Supplementation of different selenium sources during early lactation of native goats and their effects on nutrient digestibility, nitrogen and energy status

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ABSTRACT
The aim of this study was to compare the effects of two Se sources on the early lactation of native goats, on nutrient digestibility, as well as nitrogen and energy status of Iranian native goats. Twenty-one native goats aged, approximately 41 ± 9 months and having body weights of 46 ± 8 kg were selected for the experiment. The goats were randomly divided into three groups with an equal number of goats. One group was supplemented with Selemax 2000™ as the organic selenium (OS), the second group received diluted sodium selenite as the inorganic selenium, while the third group received no supplementation and served as the control group (C). The results of this research showed that the selenium supplementation did not have a significant effect on nutrient digestibility (apart from crude fat) (P > .05) but, the dry matter, organic matter and crude protein intake significantly increased. However, faecal N, urinary N, total N production and energy status were affected by the treatments (P < .05). It can be concluded that OS seems to be a better choice, considering the nitrogen and energy available for metabolism and its partition between milk production and deposit/mobilization within the body.

Introduction
The interest in selenium (Se) by nutritionists is as a result of its high concentration in a certain range of plants and the consequent toxicosis in animals that grazed on these plants. Consequently, the essential nature of selenium has become the centre of attention, and this element is now known to be required by laboratory animals, food animals (including fish) and humans (NRC 1983). Selenium is involved in several biological functions and its supplementation is necessary in farm animals. Mainly, Se is bound to proteins, and many of them have enzymatic functions. A group of selenium-dependent enzymes, glutathione peroxidase, thioredoxin reductase, iodothyronine deiodinase, seleno-phosphate synthetase 2, selenoprotein P and different kinds of selenoproteins are involved in the reduction of oxidized antioxidants, scavenging reactive oxygen species, synthesis of thyroid hormones, protection of DNA and proteins from oxidation, redox signals and immune responses (Lu & Holmgren 2009). Dietary Se can be supplemented with the inorganic or organic forms. Due to a different metabolism, inorganic forms are characterized by a lower bioavailability in comparison to the organic forms (Weiss 2005). The most common symptoms of Se deficiency are subclinical symptoms such as weakness in kids, reduced feed consumption and pregnancy complications (NRC 2007). During pregnancy, Se is efficiently transferred to the placenta and prioritized to the fetus (Ghanzy-Hefnawy et al. 2007).

On the other hand, studies with regard to the effect of Se on nutrient digestibility are few (Serra et al. 1994; Hernandez-Calva et al. 2007). Some effects on microbial activity and digestibility could be observed with a relatively high concentration of Se in the diet (Rodriguez et al. 2013). It was hypothesized that short-term Se supplementation may improve the performance of goats during the transitional period, with a minimal impact on production cost. Therefore, the aim of this study was to evaluate the effect of supplemental Se, as sodium selenite or in its organic form, on nutrient digestibility, as well as nitrogen and energy status in the early lactation of native goats.

Materials and methods
Management, experimental design and sampling of goats
Twenty-one pregnant, Iranian native goats aged approximately 41 ± 9 months and having body weights (BW) of 46 ± 8 kg and 9 ± 12 days in milk were selected for the experiment. After parturition, all the goats were randomly divided into three groups, housed in individual metabolic cages and fed the same basal ration twice daily for 45 days. One group was supplemented with Selemax 2000™ (150 mg per head per day, containing 0.3 mg organic selenium (OS) in the form of selenomethionine) as OS, the second group received 1 mg hydrated sodium selenite per head per day, containing 0.3 mg selenium as inorganic selenium (IS) and the third group received no supplementation and served as the control group (C). The dosage of Se supplement for each group mixed with 10 ml warm water and offered to goats by help of drencher. The goats were receiving Se supplement twice daily before feeding; half dose was given at each time.
Good-quality sun-dried alfalfa was chopped into a size of about 1–3 cm lengths and formed 40% of the ration. The selenium content in the basal diet was 0.15 ppm (dry matter, DM basis). The ingredients used in preparing the total mixed rations are shown in Table 1. The goats were fed on the diets twice daily at 07.00 and 16.00 h; half the ration was given at each feeding. Clean water was offered ad libitum. Daily feed intake was recorded by collecting any feed remnant (usually less than 10% of total daily feed) before each morning feeding.

**Digestion trial**

On the last three days of the experiment, the rations and remnants were sampled daily for determination of DM offered and DM remnants, respectively. The urine of each goat was collected in a plastic bucket and sampled two times per day. The amount of urine was measured by volume and 10% of it was taken and placed in a separate bottle for each animal and stored at 4°C until analysis. The total faeces for each goat were weighed during the last three days of the experiment and 10% of it was taken for future analysis. Feeds and faeces samples were oven dried at 60°C. All the samples were grounded on a 0.9-mm screen prior to determining the chemical composition.

**Chemical analysis**

Samples of feed and faeces were analysed for crude protein (CP) (copper catalyst Kjeldahl method ID 984.13), fat (solvent extraction method ID 991.36) and ash (ID 923.03) content (AOAC 2003). Ash in fibre residues was determined by ignition at 525°C and neutral detergent fibre (NDF) was determined as ash-free NDF according to the method of Mertens (2002). The total N content of urine samples was analysed using the Kjeldahl method. Total urine energy was estimated according to Street et al. (1964).

**Calculation and statistical analysis**

Crude protein was defined as (CP: nitrogen × 6.25). Dermal losses of CP as scurf and fibre were calculated as a function of

**Table 1. Ingredients and nutrient composition of experimental diet.**

| Feedstuff          | g/kg          |
|--------------------|--------------|
| Alfalfa hay        | 400          |
| Barley grain       | 400          |
| Corn grain         | 190          |
| Dicalcium phosphate| 5            |
| Na bicarbonate     | 5            |
| Dry matter (g/kg)  | 884          |
| ME (Mcal/kg)       | 2.664        |
| **Chemical composition (g/kg DM)** |            |
| CP (X × 6.25)      | 141.7        |
| RDPa               | 105.4        |
| UDPb               | 36.3         |
| Crude fatb         | 27.3         |
| NDFb               | 277.9        |
| Ashb               | 46.6         |
| NFCc               | 506.5        |
| Seleniumb          | 0.00015      |

Note: ME, metabolizable energy; CP, crude protein; RDP, rumen degradable protein; UDP, undegradable rumen protein; NDF, neutral detergent fibre; NFC, non-fibre carbohydrate.

aAnalysed in nutrition laboratory.
bCalculated from other parameters which comes from laboratory analyse.
cCalculated according to NRC (2007) for diet component.

BW. For lactating goats, the assumption of 0.2 g/kg BW$^{0.60}$ of NRC (2007) was used.

According to AFRC (1992), tissue protein is mobilized with an efficiency of 1.0, and hence, Net protein is equal to Metabolizable protein. In this way, and according to AFRC (1992), MP from live weight loss is equal to 119 g/kg. The mean of milk protein in native goats of the Animal Husbandry Station was reported to be 35.728 g/kg fresh milk. To calculate the amount of nitrogen in milk, the index of 6.38 was used. The Nitrogen (N) content in milk production was calculated as follows:

\[
\text{N Milk (g/day)} = (\text{N intake} + \text{N from body loss}) - (\text{Fecal N} + \text{Urinary N} + \text{Scurf N}).
\]

Milk production (kg/day) = N milk (g/day)/5.6.

Definition and conversion of energy expression was calculated as follows (NRC 2007):

1 kg total digestible nutrient (TDN) = 4.4 Mcal digestible energy (DE) = 3.6 Mcal Metabolizable energy (ME).

Tissue accreted or mobilized by all the goats was assumed to have an energy concentration of 5.71 Mcal/kg. For lactating goats, it was assumed that all the mobilized tissue energy was used for milk production (NRC 2007). For all the goats, ME requirements were determined for 1 kg of 4% fat-corrected milk (FCM; 1.25 Mcal/kg) (NRC 2007). Metabolizable energy for maintenance requirements (MEM) was calculated as follows:

\[
\text{MEM (Kcal/day)} = (\text{ME intake Kcal/day} + \text{ME from body loss Kcal/day}) - (\text{ME in FCM Kcal/day}).
\]

This experiment was designed based on three types of Se supplementation (OS, IS and C) in seven replicates for each treatment. All measurements in the chemical analysis were performed in at least, duplicate. A complete randomized design was used to indicate significant differences between the groups (P < .05). All data were analysed using SAS (2009).

**Results**

A summary of the influence of Se supplementation on DM intake and apparent digestible parameters is presented in Table 2. The DM, organic matter (OM) and CP intake were affected by Se sources. Organic source of Se increased more than 25% DM, OM and CP intake when compared to the inorganic source of Se (P < .05). Goats in the control group showed no significant difference in DM, OM and CP intake (P > .05).

Apart from crude fat, no significant difference was found for all other apparent nutrient digestibility, as well as total digestible nutrients (P > .05). Selenium supplementation in both forms (organic and inorganic), increased crude fat digestibility (P < .05).

Table 3 shows the results obtained for utilization of N from diet consumed and Table 4, the results obtained for energy
The mean daily DM, OM and CP intake was found to be similar among the control and IS groups, which indicated that supplementation of IS at the 0.3 ppm level in Holstein cows (Fehrs et al. 1981), at the 0.3 ppm level in buffalo calves (Mudgal et al. 1981), and at the 0.65 ppm level in Merino weathers (White & Somers 1977). Similarly, supplementation of Se at the 1 ppm level in male Holstein (Fehrs et al. 1995), at the 0.3 ppm level in beef steers (Lawler et al. 2004) and at the 0.65 ppm level in crossbred beef steers (Lawler et al. 2004) and at the 0.65 ppm level in guinea pigs (Mahima 2006) also did not have any effect on DMI. In this way, the results of Wichtel’s (1995) study suggested that selenium supplementation in kids, does not affect the short-term intake of a Se-deficient diet. The selenium concentrations of basal diets in the above literature were contained from 0.02 ppm (Wichtel’s 1995) to 0.23 ppm in study of Mudgal et al. (2008). However, DM, OM and CP intake were influenced by OS supplementation in the present study, which is consistent with the findings of Hemken (1998) who reported a significant increase in the daily DM intake in 0.15 and 0.3 ppm Se-supplemented lactating cows when compared to the unsupplemented cows. On the other hand, Tian et al. (2006) showed dietary ME used for maintenance was greater for those that consumed the control diet as compared to the Se supplementation groups (P < .05). In this manner, the Se supplementation was found to affect the following ratio values of ME intake (P < .05; Table 4): urinary energy, maintenance energy and production energy.

**Discussion**

The mean daily DM, OM and CP intake was found to be similar among the control and IS groups, which indicated that supplementation of IS at the 0.30 mg per head per day level had no effect on palatability and feed intake pattern of the animals. The results of most earlier studies are consistent with the present study results, where DMI remained unaffected due to supplementation of IS at the 0.3 ppm level in Holstein cows (Ivancic & Weiss 2001), at the 0.38 ppm level in crossbred beef steers (Lawler et al. 2004) and at the 0.65 ppm level in Merino weathers (White & Somers 1977). Similarly, supplementation of Se at the 1 ppm level in male Holstein (Fehrs et al. 1981), at the 0.3 ppm level in buffalo calves (Mudgal et al. 2008) and at 0.1, 0.2 and 0.3 ppm levels in guinea pigs (Mahima 2006) also did not have any effect on DMI. In this way, the results of Wichtel’s (1995) study suggested that selenium supplementation in kids, does not affect the short-term intake of a Se-deficient diet. The selenium concentrations of basal diets in the above literature were contained from 0.02 ppm (Wichtel’s 1995) to 0.23 ppm in study of Mudgal et al. (2008). However, DM, OM and CP intake were influenced by OS supplementation in the present study, which is consistent with the findings of Hemken (1998) who reported a significant increase in the daily DM intake in 0.15 and 0.3 ppm Se-supplemented lactating cows when compared to the unsupplemented cows. On the other hand, Tian et al. (2006) showed dietary ME used for maintenance was greater for those that consumed the control diet as compared to the Se supplementation groups (P < .05). In this manner, the Se supplementation was found to affect the following ratio values of ME intake (P < .05; Table 4): urinary energy, maintenance energy and production energy.

**Table 3.** Nitrogen status (g/kg metabolic BW per day) in goats on different selenium supplements.

| Item                      | Control | OS   | IS   | RMSE | Probability |
|---------------------------|---------|------|------|------|-------------|
| Nitrogen intake           | 1.65    | 1.77 | 1.42 | 0.322| 0.166       |
| Digestible nitrogen intake| 0.977   | 1.178| 0.954| 0.271| 0.262       |
| Faecal nitrogen           | 0.670a  | 0.591a| 0.466| 0.170| 0.105       |
| Urinary nitrogen          | 0.696a  | 0.437b| 0.432b| 0.159| 0.008       |
| Body weight change nitrogen| 0.105  | 0.031| 0.093| 0.154| 0.266       |
| Milk nitrogen             | 0.368   | 0.723| 0.699| 0.350| 0.179       |
| Total nitrogen production | 0.279b  | 0.755a| 0.678a| 0.266| 0.020       |
| Fecal N/intake            | 0.391   | 0.336| 0.327| 0.076| 0.347       |
| Urine N/intake            | 0.435a  | 0.241b| 0.271b| 0.096| 0.009       |
| Digestible N/intake       | 0.609   | 0.664| 0.673| 0.076| 0.347       |
| Milk N/intake             | 0.252   | 0.395| 0.459| 0.182| 0.212       |
| Total N production/intake | 0.162a  | 0.413a| 0.391a| 0.137| 0.015       |
| Urine N/Digestable N      | 0.741a  | 0.366b| 0.403b| 0.186| 0.008       |
| Milk N/Digestable N       | 0.398   | 0.589| 0.682| 0.266| 0.254       |
| Total N production        | 0.240b  | 0.619a| 0.581a| 0.187| 0.008       |
| Milk N/Total N production | 3.508   | 0.952| 1.581| 2.970| 0.306       |

Note: OS, organic selenium; IS, inorganic selenium; RMSE, root mean square error. Means in row with no common superscript differ significantly (P < .05).
that pigs fed organic Se had a greater DMI when compared with unsupplemented animals fed during the growing phase, while Payne and Southern (2005) showed no effect for broilers. The selenium concentration of basal diets in Tian et al. (2006) study was 0.06 ppm and in Payne and Southern (2005) experiment the selenium concentration of basal diets in starter and grower were 0.12 ppm and in finisher was 0.11 ppm.

It is concluded that increased appetite is likely to be the primary mechanism involved in the production response to OS (selenomethionine) supplementation in Iranian native lactating goats.

The digestibility of organic nutrients (apart from crude fat) and TDN was also found to be similar ($P > .05$) among the three groups (Table 2), suggesting that supplementation of Se in both forms (organic and inorganic) had no effect on the digestibility of these nutrients. In agreement with these observations supplementation of 1 ppm of Se had no effect on the digestibility of OM, CP and NDF in cattle calves (Nicholson et al. 1991). Similarly, there was no effect of 0.3 ppm selenium supplementation on intake and digestibility of organic nutrients in male buffalo calves (Mudgal et al. 2008) and 0.1, 0.2 and 0.3 ppm Se supplementation on intake and digestibility of OM, CP, EE and crude fibre in guinea pigs (Mahima 2006) and lambs (Kumar 2006). These results indicated that supplementation of selenium up to 0.3 ppm level in the diet of lactating goats had no effect on the digestibility of organic nutrients. No reason was found for higher crude fat digestibility in goats when supplemented with Se. However, similar to the present findings, Glienke and Ewan (1977) found an improved digestibility of ether extract in 0.05 ppm Se supplemented pigs. On the contrary, there was no effect on the digestibility of EE in growing lambs (Kumar 2006) and male buffalo calves (Mudgal et al. 2008) supplemented with 0.15 and 0.3 ppm Se, respectively.

With respect to the values obtained for N utilization (Table 3), the first noteworthy part is that, the supplementation of selenium in the diet of lactating goats affected N utilization. Lactating goats in the present experiment showed the same excretion of nitrogen via urine and faeces. However, goats on Se supplementation had lower N excretion via better N absorption and metabolism. On the other hand, lower N release from the body reserve and higher N production via milk resulted in higher total N production in goats on Se supplement. Lindberg and Gonda (1996) reported that in lactating goats, the largest loss of N is via urinary excretion (43%), followed by faecal excretion (29%) and N in the milk produced (24%). No difference was observed between the treatments considering the quantities of N in milk or in the ratios between the latter and the consumption of N.

It is believed that the Se content of the ration might improve the metabolism of nutrients such as CP in each form of Se supplied. So, at first, it might be considered that, in accordance with the availability of metabolic N, the OS diet is the most suitable. Better N utilization for milk production in refreshing goats caused the reduction of N loss via urine, and lower mobilization of body reserve for milk production.

In the ruminant animal, to calculate the energy status, it is necessary to determine the energy losses from the formation of faeces, urine, BW change, maintenance and production. The information available on energy utilization directed towards milk production is still very limited. With respect to the utilization of an energy intake for milk production, and provided the corresponding intakes do not differ, the most informative value is the ratio between the energy directed to milk production and the intake of metabolizable energy. However, in early lactation, the body reserve also provides energy for milk production. Thus, loss of energy via urine, and energy needed for maintenance also affected the net energy utilization for production. In the present study, these values were reduced in goats on Se supplements. Therefore, this analysis led to considering diets supplemented with Se to be more valuable than the control. In the available literature, prevailing research results show the lack of influence of Se supplement in organic form on milk production. However, few studies demonstrate the influence of selenium on production characteristics. This discrepancy is probably caused by a short research period of some studies as well as by the lack of information on Se deficiency in goats existing before the beginning of the research. Nevertheless, Wang et al. (2009) showed that Se supplementation of a cow’s diet in the form of selenium yeast positively influenced milk production. The effect was obtained due to the positive influence of selenium yeast on fermentation in the rumen, which in turn resulted in the enhanced digestibility of nutrients contained in feed rations.

Lower consumption energy for maintenance in goats on Se supplementation and higher energy consumption in goats on control diet confirmed that selenium is one of the effective mineral for energy metabolism in the body. Higher milk production in goats on Se supplemented diets ($P = .09$) also confirmed the better utilization of energy for production in refreshing goats. This aspect of Se supplementation might be referred to as higher enzyme activity in metabolic axes for energy utilization in the body. The main functions of selenium are exerted by selenoproteins. Selenoproteins contain one or more atoms of selenium. The most common chemical form of selenium in animals is selenocysteine. It has been reported that selenocysteine, rather than cysteine, in an enzyme active site, increases enzyme activity (Burk 2002). The wide array of involvement of selenoproteins in the various metabolic pathways explains selenium status on maintenance, growth, reproduction, immunity and mortality of animals (NRC 2007).

**Conclusions**

With respect to the normal situation for refreshing lactating goats, nitrogen and energy utilization obtained with the different Se supplementation assayed was adequate; milk N/intake nitrogen varied from 0.25 to 0.46, milk N/digestible N varied from 0.40 to 0.68 and milk energy/ME intake varied from 0.27 to 0.47.

Selenium supplementation affected nitrogen and energy metabolism. However, OS seems to be the better choice, considering the nitrogen and energy available for the metabolism and its partition between milk production and deposit/mobilization within the body. Further research is required to determine detailed metabolism of selenium in maintenance and production in lactating goats.
Acknowledgements

The authors are grateful to all members of staff of the Research Department of Shahrekord University.

Disclosure statement

No potential conflict of interest was reported by the authors.

Funding

This work was supported by Shahrekord University.

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