Blood Haematology, Serum Thyroid Hormones and Glutathione Peroxidase Status in Kacang Goats Fed Inorganic Iodine and Selenium Supplemented Diets

Z. A. Aghwan1,4, A. Q. Sazili2,3, A. R. Alimon1, Y. M. Goh4, and M. Hilmi1
1 Department of Animal Science, Faculty of Agriculture, Universiti Putra Malaysia, 43400 UPM Serdang, Selangor Darul Ehsan, Malaysia
2 Halal Products Research Institute, Universiti Putra Malaysia, 43400 UPM Serdang, Selangor Darul Ehsan, Malaysia.
3 Department of Veterinary Preclinical Sciences, Faculty of Veterinary Medicine, Universiti Putra Malaysia, 43400 UPM Serdang, Selangor Darul Ehsan, Malaysia.
4 Department of Animal Science, College of Agriculture, University of Mosul, Mosul, Iraq.

ABSTRACT: The effects of dietary supplementation of selenium (Se), iodine (I), and a combination of both on the blood haematology, serum free thyroxine (FT4) and free triiodothyronine (FT3) hormones and glutathione peroxidase enzyme (GSH-Px) activity were examined on twenty four (7 to 8 months old, 22±1.17 kg live weight) Kacang crossbred male goats. Animals were randomly assigned to four dietary treatments (6 animals in each group). Throughout 100 d of feeding trial, the animals of control group (CON) received a basal diet, while the other three groups were offered basal diet supplemented with 0.6 mg/kg diet DM Se (SS), or 0.6 mg/kg diet DM I (PI), or a combination of both Se and I, each at 0.6 mg/kg diet DM (SSPI). The haematological attributes which are haemoglobin (Hb), red blood cell (RBC), packed cell volume (PCV), mean cell volume (MCV), white blood cells (WBC), band neutrophils (B Neut), segmented neutrophils (S Neut), lymphocytes (Lymph), monocytes (Mono), eosinophils (Eosin) and basophils (Baso) were similar among the four treatment groups, while serum levels of Se and I increased significantly (p<0.05) in the supplemented groups. The combined dietary supplementation of Se and I (SSPI) significantly increased serum FT3 in the supplemented animals. Serum GSH-Px activity increased significantly in the animals of SS and SSPI groups. It is concluded that the dietary supplementation of inorganic Se and I at a level of 0.6 mg/kg DM increased serum Se and I concentration, FT3 hormone and GSH-Px activity of Kacang crossbred male goats. (Key Words: Kacang Goats, Selenium, Iodine, Thyroid Hormones, Glutathione Peroxidase)

INTRODUCTION

All living organisms require minerals for proper function (McDowell, 2003). Minerals are naturally present in food or they may be added as dietary supplement to meet the requirement. The involvements of trace elements in metabolic and protective processes make them important in human and animal nutrition. It is important to supplement the animal’s feed with trace elements up to requirement level. This is because there are organic and inorganic inhibitors for some of the trace elements present in natural dietary sources, as well as naturally low concentrations of trace elements in feed (Pallauf and Muller, 2006). Both I and Se are highly essential for the function of thyroid gland to synthesise thyroid hormones namely thyroxine (T4) and triiodothyronine (T3) (Underwood, 1977). These hormones regulate energy metabolism, thermoregulation, reproduction, growth and development (Herdt and Hoff, 2011). A study on relationships between thyroid gland activity and energy balance in goats reported that circulating thyroid hormones could reflect the nutritional and metabolic status of the animals (Todini et al., 2007). Although the majority of circulating thyroid hormones (T4 and T3) are bound to proteins and only a little quantity of them are free (FT4 and FT3) or unbound; only the free hormones correspond to the active hormone offered and able to get through into the cells and affect their function (Todini, 2007).

Selenium is important as an antioxidant and it promotes health and immune status of animals (NRC, 2005). It has been reported that Se is an integral part of the antioxidant enzyme GSH-Px (Rotruck et al., 1973). Findings of Yue et
al. (2009) and Shi et al. (2011) demonstrated that serum GSH-Px activity in goats was significantly increased subsequent to Se supplementation.

In our study, the supplementation of I and Se (0.6 mg/kg DM) in the diet was twice higher than the recommended levels for goats (NRC, 1981) at which would be safe for the animals in term of toxicity. Thus, the haematological profile generated in the present study was to help in indicating if there were any clinical conditions associated with toxicity possibly arise due to the higher than the recommended level of supplementation of Se and I (NRC, 1981). Determination of total mineral concentration in serum could be an indicator for metabolism, immunity and antioxidant status in the farm animals (Herdt and Hoff, 2011).

Earlier studies have documented the effect of dietary Se supplementation on serum concentrations of GSH-Px (Yue et al., 2009; Shi et al., 2011) with very limited work been carried out to examine its effects on the FT₃ and FT₄ hormones in goats. Iodine is the main constituent of T₃ and T₄ hormones, while Se is important for the biosynthesis of GSH-Px involved in thyroid hormone metabolism and both elements have been associated with improved animal growth, immune system and meat quality (Schomburg and Köhrle, 2008).

However, data on the influence of dietary supplementation of I and the combination of I and Se on serum concentrations of GSH-Px, FT₃ and FT₄ hormones in goats are still scarce. Therefore, the present study was conducted to examine the effects of dietary supplementation of inorganic Se, I, and a combination of both on their concentrations in the serum, the activity of GSH-Px and thyroidal hormones in the serum of Kacang crossbred male goats.

MATERIALS AND METHODS

The experiment was conducted following the guidelines of the research policy of the Universiti Putra Malaysia on animal ethics.

Animals and diets

A total of 24, 7 to 8 months old bucks with a mean live weight of 22±1.17 kg were randomly assigned to either one of four dietary treatment groups each consisting of six animals. The animals were housed individually in wooden slatted floor pens measuring 1.20 m×0.80 m each, 0.70 meter above ground, equipped with feeding and drinking facilities. The four dietary treatments were; control (CON): basal diet without supplementation, SS: basal diet with 0.6 mg Se/kg DM, PF: basal diet with 0.6 mg I/kg DM, SSPI: basal diet with combination of 0.6 mg Se/kg DM and 0.6 mg I/kg DM. The inorganic selenium was given in the form of sodium selenite while the inorganic iodine was in the form of potassium iodide. The basal diet offered was a concentrate mix based on palm kernel cake, corn and rice bran (Table 1). The amount of concentrate offered was based on 1% of body weight with ad libitum amount of fresh guinea grass for 100 consecutive days.

Blood sampling

At d 75 of the experiment, blood samples from each individual animal were collected aseptically via jugular venipuncture into 5 mL Vacutainer K3 ethylene diamine tetraacetic acid (EDTA) tubes. The tubes were rolled gently several times to ensure enough anticoagulant mixing, and the samples were processed immediately for haemogram analysis (Brockus and Andreasen, 2003). Blood samples from all animals were collected at d 95 of the experiment, for the assessment of serum Se and I concentrations, GSH-Px activity and FT₃ and FT₄ hormones. Samples were aseptically collected by jugular venipuncture using 21-gauge needles and a 10 mL Vacutainer (BD Franklin Lakes NJ, USA) serum tube and kept slanting for 1h, followed by centrifugation at 3,000 g for 10 min. The resulted serum was frozen at -20°C until subsequent analyses.

Analytical techniques

The haematological parameters were evaluated using haematology analyser (CELL- DYN 3700 Abbott, USA). The haematocrit [packed cell volume (PCV)] value was measured using microhaematocrit method by centrifuging (Biofuge Primo R Centrifuge, Thermo, Germany) the blood samples at 17,500 g for 5 min at 4°C. For differential cell analysis, Wright’s stain technique was used. In the

Table 1. The ingredients (% as fed) and chemical composition (%) of the basal diet

| Ingredients            |        |
|------------------------|--------|
| Palm kernel cake       | 43     |
| Corn                   | 25     |
| Rice bran              | 30     |
| Limestone              | 1      |
| Salt                   | 0.5    |
| Vitamin-mineral premix | 0.5    |

Chemical composition

|                      |        |
|----------------------|--------|
| Metabolizable energy (Mcal/kg DM)² | 2.35   |
| Dry matter            | 90.32  |
| Crude protein         | 12.90  |
| Crude lipids          | 3.28   |
| Ash                   | 9.43   |
| Neutral detergent fibre | 55.75 |
| Acid detergent fibre  | 25.92  |
| Selenium(mg/kg DM)³   | 0.124  |
| Iodine (mg/kg DM)⁴    | 0.025  |

¹Analysed values except metabolizable energy.
² Metabolizable energy: calculated (Alderman, 1985).
³ Analysed by inductively coupled plasma-mass spectrometry (ICP-MS).
technique, a drop of blood was placed over a slide, air-dried, stained, and then covered with microscope cover glass. Thereafter, 200 cells were manually counted and classified. For the estimation of Se (AOAC, 1984) and I (Schone et al., 2001) concentrations in the serum, 2 mL of each sample was directly diluted in 18 mL of deionized distilled water (ddH₂O) and measured by inductively coupled plasma-mass spectrometry (ICP-MS) using Se standard (Perkin Elmer Pure Plus Multi-element ICP-MS Calibration Std.3, USA) and I standard (Anion Standard Iodide As-19-24 SPEX Certiprep, USA). The determination of FT₄ and FT₃ were conducted at Gribbles Pathology Laboratory, Pty. Ltd. Malaysia, using labelled antibody method by ADVIA Centaur (Siemens, USA). The ADVIA Centaur system performed the detection of FT₄ and FT₃ automatically using direct chemiluminescence technology. The activity of GSHPx enzyme in the serum was quantitatively determined using EnzyChrom Glutathione Peroxidase Assay Kit EGPX-100, (BioAssay Systems, USA). The assay measured the consumption of nicotinamide adenine dinucleotide phosphate (NADPH) in the enzyme coupled reactions by recording the decrease in absorbance at 340 nm, and was expressed as U/L, whereby, one unit (U) is the amount of GSH-Px that produces 1 μM of Glutathione disulfide (GS-SG) per min at pH 7.6 at room temperature.

Statistical analysis
The experiment was of a completely randomized design (CRD). The experimental unit was the animal for all the variables measured during the conduct of the entire study. The data were statistically analyzed using the general linear model (GLM) procedure of Statistical Analysis System package (SAS) Version 9.2 software (SAS, 2007) and statistical significance was set at p<0.05. Duncan multiple range test was used to test the significance of variance between the means of the studied parameters.

RESULTS AND DISCUSSION

Blood haematological parameters
The data of complete blood count (CBC) test of the animals are as presented in Table 2. The erythrocyte indices (Hb, PCV, and MCV) of the animals of all treatments were in the normal physiological reference range. Results of these parameters did not show any significant differences between the supplemented groups and control. The values of the RBC counts were apparently similar across the supplemented groups (p>0.05) and were within the normal reference range of healthy goats. Similarly, no significant differences were found in the differential leukocyte parameters (B Neut, S Neut, Lymph, Mono, Eosin, and Baso) between the supplemented goats and those of control. Additionally, means of WBC count for the supplemented animals was comparable with that of control, and was also within the normal reference range of healthy goats.

In the current study, animals were all healthy, and that probably is why the hematological parameters were not different between the supplemented and control groups. Increased immune function by Se supplementation may only be apparent when animals are challenged by mitogen or pathogens in vivo or in vitro (McClore, 2008).

Studies related to the effect of dietary supplementation of I and Se on goat haematology are rather limited. However, Juniper et al. (2008) and Alhidary et al. (2012) showed that dietary supplementation of Se did not affect (p>0.05) the haematological parameters of lambs and sheep, respectively. In line with our findings, the concentrations of Hb and PCV were also unaffected by the iodine supplementation in male goats (Rajendran et al., 2001). Contradicting with the present results on the effect of

| Table 2. Haematological parameters of goats fed different dietary treatments |
|-----------------------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|
|                             | CON             | SS              | PI              | SSPI             | SEM             | Ref             |
| RBC ×10¹²/L                 | 12.75           | 12.97           | 13.05           | 12.68            | 0.27            | 5-17            |
| Hb g/L                      | 100             | 101             | 106             | 96               | 3.92            | 66-146          |
| PCV L/L                     | 0.19            | 0.20            | 0.21            | 0.20             | 0.01            | 0.22-0.38       |
| MCV f/L                     | 15.16           | 15.50           | 15.67           | 15.50            | 0.33            | 16-25           |
| WBC ×10⁹/L                  | 12.32           | 12.97           | 12.38           | 12.52            | 0.72            | 4-13            |
| B Neut ×10⁹/L               | 0               | 0               | 0               | 0                | 0               | 0               |
| S Neut ×10⁹/L               | 5.96            | 6.35            | 6.15            | 6.26             | 0.49            | 1.2-7.2         |
| Lymph ×10⁹/L                | 5.74            | 5.26            | 6.15            | 5.39             | 0.48            | 2-9             |
| Mono ×10⁹/L                 | 0.52            | 0.50            | 0.47            | 0.49             | 0.05            | <0.55           |
| Eosin ×10⁹/L                | 0.23            | 0.22            | 0.25            | 0.27             | 0.07            | 0.05-0.65       |
| Baso ×10⁹/L                 | 0.06            | 0.07            | 0.08            | 0.07             | 0.01            | <0.2            |

1 CON = Control, basal diet without supplementation; SS = Basal diet+0.6 mg Se/kg DM; PI = Basal diet+0.6 mg I/kg DM; SSPI = Basal diet+ (0.6 mg Se/kg DM+0.6 mg I/kg DM); SEM = Standard error of means; Ref = Reference range of healthy goats (Rasedee, 1981).

* RBC = Red blood cell; Hb = Haemoglobin; PCV = Packed cell volume; MCV = Mean cell volume; WBC = White blood cells; B Neut = Band neutrophils; S Neut = Segmented neutrophils; Lymph = Lymphocytes; Mono = Monocytes; Eosin = Eosinophils; Baso = Basophils.
dietary I supplementation on Hb concentration, Pattanaik et al. (2011) reported higher (p<0.05) Hb concentration in goats subjected to dietary supplementation of iodine. The authors attributed this high concentration of Hb in iodine-supplemented goats to their superior protein status, which could be resulted by not only better nitrogen utilisation, but also enhanced consumption of digestible crude protein.

**Serum selenium and iodine concentrations**

In the present study, animals subjected to the dietary supplementation of Se (SS) presented higher (p<0.05) serum concentration of Se than the control group (Table 3). The present results further support a previous report by Shi et al. (2011) which documented greater blood Se values in the supplemented than the control growing male goats. Likewise, the dietary supplementation of I significantly increased I concentration in the serum of supplemented animals (PI) compared with the control group (Table 3). In line with our results, Meyer et al. (2008) reported significant elevation of serum I concentrations in I supplemented bulls. In the present study, goats supplemented with both Se and I (SEPI) demonstrated positive results in terms of the concentration of Se and I in serum, and this suggests possible synergistic effects of combined Se and I. It has been reported that Se concentration in the blood could be an indicator for Se content in goat meat (Shi et al., 2011; Aghwan et al., 2012).

Furthermore, Aghwan et al. (2012) concluded that increasing iodine levels in the serum resulted in increased I content in the muscles and organs of supplemented goats.

**Serum free thyroxine and free triiodothyronine**

Dietary supplementation of iodine, selenium, and combination of both had no effect on FT4 levels (p>0.05) (Table 3). However, the FT3 level of animals supplemented with combination of I and Se (SSPI) was significantly increased with respect of the animals supplemented with I (PI) (Table 3). Additionally, no significant differences in FT3:FT4 were observed between the supplemented animals and those of control group (Table 3).

In our study, the concentrations of FT4 and FT3 were not influenced by Se supplementation (SS). This could be explained by the Se level in the basal diet (0.124 ppm) which was enough for the regulation and control of thyroid gland metabolism and hormone biosynthesis. In agreement with our findings, dietary Se supplementation (0.11 Se in the basal diet) did not show any significant effects on the serum concentration of thyroid hormones (T3 and T4) in sheep (Chadio et al., 2006).

The absence of effects of I supplementation (PI) on the thyroid hormones in our study could be explained by the fact that the diets offered to the animals in different treatments were isonitrogenic and isocaloric. Todini, (2007) reported that the concentrations of total plasma T3 significantly correlated with nitrogen and energy balance. The concentrations of T3 and FT3 in adult sheep were decreased in case of energy deprivation, whereas subsequent realimentation of energy elevated their concentrations. It has been reported that the dietary supplementation of I significantly increased serum T4 concentration as well as T3: T4 in goats (Pattanaik et al., 2011). The authors documented that the higher serum T4 noted in their study was correlated with higher ME intake.

In this study, the concentration of FT3 but not that of FT4 of the animals supplemented with both Se and I (SSPI) was significantly higher than those of I supplemented animals (PI). Arthur et al. (1990) showed that type 1 5’-deiodinase (D1) is the selenoprotein mainly established in the liver, kidney, and thyroid, and it regulates T3 conversion into the biologically active form, T2. Furthermore, selenium deficiency in rats fed a purified amino acid diet depressed the activity of D1 (Beckett et al., 1993). In rats, supplemental selenium was found to be able to mitigate the toxic effects of excessive iodine and increased the activities

**Table 3. Serum iodine, selenium, thyroid hormones concentrations and glutathione peroxidase (GSH-Px) enzyme activity of goats fed different dietary treatments**

|               | CON      | SS       | PI       | SSPI     | SEM       |
|---------------|----------|----------|----------|----------|-----------|
| Serum iodine (µg/L) | 56.17b   | 61.90b   | 172.64a  | 158.84a  | 5.18      |
| Serum selenium (µg/L) | 53.11b   | 154.02a  | 54.79b   | 137.00b  | 10.56     |
| Serum GSHPx (U/L)² | 54.35b   | 138.63b  | 41.40b   | 109.76b  | 12.48     |
| FT4 (pmol/L)³   | 12.66    | 13.40    | 13.90    | 14.30    | 0.85      |
| FT3 (pmol/L)³   | 3.63ab   | 3.68ab   | 3.33b    | 4.03a    | 0.18      |
| FT3:FT4         | 0.30     | 0.28     | 0.26     | 0.30     | 0.03      |

¹ CON = Control, basal diet without supplementation; SS = Basal diet+0.6 mg Se/kg DM; PI = Basal diet+0.6 mg I/kg DM; SSPI = Basal diet+(0.6 mg Se/kg DM+0.6 mg I/kg DM).

² U = Amount of GSH-Px that produces 1 µM of Glutathione disulfide (GS-GS) per minute at pH 7.6 in room temperature.

³ FT4 = Free thyroxine hormone. ⁴ FT3 = Free triiodothyronine hormone.

ab Means with different superscripts within the same row differ significantly at p<0.05.

SEM = Standard error of means.
of D1 (Xu et al., 2011). In our study, the four dietary treatments were analysed and found to be similar in their protein and energy levels. The probable elucidation for our results is that Se supplementation in the animals supplemented with both I and Se (SSPI) could have enhanced the activity of D1, which then increased the conversion from T4 to T3.

Serum glutathione peroxidase enzyme activity

In comparison with animals in the Con and PI groups, glutathione peroxidase concentration was significantly higher in the SS and SSPI groups (Table 3). Glutathione peroxidase plays vital defence function in the body by reducing lipid and hydrogen peroxides to less hazardous hydroxides through oxidation (Arteel and Sies, 2001). The measurement of GSH-Px activity in the blood can also be used as indicator for the assessment of Se status (Herdt and Hoff, 2011).

In this study, the results of serum GSH-Px activity were found to be parallel with higher concentration of serum Se noted in the animals of SS and SSPI groups. This may be due to larger proportion of Se in the blood which has been incorporated into functional GSHPx (Juniper et al., 2009). It has been reported that Se must be converted to selenocysteine (Se-Cys) before it can be incorporated to GSHP-x (Forstrom et al., 1978). Furthermore, Wang et al. (2011) reported that Se in the form of Na Selenite was metabolised efficiently into Se-Cys and rapidly incorporated into GSH-Px.

In line with our results, Yue et al. (2009) and Shi et al. (2011) reported significantly higher serum Se and GSH-Px activity in Taihang Black goats supplemented with Se compared to the non-supplemented animals. However, Chung et al. (2007) reported no differences in serum GSH-Px activity between goats supplemented with 0.25 ppm of inorganic or organic Se and the non-supplemented ones. The authors suggested that it could be attributed by a plateau possibly attained by Se even in the basal diet. The concentration of GSHP-x did not differ between the iodine supplemented (PI) and the CON groups. The level of I supplemented in this study may be not high enough to cause changes in the concentration of GSHP-x. Reports by Xu et al. (2011) documented 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 the activity of serum GSH-Px in the goats supplemented with 2 mg I/kg DM was not affected, while the activity of serum GSH-Px was decreased significantly in the animals supplemented with excessive I (4 mg/kg DM) compared to the non-supplemented group. The authors elucidated that excessive I could have resulted in the production of extreme free radicals during thyroid hormones metabolism which in turn, could increase oxidative damage in thyroid gland and consequently result in extra consumption of GSH-Px for the protection of thyroid gland.

In the present study, the dietary supplementation of both Se and I (SSPI) significantly increased serum GSH-Px activity in the animals. This could also display similar trend of possible synergistic effects of combined supplementation of Se and I at the level of 0.6 mg through increased serum GSH-Px activity in the animals from the SSPI group.

In conclusion, the present study demonstrated that the dietary supplementation of combined inorganic I and Se at the level of 0.6 mg/kg DM has resulted in higher concentration of both elements in the serum, and these were not different compared to the supplementation of I and Se alone. The concentration of FT3 has markedly increased following supplementation of combined I and Se treatment. Serum GSH-Px activity increased significantly in the animals of SS and SSPI groups. These suggest possible synergistic effects of combined Se and I in improving metabolism, immunity and antioxidant status of the animals. The data generated from this study also provide a basis for future work on growth performance, carcass characteristics, and meat quality traits in relation with the supplementation of Se and I.

ACKNOWLEDGEMENTS

The authors would like to thank the staffs of Haematology Laboratory, Faculty of Veterinary Medicine, Universiti Putra Malaysia for their technical support on blood haematology analysis. This project was funded by the Ministry of Higher Education, Malaysia through the Fundamental Research Grant Scheme (Project No. 015-01-07-370).

REFERENCES

Aghwan, Z. A., A. Q. Sazili, A. R. Alimon, Y. M. Goh, and M. A. Hilmi. 2012. Effects of dietary inorganic iodine and selenium on their concentrations in serum, muscle and organs in Kacang goats. J. Anim. Vet. Adv. 11:3894-3897.

Alderman, G. 1985. Prediction of the energy value of compound feeds. In: Recent Advances in Animal Nutrition (Ed. W. Haresign and D. J. A. Cole). Buttersworths, London, pp. 3-52.

Alhidary, I. A., S. Shini, R. A. M. Al Jassim, and J. B. Gaughan. 2012. Effect of various doses of injected selenium on performance and physiological responses of sheep to heat load. J. Anim. Sci. 90:2988-2994.

AOAC. 1984. Official methods of analysis, 14th edition. Association of Official Analytical Chemists, Arlington, VA.

Arteel, G. E. and H. Sies. 2001. The biochemistry of selenium and the glutathione system. Environ. Toxicol. Pharmacol. 10:153-158.

Arthur, J. R., F. Nicol, P. W. H. Rae, and G. J. Beckett. 1990. Effect of selenium deficiency on the thyroid gland and plasma
and pituitary thyrotrophin and growth hormone concentration in the rat. Clin. Chem. Enz. Commun. 3:209-214.
Beckett, G. J., F. Nicol, P. W. Rae, S. Beech, Y. Guo, and J. R. Arthur. 1993. Effects of combined iodine and selenium deficiency on thyroid hormone metabolism in rats. Am. J. Clin. Nutr. 57:240S-243S.
Brocks, C. W. and C. B. Andreasen. 2003. Erythrocytes. In: Duncan and Prasse’s Veterinary Laboratory Medicine – Clinical Pathology, 4th Ed. (Ed. K. S. Latimer, E. A. Mahaffey and K. W. Prasse.) Iowa State University Press, Ames, pp. 3-45.
Chung, J. Y., J. H. Kim, Y. H. Ko, and I. S. Jang. 2007. Effects of dietary supplemented inorganic and organic selenium on antioxidant defense systems in the intestine, serum, liver and muscle of Korean native goats. Asian-Aust. J. Anim. Sci. 20:52-59.
Forstrom, J. W., J. J. Zakowski, and A. L. Tappel. 1978. Identification of the catalytic site of rat liver glutathione peroxidase as selenocysteine. Biochemistry 17:2639-2644.
Herdt, T. H. and B. Hoff. 2011. The use of blood analysis to evaluate trace mineral status in ruminant livestock. Vet. Clin. Food Anim. 27:255-283.
Juniper, D. T., R. H. Phipps, E. Ramos-Morales, and G Bertin. 2008. Effect of dietary supplementation with selenium-enriched yeast or sodium selenite on selenium tissue distribution and meat quality in beef cattle. J. Anim. Sci. 86:3100-3109.
Juniper, D. T., R. H. Phipps, E. Ramos-Morales, and G Bertin. 2009. Effect of high dose selenium enriched yeast diets on the distribution of total selenium and selenium species within lamb tissues. Livest. Sci. 122:63-67.
McClure, S. J. 2008. How minerals may influence the development and expression of immunity to endoparasites in livestock. Parasite Immun. 30:89-100.
McDowell, L. R. 2003. Minerals in animal and human nutrition. 2nd edn. Elsevier Science, B.V. Amsterdam.
Meyer, U., K. Weigel, F. Schone, M. Leiterer, and G. Flachowsky. 2008. Effect of dietary iodine on growth and iodine status of growing fattening bulls. Livest. Sci. 115:219-225.
National Research Council. 2005. Mineral tolerance of animals. 2nd Ed. The National Academies, Washington, DC.
National Research Council. 1981. Nutrient requirements of goats. National Academy Press, Washington, DC.
Pallauf, J. and A. S. Muller. 2006. Inorganic feed additives. In: Biology of nutrition in growing animals (Ed. R. Mosenthin, J. Zentek, and T. Zebrowska). Elsevier, London. pp. 179-249.
Pattanaik, A. K., S. A. Khan, and T. K. Goswami. 2011. Iodine supplementation to a diet containing Leucaena leucocephala leaf meal: consequences on nutrient metabolism, clinical chemistry and immunity of goats. Anim. Prod. Sci. 51:541-548.
Qin, F., X. Zhu, W. Zhang, J. Zhou, S. Zhang, and Z. Jia. 2011. Effects of dietary iodine and selenium on nutrient digestibility, serum thyroid hormones and antioxidant status of Liaoning Cashmere goats. Biol. Trace Elem. Res. 143:1480-1488.
Rajendran, D., A. Pattanaik, S. Khan, and S. Bedi. 2001. Iodine supplementation of leucaena leucocephala diet for goats. I. Effects on nutrient utilization. Asian-Aust. J. Anim. Sci. 14:785-790.
Rasedee, A. 1981. Blood parameters of kambing Katjang-Jumnapari crossbred goats in Malaysia. Pertanika 4:87-90.
Rothuck, J. T., A. L. Pope, H. E. Ganther, A. B. Swanson, D. G. Hafeman, and W. G. Hoekstra. 1973. Selenium: biochemical role as a component of glutathione peroxidase. Science 179:588-590.
SAS. 2007. User’s guide: Statistics. Version 9.2. SAS Institute Inc., Cary, NC, USA.
Schomburg, L. and J. Köhrle. 2008. On the importance of selenium and iodine metabolism for thyroid hormone biosynthesis and human health. Mol. Nutr. Food Res. 52:1235-1246.
Shi, L., W. Xun, W. Yue, C. Zhang, Y. Ren, L. Shi, Q. Wang, R. Yang, and F. Lei. 2011. Effect of sodium selenite, Se-yeast and nano-elemental selenium on growth performance, Se concentration and antioxidant status in growing male goats. Small Rumin. Res. 96:49-52.
Todini, L. 2007. Thyroid hormones in small ruminants: effects of endogenous, environmental and nutritional factors. Animal 1:997-1008.
Todini, L., A. Malfatti, A. Valbonesi, M. Trabalza-Marinucci, and A. Debbenedetti. 2007. Plasma total T3 and T4 concentrations in goats at different physiological stages, as affected by the energy intake. Small Rumin. Res. 68:285-290.
Underwood, E. J. 1977. Trace elements in human and animal nutrition. 4th Ed. Academic Press, New York.
Xu, J., X. L. Liu, X. F. Yang, H. L. Guo, L. N. Zhao, and X. F. Sun. 2011. Supplemental selenium alleviates the toxic effects of excessive iodine on thyroid. Biol. Trace Elem. Res. 141:110-118.
Yue, W., C. Zhang, L. Shi, Y. Ren, Y. Jiang, and D. O. Kleemann. 2009. Effect of supplemental selenomethionine on growth performance and serum antioxidant status in Taihang Black goats. Asian-Aust. J. Anim. Sci. 22:365-370.