b|
| Se0.25I0.40      | 94.45a | 228.72a| 181.98| 71.29 a| 264.13 a| 163.83b|
| SEM              | 1.22   | 1.61   | 12.38| 0.84   | 1.86   | 7.33 |
| **Kids**         |        |        |      |        |        |      |
| Se level         |        |        |      |        |        |      |
| Se0              | 69.52  | 77.52  | 186.14| 39.05  | 68.87  | 199.11|
| Se0.25           | 94.48  | 229.48 | 182.13| 71.29  | 264.13 | 163.83b|
| SEM              | 0.86   | 1.14   | 8.75 | 0.59   | 1.31   | 5.18 |
| I level          |        |        |      |        |        |      |
| I0               | 82.35  | 153.91 | 176.27| 54.12  | 163.18 | 178.28|
| I0.40            | 81.67  | 153.10 | 192.45| 55.56  | 169.49 | 181.4 |
| SEM              | 0.86   | 1.14   | 8.75 | 0.59   | 1.31   | 5.18 |
| **Time**         |        |        |      |        |        |      |
| −10 or 10        | 76.53b | 147.05c| 139.67b| 49.71b | 151.46c| 214.13a|
| 30               | 85.20b | 154.53b| 212.58a| 57.02a | 163.03b| 163.29b|
| 60               | 84.27b | 158.92b| 200.15a| 57.72a | 184.25a| 161.98b|
| SEM              | 0.86   | 1.14   | 8.75 | 0.59   | 1.31   | 5.18 |
| **p-Value**      |        |        |      |        |        |      |
| Treatment        | <.0001 | <.0001 | .22  | <.0001 | <.0001 | .0017|
| Se level         | <.0001 | <.0001 | .6245| <.0001 | <.0001 | .0002|
| I level          | .8228  | .5842  | .2007| .4167  | .3252  | .8225|
| Se level × I level| .7906  | .6225  | .1938| .6030  | .6262  | .575 |
| Time             | <.0001 | <.0001 | .0001| <.0001 | <.0001 | <.0001|
| Treatment × time | .9356  | .3907  | .8463| .6678  | .7568  | .0798|

Means with different superscript letters in columns are significantly different (p < .05).

¹Se0I0: 0 mg Se and 0 mg I; Se0I0.40: 0 mg Se and 0.40 mg I; Se0.25I0: 0.25 mg Se and 0 mg I; Se0.25I0.40: 0.25 mg Se and 0.4 mg I.

SEM: standard error of the mean.
dietary I supplementation ranging from 0.1 to 7.6 mg/kg DM had no effect on milk fat content in dairy cows (Norouzian et al. 2009). Angelov et al. (2011) observed that daily milk fat production was increased by 35% in Se-I- supplemented ewes compared to the not-supplemented ones, which was due to a higher milk production in the former groups as both elements have important roles in intermediary metabolism and are involved in normal function of mammary glands.

Our results are consistent with previous findings where iodine supplementation in dairy animals increased milk concentration of iodine (Nudda et al. 2009; Moschini et al. 2010), and enhanced the supply of iodine to suckling animals and humans. Groppel (1991) noted that the colostrum and milk of sheep and goats contained more iodine than that of cows under the same diet, and that iodine concentrations of less than 62 μg/L in goats and 79 μg/L in sheep are considered as deficient. Concentrations of milk iodine in goats received slow-release boluses containing I showed the sufficient I supply, while those from unsupplemented goats (118.37 vs. 71.43 μg/L, respectively) indicated the marginal I deficiency.

In this study, maternal Se supplementation significantly increased growth performance of kids so that kids of Se-supplemented goats were heavier at weaning and had a greater pre-weaning average daily gain (Table 2). In agreement with our findings, Zarbalizadeh-Saed et al. (2020) reported that intra-ruminal administration of a slow-release bolus containing Se at late gestation to ewe increased performance of their lambs. Moreover, injection of vitamin E plus Se in ewes 4 weeks prepartum and during the suckling period for 12 weeks significantly improved pre-weaning body weight and daily weight gain of their offspring (Soliman et al. 2012). Such improvements may be an indication of a greater efficiency of feed utilisation in treated-goats and viability of their offspring.

Regardless of Se supplementation, kids from I-supplemented goats had a greater pre-weaning ADG and were heavier at weaning (Table 2), which was in agreement with findings of Zarbalizadeh-Saed et al. (2020). Aghwan et al. (2016) reported a greater ADG and final body weight in I-supplemented growing male goats compared with the control animals. The improved average daily gain in kids of I-supplemented goats could be attributed to the greater thyroxine concentrations which may modify their metabolic processes (Aghwan et al. 2013).

### Selenium status and activities of GSH-Px and CPK

In this study, a significant effect of Se supplementation on serum Se concentration of goats was observed.

| Table 4. Effects of Se and I supplementation in late pregnancy of dairy goats on serum T3, T4 concentrations (nmol/L) and ratio T4/T3 of goats and their kids. |
|---|---|---|---|---|---|---|---|
| **Goats** | **Kids** |
| **T1** | **T4** | **T4/T3** | **T1** | **T4** | **T4/T3** |
| **Treatment** | | | | | | |
| Se0I0 | 1.55<sup>d</sup> | 56.24<sup>c</sup> | 36.08<sup>b</sup> | 1.94<sup>d</sup> | 56.89<sup>c</sup> | 29.26<sup>c</sup> |
| Se0I0.40 | 2.06<sup>d</sup> | 63.42<sup>a</sup> | 30.83<sup>b</sup> | 2.35<sup>c</sup> | 69.11<sup>a</sup> | 29.42<sup>c</sup> |
| Se0.25I0 | 2.23<sup>b</sup> | 53.93<sup>d</sup> | 24.10<sup>c</sup> | 2.55<sup>d</sup> | 50.04<sup>d</sup> | 19.62<sup>c</sup> |
| Se0.25I0.40 | 2.73<sup>a</sup> | 60.45<sup>b</sup> | 22.15<sup>d</sup> | 2.92<sup>d</sup> | 62.11<sup>b</sup> | 21.28<sup>b</sup> |
| SEM | 0.01 | 0.63 | 0.39 | 0.02 | 0.83 | 0.38 |
| **Se level** | | | | | | |
| Se0 | 1.79 | 59.63 | 33.60 | 2.13 | 62.66 | 29.34 |
| Se0.25 | 2.48 | 57.19 | 23.12 | 2.73 | 56.05 | 20.45 |
| SEM | 0.01 | 0.45 | 0.27 | 0.01 | 0.72 | 0.27 |
| **I level** | | | | | | |
| I0 | 1.88 | 55.11 | 30.25 | 2.23 | 53.55 | 24.57 |
| I0.40 | 2.40 | 61.89 | 26.37 | 2.64 | 65.55 | 25.23 |
| SEM | 0.01 | 0.45 | 0.27 | 0.01 | 0.72 | 0.27 |
| **Time** | | | | | | |
| –10 or 10 | 2.14 | 58.67 | 28.43 | 2.44 | 59.80 | 25.10 |
| 30 | 2.14 | 58.49 | 28.34 | 2.43 | 59.27 | 24.87 |
| 60 | 2.13 | 58.07 | 28.31 | 2.43 | 58.99 | 24.70 |
| SEM | 0.01 | 0.55 | 0.34 | 0.01 | 0.59 | 0.33 |
| **p-Value** | | | | | | |
| Treatment | .0001> | .0001> | .001> | .0078 | .001> | .001> |
| Se level | .0001> | .0024 | .001> | .0001> | .0001> | .0001> |
| I level | .0001> | .0001 | .0001 | .0001 | .0001 | .0101 |
| Se level × I level | .8541 | .7350 | .0886 | .2467 | .9437 | .9744 |
| Time | .8420 | .9320 | .8712 | .4039 | .8434 | .6070 |
| SEM | 0.01 | 0.55 | 0.34 | 0.01 | 0.59 | 0.33 |

Means with different superscript letters in columns are significantly different (p < .05).

1Se0I0: 0 mg Se and 0 mg I; Se0.40: 0 mg Se and 0.40 mg I; Se0.25: 0.25 mg Se and 0 mg I; Se0.25I0.40: 0.25 mg Se and 0.4 mg I. SEM: Standard error of the mean.
Our results are consistent with findings of Zervas (1988) who reported that administration of slow-release bolus containing Se, Cu and Co enhanced plasma Se level of pregnant ewes from 3 months prepartum until three months postpartum. Furthermore, Hefnawy et al. (2014) reported that Se injection in pregnant ewes, 8 and 5 weeks before lambing and 1 week after lambing increased pre and post-partum serum Se concentration. Aliarabi et al. (2019) also observed the increased plasma concentration of Se in Se-supplemented ewes.

In line with our results, Pechova et al. (2012) found that maternal Se supplementation in goats resulted in a heavier kids at birth with a greater serum Se concentration. Abdelrahman et al. (2017) also reported that intraruminal administration of a slow-release bolus containing Se, copper, zinc, cobalt, phosphorous, manganese and iodine at late gestation to ewe increased serum Se level in the newborn lambs. It has been shown that selenium administration to the mother increased serum Se level in the newborn lambs, because the milk selenium level was greater in Se-supplemented ewes than unsupplemented ones, at least for the first 2 months of lactation (Aliarabi et al. 2019). Maternal Se supplementation increased serum Se concentration in newborn kids (Kachuee et al. 2014) and lambs (Hefnawy et al. 2014; Erdoğan et al. 2017; Zarbalizadeh Saed et al. 2020). Hefnawy and Törtora-Pérez (2010) demonstrated that prepartum dietary supplementation of Se in sheep had a vital role in maintaining optimal plasma selenium level, while postpartum addition of Se ensured an optimal milk production. Serum concentrations of kids in experimental groups showed the sufficient Se supply, whereas those form unsupplemented animals (70.59 vs. 39.05 μg/L, respectively) showed Se deficiency. Deficiency is defined as an animal with a blood Se concentration of below 80 μg/L (Bickhardt et al. 1999). However, other authors report serum Se concentration ranging from 63 to 158 μg/L as the reference values for goats (Schweinzer et al. 2017).

The results of the current study indicated that prepartum I supplementation had no effect on serum Se concentration in both goats and their kids, which was in consistent with findings of Aghwan et al. (2013) who reported that I supplementation had no effect on serum Se concentration in goats. Zarbalizadeh-Saed et al. (2020) also reported that intraruminal administration of a slow-release bolus containing I at late gestation to ewe had no effect on serum Se concentration their lambs. Increased activity of GSH-Px in goats as a result of prepartum Se supplementation in this study was in consistent with the results of Lacetera et al. (1999) where injection of pregnant ewes with selenium at day 30 prepartum increased the activity of GSH-Px pre and post-partum. Also, Zervas (1988) indicated that intra-ruminal administration of a slow release bolus containing Cu, Co and Se, 3 months prepartum in ewes, increased the GSH-Px activity until three months postpartum. Pavlata et al. (2012) also found that Se supplementation in pregnant goats increased GSH-Px activity on the day of parturition. Ran et al. (2010) also indicated that Se supplementation in pregnant cows increased GSH-Px activity after calving.

Similar to our results Pechova et al. (2012) reported that prepartum supplementation of pregnant goats with Se increased whole blood GSH-Px activity of their kids at the time of weaning. Pavlata et al. (2012) also observed that whole blood GSH-Px activity of kids whose dams supplemented with Se was significantly greater on the day of parturition compared to those whose dams were not supplemented with Se. Zarbalizadeh Saed et al. (2020) reported that intra-ruminal administration of a slow-release bolus containing Se at late gestation to ewe increased GSH-Px activity in their lambs. Aliarabi et al. (2019) also reported that administration of a slow-release bolus containing Se, zinc and cobalt, at the late gestation to ewe increased GSH-Px activity in the newborn lambs.

We found that prepartum I supplementation of pregnant goat in the late gestation via the administration of slow-release blouses containing I or I along with Se had no effect on whole blood GSH-Px activity in them, which agrees with findings of Aghwan et al. (2013). In the present study, the lack of an effect of I supplementation on the activity of GSH-Px in goats and their kids might be attributed to the low level of I supplementation. Xu et al. (2011) showed that the activities of GSH-Px and type 1 5’-deiodinase were significantly decreased in rats supplemented with excessive I. Additionally, Qin et al. (2011) reported that supplementing goats with 2 mg I/kg DM had no effect on serum activity of GSH-Px, while the activity of serum GSH-Px was decreased when goats supplemented with excessive I (4 mg/kg DM) compared to the not-supplemented group. The authors speculated that excessive I could have resulted in the production of free radicals during the metabolism of thyroid hormones, which in turn could increase the oxidative damage in thyroid gland and consequently resulted in extra consumption of GSH-Px for the protection of thyroid gland.
Selenium supplementation had no effect on serum CPK activity in goats, but significantly decreased serum CPK activity in their kids, which was in agreement with some previous reports in sheep (Faixova et al. 2007; Mohri et al. 2011; Zarbalizadeh-Saed et al. 2020). Aliarabi et al. (2019) also reported that administration of a slow-release bolus containing Se, Zn and Co, in the late gestation in ewes decreased CPK activity in the newborn lambs. While overt lesions of muscular dystrophy were not observed in this study, the low whole blood GSH-Px activity, low serum selenium concentrations, and elevated serum CPK activity in kids born form unsupplemented goats with selenium was an evidence for marginal selenium deficiency in goats not receiving Se.

**Thyroid hormones status in goats and their kids**

The results of present study showed that thyroid activity and secretion of its metabolic hormones could be modified in goats and their kids by prepartum Se supplementation via administration of a slow-release bolus. Similar to our findings, the increased serum T₃ and the decreased serum T₄ has been reported in ewes and their lambs supplemented with Se (Aliarabi et al. 2019). Similar T₄ response to Se supplementation was reported by El-Shahat and Monem (2011) in Baladi ewes, but they found insignificant increase in plasma T₃ level. In dairy cows, parental administration of vitamin E and Se, 4 weeks prior to parturition, significantly increased T₃ concentration (Pavlata et al. 2004). In a study, Se supplementation in goats resulted in a significant increase in serum concentration of T₃ and T₃/T₄ in concomitant with a decrease in serum T₄ concentration (El-Sisy et al. 2008). Normal functioning of thyroid depends on the presence of some trace elements (I, Se, Zn and Fe) for both the synthesis and metabolism of thyroid hormones (Arthur et al. 1999). Selenium has a critical role in the synthesis and homoeostatic control of the thyroid hormones. About 80% of T₃ in serum is produced in the liver, kidney, muscle, and all these tissues contain the selenium depended enzyme deiodinases that convert T₄ to T₃ (Köhrl 2000). Positive correlations were also reported between plasma selenium level of ewes and T₃ level of their lambs ($r = 0.72$), and between milk Se concentration and lamb’s plasma Se concentration ($r = 0.84$) (Hefnawy et al. 2014). Therefore, consumption of Se enriched milk by kids born from goats received supplemental Se via administration of intraruminal slow-release bolus would explain the greater serum concentration of T₃ and lower serum T₄ concentration and T₄/T₃ in them compared to the kids born from non-Se supplemented goats.

The present study also showed that thyroid activity and secretion of its metabolic hormones could be modified in goats and their kids by prepartum I supplementation through intra-ruminal administration of slow-release. Similar to our findings, the increased serum T₃ and T₄ has been reported in dairy goats supplemented with 0.90 mg/day I as KI (Nudda et al. 2013). Zarbalizadeh-Saed et al. (2020) also reported that intra-ruminal administration of a slow-release bolus containing Se and I at late gestation to ewe increased serum concentrations of T₃ in the newborn lambs. Pattanaik et al. (2001) reported that the concentrations of T₃ and T₄ were significantly greater when goats received 0.075 mg I daily. Additionally, Qin et al. (2011) reported that the concentration of T₄, but not T₃ was significantly increased by I supplementation in Cashmere goats. Our results are consistent with findings of Qin et al. (2011) who found no interaction between I and Se supplementation on serum concentrations of thyroid hormones. While overt hyperplasia of the thyroid tissue (goitre) were not observed in this study, the low milk iodine concentration and elevated serum T₃ and T₄ concentrations in unsupplemented goats with iodine provided the evidence for marginal iodine deficiency in them. Iodine supplementation as intra-ruminal I boluses restored these values to the normal values.

**Conclusions**

Our results showed that maternal supplementation of selenium and iodine as slow-release ruminal bolus in late pregnancy increased milk production of grazing goats and performance of their kids.

**Disclosure statement**

No potential conflict of interest was reported by the author(s).

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