

## Effect of palm kernel cake and trace minerals on performance of growing Naemi lambs

Mutassim M. Abdelrahman<sup>1</sup>, Riyadh S. Aljumaah<sup>1</sup>, Abdullah H. Alyemni<sup>2</sup>, Moez Ayadi<sup>1</sup>, Hassan Metwally<sup>1</sup> and M. Y. Al-Saiady<sup>2</sup>

<sup>1</sup>King Saud University, College of Food and Agriculture Sciences, Department of Animal production, P. O. Box 2460, Riyadh 11451, Kingdom of Saudi Arabia; <sup>2</sup>ARASCO Company, P.O. Box 53845, Riyadh 11593, Kingdom of Saudi Arabia

### Abstract

An experiment was conducted to investigate the effect of feeding palm kernel cake (PKC) in a total mixed ration (TMR) on performance of Naemi lambs. Thirty six growing male Naemi lambs (25.9±1.3 kg), 3-4 months old, were distributed into three treatments (three replicates/treatment) as follow: Control group (C), fed traditional diet containing alfalfa hay and barley grain; Treatment 1 (T1), fed TMR containing 0% palm kernel cake; Treatment 2 (T2): fed TMR containing 20% palm Kernel cake. Body weight and feed intake were determined and blood samples were collected. Five lambs from each group were slaughtered at the end of the trial and tissues samples were collected. A significant effect ( $P<0.05$ ) of feeding TMR with or without PKC on total feed intake and weight gain was recorded as compared to C group. Feeding PKC significantly increased iron concentration in serum, liver and meat. Zinc concentration in the serum and liver also increased significantly by feeding PKC. Furthermore, total serum iron concentration was positively correlated to the liver ( $R^2=0.478$ ;  $P<0.04$ ) and meat iron ( $R^2=0.421$ ;  $P<0.05$ ). It was concluded that feeding PKC (20%) in TMR to growing Naemi lambs improved body weight gain and feed intake without producing negative effects on the absorption and metabolism of trace minerals.

**Keywords:** palm kernel cake, iron, trace minerals, hormones, naemi lambs

**To cite this article:** Abdelrahman MM, RS Aljumaah, AH Alyemni, M Ayadi, H Metwally and MY Al-Saiady, 2014. Effect of palm kernel cake and trace minerals on performance of growing Naemi lambs. Res. Opin. Anim. Vet. Sci., 4(5): 268-272.

### Introduction

As a result of increasing prices of different ingredients of farm animal feeds, nutritionists have been earnestly searching for potential unconventional crop by-products. Palm kernel cake (PKC) and other oil meals represent cheap alternative feed sources and are widely used in feed manufacturing as a part of total mixed rations (TMR) for feeding farm animals. In general, by-products may contain high concentrations of some nutrients and anti-nutrients which may affect nutrients' digestibility, absorption and utilization and consequently animal productivity. Because of that, special consideration must be given not only to positive

but also to potential negative effects of by-products especially when used in high levels as these effects may be caused both by the levels used and the chemical composition of the by-products.

Most of the mineral contents in PKC are within acceptable range, except for copper (21-28 ppm) and iron (801-6130 ppm) which may lead to copper toxicity (Soli, 1980) and other health problems. Minerals are mostly intended to interact with each other due to their tendency to form bonds and thus affect binding sites in the small intestines. Antagonistic or synergistic interactions between minerals cause negative or positive effects on mineral status of the animal, depending on their bioavailability.

\*Corresponding author: Prof. Mutassim M Abdelrahman, King Saud University, College of Food and Agriculture Sciences, Department of Animal production; E mail: amutassim@ksu.edu.sa  
Mobile: 00966566194484; Fax: 0096614678474.

It is fairly well documented in the literature that changes in dietary iron may influence copper metabolism negatively or positively (Humphries et al., 1983). Several studies reported the effect of using different levels of PKC on the productive performance and carcass characteristics of different species of farm animals (Chanjula et al., 2010; Macome et al., 2011; Ferreira et al., 2012), but very little attention has been paid to the interrelationship between minerals although PKC contains very high iron and copper levels.

This research was conducted to study the effect of feeding Naemi lambs TMR diet consisting 20% PKC on the performance and trace mineral status compared with traditional feeding and TMR without PKC.

## Materials and Methods

Growing Naemi male lambs ( $n= 36$ ;  $25.9 \pm 1.3$  kg Body weight), 3-4 months old, were used in this experiment. Animals were housed at King Saud University (KSU) research station. They were vaccinated against enterotoxaemia and treated with Ivermectin parentally. After 15 days adaptations period, the lambs were randomly divided into three treatments, each comprising three replicates of four lambs/replicate. The dietary treatments were: Control group: fed traditional feeding protocol (Barley and alfalfa hay); T1: fed TMR containing 0% of PKC; and T2: fed TMR containing 20% PKC.

All diets were formulated to be isonitrogenous and isocaloric except for the traditional feeding protocol. The lambs in each group were fed their respective diets for 12 weeks. Feed samples were collected regularly for nutritional analysis. All lambs were bled at the beginning of the experiment and at 4 week intervals via the jugular vein. Blood samples were centrifuged at 3000 rpm for 15 minutes and serum was separated (AOAC, 2005). Serum samples were stored at  $-20^{\circ}\text{C}$  until analysis. Feed intake was recorded daily. Body weight was recorded at the beginning of the experiment and every two weeks intervals thereafter. At the end of experiment, five lambs were slaughtered after a 16 hr fasting according to Islamic jurisdiction by severing the jugular vein and the carotid artery. Liver and meat samples were collected and wet digested for trace minerals analysis using Atomic Absorption Spectrophotometry. Serum samples were prepared and analyzed for trace mineral concentrations using atomic absorption spectrophotometer. Thyroid and cortisol hormones were analyzed spectrophotometrically in the serum using commercially available reagent kits (United Diagnostic Industry, Dammam, Kingdom of Saudi Arabia).

## Statistical Analysis

Data were subjected to analysis of variance using the General Linear Model (GLM) procedure of Statistical

Analysis System Institute, Inc. (SAS, 2002), according to the following models:

$$Y_{ij} = \mu + C_i + e_{ij} \quad \text{Where}$$

$Y_{ij}$  = Measurements of the variables,

$\mu$  = overall mean,

$C_i$  = Effect of the  $i^{\text{th}}$  treatments (C, T1 and T2) and

$e_{ij}$  = Residual error

Individual animals were used as the experimental unit for gain data, except that of feed intake and efficiency where pen served as the experimental unit. Means of each treatment were compared using protected least significant differences (LSD). Pearson correlation analysis was applied to find the correlation between concentration of minerals in serum, liver and meat. Pearson correlation was applied on the serum minerals concentration. Significant level was set at  $P < 0.05$  unless otherwise mentioned.

## Results and Discussion

Feeding growing Naemi lambs TMR with or without PKC and minerals mixture (T1 and T2) caused a significant increase ( $P < 0.05$ ) in total weight gain compared with the control (Table 2). There was no significant difference in total feed intake (TFI) as a result of adding 20% PKC in the TMR in T2 compared with T1 groups, but significantly higher was recorded compared with the control. Moreover, feeding TMR with or without PKC did not cause ( $P > 0.05$ ) any significant effect on feed conversion ratio compared with the control. This finding agrees with the results reported by Macome et al. (2011) in lambs fed different levels of PKC (0, 6.5, 13.0 and 19.5%). Correia (2011) and Costa et al. (2010) reported a significant reduction in feed intake by increasing the inclusion of PKC in cattle and sheep in the daily TMR, and attributed this reduction to the high fibre content in the PKC. In contrast, feeding goats up to 35% PKC did not cause any negative effect on feed intake, nutrients digestibility, blood metabolites and rumen fermentation patterns (Chanjula et al., 2010).

PKC is an excellent alternative feed for ruminant animals since it contains high fibre and protein levels; hence it may reduce feeding cost with perfect animal performance. On the other hand, high concentrations and unbalanced levels of some minerals may lead to mineral toxicities or deficiencies.

Feeding PKC (T2) to growing Naemi lambs significantly increased ( $P < 0.01$ ) blood iron compared to the TMR without PKC and control as shown in Table 3. The same trend was found for zinc concentration ( $P < 0.05$ ), but there was no significant effect of feeding TMR with or without PKC on copper, cobalt, manganese and molybdenum concentrations in the serum. The general ranges of iron, copper, zinc, Cobalt, manganese and molybdenum concentrations in the serum. The normal ranges of iron, copper, zinc, Cobalt, manganese and

**Table 1: Ingredients and chemical composition of the experimental diets**

Ingredients, %	AH <sup>1</sup>	BG <sup>2</sup>	PKC <sup>3</sup>	Treatments <sup>4</sup>		
				Control	T1	T2
Alfalfa Hay				25.22	-	-
Barley grain				74.78	27.0	17.0
Feed Wheat				-	29.95	29.92
Wheat Bran				-	5	5
Sunflower Meal				-	17.35	10.05
Soya Hulls				-	13.55	11.03
Palm Kernel Meal				-	0	20
Salt				-	0.54	0.47
Limestone				-	2.51	2.58
Molasses				-	3	3
Acid buffer <sup>5</sup>				-	0.95	0.80
Commercial Premix <sup>6</sup>				-	0.15	0.15
TMS <sup>7</sup>				free	-	-
Proximate analysis, % as DM basis						
DM	93.44	90.49	94.56	91.23	90.8	91.40
CP	15.69	12.79	15.33	13.53	13.24	13.79
CF	26.01	5.70	16.58	10.82	12.72	11.98
EE			11.27		1.40	2.61
Ash	11.20	2.93	4.11	5.02	10.30	9.09
ME, Mcal/kg <sup>8</sup>	2.03	3.11	2.66	2.83	2.80	2.79
Macro-minerals, %						
Calcium	1.41	0.05	0.31	0.39	1.90	1.7
Phosphorous	0.24	0.38	0.50	0.35	0.39	0.42
Magnesium	0.31	0.15	0.23	0.19	0.38	0.28
Potassium	1.71	0.47	0.44	0.78	0.78	0.75
Micro-minerals, mg/kg						
Iron	134	85	801	97	193	336
Copper	14	9	21.6	10.3	12.4	26.8
Zinc	23	19	34.5	20.0	39.3	269
Manganese	28	18	259	20.5	133	99.2
Selenium	-	0.22	-	0.16	0.48	0.25

<sup>1</sup>AH= Alfalfa Hay; <sup>2</sup>BG= Barley Grain; <sup>3</sup>PKC= Palm Kernel cake; <sup>4</sup>Control= traditional feeding protocol (loose whole barley grain + alfalfa hay); T1 (0% PKC) and T2 = 20% PKC; <sup>5</sup>Neutral buffer derived from seaweed (celtic Sea Company, Ireland); <sup>6</sup>Contained per kg, 10000 IU vitamin A, 1000 IU vitamin D, 20 IU vitamin E, 300 mg Mg, 24 mg Cu, 0.6; mg Co, 1.2 mg I, 60 mg Mn, 0.3 mg Se, 60 mg Zn; <sup>7</sup> Vitamin A 3335000 IU/kg, Vitamin D 335000 IU/kg, Vitamin E 16670 IU/kg, Cobalt 200 mg/kg, Copper 1600 mg/kg, Iodine 500 mg/kg, Iron 0.0 mg/kg, Magnesium 100000 mg/kg, Manganese 10000 mg/kg, Selenium 100 mg/kg, Zinc 33340 mg/kg; <sup>8</sup>Based on tabulated values.

**Table 2: Performance of Naemi male lambs fed the experimental diets<sup>1</sup>**

Item	Control	Treatments <sup>2</sup>		SEM <sup>3</sup>	Significant
		T1	T2		
Initial body weight	26.32	25.78	25.66	0.232	NS
Final body weight	45.58	46.50	45.13	0.550	NS
Total gain	18.26 <sup>b</sup>	20.73 <sup>a</sup>	19.48 <sup>a</sup>	0.580	*
Total feed intake, Kg	105.6 <sup>b</sup>	120.5 <sup>a</sup>	122.2 <sup>a</sup>	11.04	*
Feed conversion	5.80	5.90	6.18	0.131	NS

Values represent means of 12 lambs or 3 pens (4 lambs each) per treatment, respectively. Feeding period lasted 84 days;

<sup>2</sup>Control = traditional feeding (loose whole barley grain + alfalfa hay); T1 & T2 = complete pelleted diets (With or without palm kernel cake, respectively); <sup>3</sup> pooled standard error of means; <sup>a, b</sup> \*P<0.05

**Table 3: Effect of experimental diets on some minerals levels in blood**

Minerals (µg/100ml)	Treatments			SEM <sup>3</sup>	Significant level
	Control	T1	T2		
Iron	215.0 <sup>c</sup>	242.00 <sup>b</sup>	251.00 <sup>a</sup>	3.85	**
Copper	107.00	117.74	120.67	2.84	NS
Zinc	101.91 <sup>c</sup>	107.33 <sup>b</sup>	130.67 <sup>a</sup>	4.72	*
Cobalt	0.29	0.28	0.28	0.014	NS
Manganese	4.79	4.61	4.95	0.071	NS
Molybdenum	4.53 <sup>a</sup>	5.19 <sup>b</sup>	5.09 <sup>ab</sup>	0.09	NS

<sup>1</sup>C=control (traditional feeding protocol; barley grain + alfalfa hay); <sup>2</sup>T1= TMR feed (0%PKC); T2=TMR<sup>®</sup> feed, (20% PKC); <sup>3</sup>pooled standard error of means; \*P<0.05; \*\*P<0.01; NS not significant

molybdenum in serum of sheep are as follow: 166 to 222 µg/100ml, 7.0 to 150 µg/100ml, 80 to 130 µg/100ml, 0.1 to 0.3 µg/100ml, 0.8 to 5.1 µg/100ml and 2 to 6.0 µg/100ml respectively (Puls, 1990; Underwood and Suttle, 2001). The concentration of all trace minerals reported in this study fell within the normal range, except for iron values which were found to be above the normal range in lambs fed TMR with or without PKC (Table 2).

For mineral concentrations in the liver (wet weight), feeding PKC significantly increased iron concentrations when compared with the T1 and the control groups (Table 3). Moreover, feeding TMR with or without PKC significantly increased copper, zinc, manganese and molybdenum compared with the control but no significant effect on cobalt concentrations was observed (Table 3). The normal ranges of iron, copper, zinc, cobalt, manganese and molybdenum in the liver (wet weight) of sheep are as follow: 30 to 300 ppm, 25 to 100 ppm, 30 to 75 ppm, 0.3 to 2.24 ppm, 2.0 to 4.40 ppm, 0.3 to 0.6 ppm, respectively (Puls, 1990; Underwood and Suttle, 2001). The concentration of all trace minerals reported in this study fell within the normal range, except for copper values which found to be above the normal rang in the lambs fed TMR with or without PKC (Table 3). Iron concentrations in meat increased significantly (P<0.05) by feeding PKC (T2) when compared with T1 and the control. For copper concentrations, feeding TMRs with or without PKC (T1 and T2) caused a significant increase compared with the control. There were no significant (P>0.05) effects on zinc, cobalt and manganese concentrations in the meat samples (Table 4). The normal ranges of iron, copper, zinc, cobalt, manganese and molybdenum in the meat (wet weight) of sheep are 10 to 20 ppm, 1.0 to 1.30 ppm, 25 to 43.3 ppm, 0.3 to 2.24 ppm, 0.001 to 0.06 to 4.40 ppm, 0.2 to 1.50 ppm respectively (Puls, 1990; Underwood and Suttle, 2001). The concentrations of all trace minerals reported in this study were within the normal range (Table 4).

The results of Pearson correlation analysis between mineral concentration in blood serum, liver and meat

**Table 3: Effect of experimental diets on some minerals levels in liver (Wet weight)**

Minerals (ppm)	Treatments			SEM <sup>3</sup>	Significant level
	Control	T1	T2		
Iron	49.19a	43.92a	66.79b	3.45	*
Copper	105.29a	191.80b	184.73b	23.09	*
Zinc	35.92a	40.93b	41.16b	2.87	**
Cobalt	0.11	0.11	0.10	0.01	NS
Manganese	3.39a	4.60b	4.20ab	0.20	*
Molybdenum	0.67a	0.42b	0.54b	0.06	*

<sup>1</sup>C=control (traditional feeding protocol; barley grain + alfalfa hay); <sup>2</sup>T1= TMR feed (0%PKC); T2=TMR<sup>®</sup> feed, (20% PKC); <sup>3</sup>pooled standard error of means; \*P<0.05; \*\*P<0.01; NS not significant

**Table 4: Effect of experimental diets on some minerals levels in meat (Wet weight)**

Minerals (ppm)	Treatments			SEM <sup>3</sup>	Significant level
	Control	T1	T2		
Iron	14.20a	13.84a	18.93b	0.86	*
Copper	1.65a	1.85b	1.89b	0.05	*
Zinc	26.85	24.18	27.08	0.84	NS
Cobalt	0.005	0.010	0.010	0.001	NS
Manganese	0.44	0.41	0.45	0.017	NS

<sup>1</sup>C=control (traditional feeding protocol; barley grain + alfalfa hay); <sup>2</sup>T1= TMR feed (0%PKC); T2=TMR<sup>®</sup> feed, (20% PKC); <sup>3</sup>pooled standard error of means; \*P<0.05; NS not significant

**Table 5: Cortisol, T3 and T4 levels in blood of experimental Naemi lambs**

Item	Treatments			SEM <sup>3</sup>	Significant level
	C <sup>1</sup>	T1	T2		
Cortisol (ng/ml)					
Initial	29.65	37.17	27.86	2.13	0.133
Ist month	27.06	30.43	22.64	1.53	0.360
2 <sup>nd</sup> month	23.17	23.89	26.10	1.30	0.062
Final	21.63	33.74	28.13	2.60	0.364
T3 (ng/ml)					
Initial	1.94	1.57	1.53	0.079	0.351
Ist month	2.21	1.64	2.35	0.126	0.138
2 <sup>nd</sup> month	1.99 <sup>a</sup>	2.47 <sup>b</sup>	1.84 <sup>a</sup>	0.099	0.014
Final	2.31	2.35	2.10	0.234	0.683
T4 (µg/dl)					
Initial	6.01	5.06	4.95	0.29	0.636
Ist month	7.31	6.33	6.70	0.33	0.576
2 <sup>nd</sup> month	8.07	8.65	8.04	0.24	0.170
Final	9.40	7.09	8.22	0.39	0.490

<sup>1</sup>C=control (traditional feeding protocol; barley grain + alfalfa hay); <sup>2</sup>T1= TMR feed (0%PKC); T2=TMR<sup>®</sup> feed, (20% PKC); <sup>3</sup>pooled standard error of means; <sup>a,b</sup>Means within rows not sharing the same letter (s) are significantly different (P<0.05)

showed a positive correlation between serum and liver iron ( $R^2=0.478$ ;  $P<0.04$ ), meat iron ( $R^2=0.421$ ;  $P<0.05$ ) serum zinc ( $R^2=0.492$ ;  $P<0.04$ ) and serum copper ( $R^2=0.465$ ;  $P<0.05$ ). Negative correlation was found between serum iron and meat copper ( $R^2=-0.738$ ;

$P<0.01$ ); meat and liver copper ( $R^2=-0.468$ ;  $P<0.05$ ) and serum copper ( $R^2=-0.368$ ;  $P<0.05$ ).

Positive, synergistic, or antagonistic, interrelationships between iron and other minerals such as copper and zinc have been documented (Suttle et al., 1985; O'Dell, 1988; Spears, 2003; Garrick et al., 2003; Hansen et al., 2008; Suttle, 2010; Sousa et al., 2012). Minerals play an important role in the biochemical processes of the animal's body by acting as catalysts of many enzymes and hormones (Suttle, 2010). Moreover, metalloenzymes contain minerals in the active sites, and are essential for the synthesis of many hormones (Hess and Zimmermann, 2004; Suttle, 2010). The interrelationship between minerals may affect the availability of each other and cause deficiencies or toxicities. Accordingly, high intake of iron by lambs fed PKC could affect hormonal activities and consequently the animal metabolism and health.

Thyroid hormones (T3 and T4) play an important role in protein and energy metabolism and consequently growth and productivity of farm animals (Huszenicza et al., 2002). Therefore, any change in thyroid and cortisol hormones levels can be used as indicator of the metabolic and nutritional status of the animals (Todini et al., 2007). Table 5 presents the levels of cortisol, T3 and T4 hormones in the blood serum of the lambs of all experimental groups. There was no significant effect of the different dietary protocols on cortisol, T3 and T4 hormones throughout the experimental periods. This means that the intake of present additives by growing lambs did not cause any negative effect on these hormone levels and can be considered as a safe.

## Conclusions

Feeding TMR with or without 20% PKC causes a significant improvement on growth of Naemi lambs and there was no clear negative effect of feeding 20% PKC in the TMR on the absorption and status of copper, zinc, cobalt, manganese and molybdenum.

## Acknowledgement

The authors extend their appreciation to the ARASCO Company for funding this work. Appreciation goes to the staff of the animal production farm for providing a proper care and management for this trial.

## References

- AOAC. 2005. Official Methods for Analysis. 18th ed. Association of Official Analytical Chemists, Washington, DC, USA.
- Chanjula, P., Mesang, A. and Pongprayoon, S. 2010. Effect of dietary inclusion of palm kernel cake on nutritional utilization, rumen fermentation characteristics and microbial population of goats fed *Paspalumplacatum* hay-based diet. *Songklanakarin. Journal of Science and Technology*, 32: 527-536.

- Correia, B.R., Oliveira, R.L., Jaeger, S.M.P.L., Bagaldo A.R., Carvalho, G.G.P, Oliveira, G.L.C., Lima, F.H.S. and Oliveira, P.A. 2011. Intake, digestibility and ruminal pH of steers fed diets with pies from the production from biodiesel to replacement soybean meal. *Arquivo Brasileiro de Medicina Veterinária e Zootecnia*, 63: 353-363.
- Costa, D.A., Ferreira, G.D., Araújo, C.V. 2010. Consumo e digestibilidade de dietas com níveis de torta de dendê para ovinos. *Revista Brasileira de Saúde e Produção Animal*, 11: 783-792.
- Ferreira, A.C., Ronaldo, L.O., et al. 2012. Intake, digestibility and intake behaviour in cattle fed different levels of palm kernel cake. *Revista MVZ Córdoba*, 17: 3105-3112.
- Garrick, M.D., Dolan, K.G., Horbinski C, et al. 2003. DMT1: a mammalian transporter for multiple metals. *BioMetals*, 16: 41-54.
- Hansen, S.L., Schlegel, P., Legleiter, L.R, Lloyd, K.E., and Spears, J.W. 2008. Bioavailability of copper from copper glycinate in steers fed high dietary sulfur and molybdenum. *Journal of Animal Science*, 86: 173-179.
- Hess, S.Y., Zimmermann, M.B. 2004. The effect of micronutrient deficiencies on iodine nutrition and thyroid metabolism. *International Journal for Vitamin and Nutrition Research*, 74: 103-115.
- Humphries W.R., Phillippo, M., Young B.W., Bremner I. 1983. The influence of dietary iron and molybdenum on copper metabolism in calves. *British Journal of Nutrition*, 49: 77-86.
- Huszenicza, G., Kulcsar, M., Rudas P. 2002. Clinical endocrinology of thyroid gland functions in ruminants. *Veterinarná medicína Czech*, 47: 199-210.
- Macome, F., Ronaldo, L.R., Adriana, R.B., Gherman, G.A., Larissa, P.B., Mauricio, C.A. 2011. Productive performance and carcass characteristics of lambs fed diets containing different levels of palm kernel cake. *Revista MVZ Córdoba*, 16: 2659-2667.
- O'Dell, B.L. 1988. Mineral interactions relevant to nutrient requirements. Symposium. *Journal of rationion*, 119: 1832-1838.
- Puls, R. 1990. Mineral levels in animal health: Diagnostic data. 2nd edition. Sherpa International, Clearbrook, BC, Canada.
- SAS, 2002. User's Guide: Statistics, Version 8e. SAS Inst., Inc. Cary, NC.
- Soli, N.E. 1980. Chronic copper poisoning in sheep. A review of the literature. *Nord. Veterinary Medicine*, 32: 75-80.
- Sousa, I.K., Minervino, A.H., Sousa, R.S., et al. 2012. Copper Deficiency in Sheep with High Liver Iron Accumulation. *Veterinary Medicine International*, 12: 1-4.
- Spears, J.W., 2003. Trace Minerals Bioavailability in Ruminants. Comparative Trace Minerals Nutrition. American Society for Nutritional Sciences. *Journal of Nutrition*, 133: 1506s-1509s.
- Suttle, N.F, Peter, D.W. 1985. Rumen sulfide metabolism as a major determinant of the availability of copper to ruminants. In: Mills CF, Bremner, I, Chesters, JK, editors. Proceedings of the 5th International Symposium on Trace Elements in Man and Animals; Farnham, UK. Royal Slough Commonwealth Agricultural Bureau; pp: 367-370.
- Suttle, N.F. 2010. Mineral Nutrition of Livestock, 4<sup>th</sup> Edition. Cabi Publishing, USA.
- Todini, L., 2007. Thyroid hormone in small ruminants: effect of endogenous, environmental and nutritional factors. *Animal*, 1: 997-1008.
- Underwood, E.J., Suttle, N.F. 2001. The Mineral Nutrition of Livestock, 4<sup>th</sup> ed. CABI. Publishing, UK.