

Original study

Influence of dietary magnesium and selenium levels in finishing diets on growth performance and carcass meat quality of feedlot Pelibuey lambs

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Abstract

The objective of this study was to evaluate the influence of supplemental dietary selenium (Se) and magnesium (Mg) on feedlot lambs. Sixty-four male lambs were randomly distributed to the following treatments: 1) low level of Mg and Se: diet with 0.18 % of Mg and 0.1 µg Se/g, 2) with supplementation of magnesium oxide (MgO): diet with 0.32 % of Mg and 0.1 µg Se/g, 3) with supplementation of Sodium selenite (Na₂SeO₃): diet with 0.3 µg Se/g and 0.18 % of Mg, 4) With supplementation of MgO and Na₂SeO₃: diet with 0.32 % of Mg and 0.3 µg Se/g. There were no differences ($P>0.05$) in the average daily gain and feed conversion but Se supplement with Na₂SeO₃ (0.3 µg Se/g) enhanced dry matter intake, dressing percentage ($P<0.05$) and leg muscle weight ($P<0.02$). The average values of the water retained potential, coordinate L, a, and sensory analysis were different with Se ($P<0.05$). Magnesium supplemented as inorganic source (0.32 % of Mg) enhanced ($P<0.05$) some characteristics in sensorial meat analysis.

Keywords: Magnesium, Selenium, lambs, feedlot, meat quality

Abbreviations: ADG: average daily gain, DMI: dry matter intake, DMI/ADG: feed conversion ratio, Mg: magnesium, MgO: magnesium oxide, Na₂SeO₃: sodium selenite, Se: selenium

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Introduction

The role of vitamin E and Se supplementation in maintenance of health, growth performance and fertility in sheep has been widely investigated (Balicka-Ramisz *et al.* 2006). The high dose of vitamin E (~1000 IU; Faustman *et al.* 1998) or organic Se (0.3 µg Se/g dry matter; Cozzi *et al.* 2011) itself have improved only the meat colour of lambs and young bulls, respectively. Other studies in steers have shown that Mg, supplemented as magnesium oxide (MgO), enhanced growth performance and carcass weight (Zinn & Shen 1996, Ramirez & Zinn 2000). Selenium and Mg are nutrients required in various vital functions of ruminants and therefore, these are considered important elements (Reinhart 1988, Rederstorff *et al.* 2006). Selenium is the key structural component of selenoproteins like glutathione peroxidase and iodothyronine deiodinase which catalyses the conversion of thyroxine into triiodothyronine (Behne & Kyriakopoulos 2001), enhances the antioxidant status in muscle, tends to improve meat quality and extends the shelf life (Mitsumoto *et al.* 1998, Morrissey *et al.* 1994). Furthermore, Se plays a role in the enhancement of the immune system by protecting it against oxidative stress, and increases carcass quality (Mateo *et al.* 2007, Quin *et al.* 2007). On the other hand, Mg acts as a cofactor or an activator of many critical enzymes for the reactions involving adenosine triphosphate that energizes all major metabolic pathways (Sommer *et al.* 1997).

Specifically, the ingredients included in the diets of feedlot lambs are sufficient to provide the amounts of Se and Mg recommended by the NRC (1985, 2007). This suggests that there is no need to provide supplement sources of these elements. Hernandez-Calva *et al.* (2006) observed that increasing supplemental Mg and Se from 0.1 to 0.32% and 0.1 and 0.3 µg Se/g respectively, improved Mg and Se digestibility. Therefore, simultaneous supplementation of Se and Mg in higher doses, using cheap inorganic sources in the diet of lambs, may cause a synergistic effect in improving some parameters of production and meat quality.

Material and methods

Animals, treatments, their management and feeding

Sixty-four intact male lambs (25 kg) of the Pelibuey breed, about 4 months old, were received at the unit research of Tlaxcala University, Mexico. Upon arrival, lambs were vaccinated against clostridial diseases (Ultrabac 8, GlaxoSmithKline, Brentford, UK) and treated for parasites (Ivomec Plus® Merck, Rahway, NJ, USA). Average daily minimum and maximum air temperature were 2.5 and 17.1 °C, respectively. Lambs were adapted to the basal grain diet for 14 d before the initiation of the trial. Afterwards, lambs were selected according to the body weight and randomly assigned within weight groupings to 16 pens, 16 lambs per treatment and 4 treatments (4 pens per treatment distributed in four lambs per pen). Pens were 4 m² with automatic water resources. The treatments used were as follows: 1) low level of Mg and Se: diet with 0.18% of Mg and 0.1 µg/g Se (these concentrations were provided only by the ingredients of the ration), 2) with supplementation of 0.32% Mg as magnesium oxide (MgO) with 0.1 µg/g Se, 3) with supplementation of 0.3 µg/g Se as sodium selenite (Na₂SeO₃) with 0.18% of Mg, 4) with supplementation of MgO and Na₂SeO₃: diet with 0.32% of Mg and 0.3 µg/g Se. The composition of experimental diets is shown in Table 1. Diets were prepared at approximately weekly intervals and stored in plywood boxes. Lambs were allowed free

access to feed. Approximately 40% of daily feed consumption was provided in the morning feeding and 60% in the afternoon feeding. Experimental feeding was done for a period of 42 days. During this process, animals were weighed on an electronic weighing balance with a precision of ± 10 g (Torrey, Morelia, Mexico) at the beginning of the study and then regularly after every 14 days before feeding and watering them from 7 to 9 a.m.. The amount of feed offered to each animal was revised at 14-day intervals as per the change in the average daily gain (ADG) and dry matter intake (DMI). Feed conversion ratios (DMI/ADG) were estimated for the 6 weeks that lambs remained in the experiment.

Table 1
Composition of experimental diets with different concentrations of magnesium and selenium

Source	T1 0.18% Mg + 0.1 $\mu\text{g/g}$ Se	T2 0.32% Mg + 0.1 $\mu\text{g/g}$ Se	T3 0.18% Mg + 0.3 $\mu\text{g/g}$ Se	T4 0.32% Mg + 0.3 $\mu\text{g/g}$ Se
Ingredients, % (dry matter)				
Alfalfa, hay	6.0	6.0	6.0	6.0
Wheat, grain	34.0	33.7	33.56	33.26
Barley, grain	30.0	30.0	30.0	30.0
Barley rootless	10.0	10.0	10.0	10.0
Fish meal	0.5	0.5	0.5	0.5
Vegetable oil	2.0	2.0	2.0	2.0
Molasses cane	6.0	6.0	6.0	6.0
Straw corn	8.0	8.0	8.0	8.0
Limestone	1.5	1.5	1.5	1.5
Urea	1.0	1.0	1.0	1.0
Trace minerals ^a	1.0	1.0	1.0	1.0
Magnesium oxide: MgO		0.30		0.30
Sodium selenite: Na_2SeO_3 , $\mu\text{g/g}$			0.44	0.44
Nutritional composition (basis dry matter)				
EN_m , Mcal/kg	1.92	1.91	1.91	1.91
EN_g , Mcal/kg	1.29	1.29	1.28	1.28
Protein, %	16.9	16.90	16.90	16.88
Calcium, %	0.72	0.71	0.71	0.70
Phosphorus, %	0.34	0.33	0.33	0.33
Magnesium, %	0.181	0.32	0.18	0.32
Selenium, $\mu\text{g/g}$	0.102	0.10	0.32	0.32

^atrace mineral salt contains: CoSO_4 , 0.068%; CuSO_4 , 1.04%; FeSO_4 , 3.57%; ZnO , 1.24%; MnSO_4 , 1.07%; KI , 0.052%; y NaCl , 92.96%.

Carcass and meat measurements

Lambs were shipped for slaughter when the average final gross weight for the pen blocks was approximately 40 kg (~60 d of experimental feeding). After slaughtering, all body components such as head, limbs (separated at metatarsal and metacarpal joints), skin, blood, viscera and gastrointestinal digesta content were weighed and classified in terms of their respective percentages with respect to animal live weight. Empty body weight (EBW) was calculated by deducting the weight of gastrointestinal content from live weight at slaughtering. Hot carcass weight was recorded and it included kidney and testicle weights

according to the Mexican norm for carcass evaluation (Mexican Norm Official 2006). Warm carcasses were chilled in a cold room maintained at 4 °C. On the next day, the cold carcass weight was registered. Commercial and biological dressing percentages were calculated according to the following formulae:

$$\text{Commercial dressing percentage} = \frac{\text{hot carcass weight}}{\text{live weight}} \times 100 \quad (1)$$

$$\text{Biological dressing percentage} = \frac{\text{hot carcass weight}}{\text{live weight}} \times 100 \quad (2)$$

After chilling the carcasses for 24 h, fat depth was measured with a fat depth knife placed in the intercostals cavity of the 12th rib, 4 cm from the spine, as described by the Mexican norm for carcass evaluation. The following carcass conformation measurements were taken: Carcass width (widest carcass measurement at the ribs), buttock width (widest buttock measurement in a horizontal plane on the hanging carcass), leg length (from the head of the femur to the distal edge of the tarsus), leg width (widest leg measurement in a horizontal plane on the hanging carcass) and cuts weight (kg) of saddle, breast, ribs, loin and legs.

Instrumental measurement

Cold carcasses were split down the transversal midline and during cut preparation. The loin and neck samples were taken from the *Longissimus lumborum*, *braquicephalic* and *sternocephalic* muscles in order to analyse pH, which was measured 1 h and 24 h after slaughter using the equipment Crison pH-metro 507 (Crison Instruments, Alella, Spain) and a 52-32 spear electrode, water activity, water holding capacity, emulsion capacity, peroxide index and colour. Colour and chromatic values were reported as L*, a*, b* and shades ($\tan^{-1}b/a$ angle and magnitude $(a^2+b^2)^{1/2}$ g). Shear force values were determined on both, raw and cooked meat, using a Warner-Bratzler shear in a TA-XT2 texture analyser (Texture Technologies, Hamilton, MA, USA) at 5 mm test speed, being applied 0.981 N force. The last variable was analysed using cooked meat from both muscles. Reposting data of the maximum force applied to cut the sample when a known force is applied.

Fatty acids content was analysed by chromatography using an automatic injector (Cañeque & Sañudo 2001). Selenium and Mg were analysed by atomic absorption spectrophotometry with hydride generation (only Se) after an acid digestion by microwave in the »Development of Analytical Methods laboratory« at FES-C, UNAM. Mexico. Approximately 1 g of sample, 10 mL of demineralized H₂O (Millipore, Billerica, MA, USA), 5 mL HNO₃ and 2 mL H₂O₂ (J.T. Baker, Ecatepec, Mexico) were placed in a teflon container for 10 min. and digested using a microwave oven (MAR 5, CEM, Matthews, NC, USA). The containers were cooled to room temperature, their contents were placed in 50 mL volumetric matrices (each container was rinsed three times with HCl 7 M), taken to the mark and was phosphorylated with HCl 7 M. Later, the samples were moved to labeled polyethylene containers and the quantification of the total Se and Mg were determined from a calibration curve (Capelo *et al.* 2006).

Sensory analysis

Lamb samples were thawed at 4 °C for 24 h before being used. They were cut into five slices of 1.5 cm thickness and cooked in a contact grill pre-heated to 200 °C until the internal temperature of the muscle reached 72 °C, as measured by a thermo-couple inserted into the approximate centre of the muscle. After cooking the slices of lean, excluding external fat and connective tissue, they were cut into two pieces and each piece was wrapped with aluminium foil, coded and placed in a heater to stop the cooling process. A panel of 56 participants were randomly selected from students and staff of the Autonomous Metropolitan University, Mexico. The panel members were situated in individual areas. Afterwards, panelists were asked to assess each sample of loin and neck for the following sensory attributes: general quality, flavour intensity (associated with the animal species or cooked lamb meat), odor intensity (odor animal species or cooked lamb meat), hardness (the force needed to chew), juiciness (water perceived during mastication), using a nonstructured 1-15 cm scale, representing at the extremes the minimum (0–absence of the sensation) and the maximum (15–sensation extremely intense). Unsalted crackers and water were served to panellists to freshen their mouth between each sample assessment. Meat was served following a randomised design for order and panellists were asked to eat a bit of cracker and to drink a bit of still water at the beginning of the sensory evaluation and between samples, to try to make the palate conditions similar for each sample. The panel members were placed according to AMSA sensory evaluation guidelines (AMSA 1995).

Statistical analysis

A design of blocks were used at random, with factorial adjustment 2×2 among treatments (treatments: control (1), Mg (2), Se (3), Se**Mg* (4)). The statistical model was the following one:

$$Y_{ijk} = \mu + t_i + b_j + t_i \times b_j + e_{ijk} \quad (3)$$

where Y_{ijk} is the variable of answer of the productive performance and characteristic of the carcass, μ is the average population, t_i is the effect of the treatment, b_j is the effect of the block, $t_i \times b_j$ is the effect of the interaction and e_{ijk} is the experimental error.

The data collected in this study were subjected to analysis of variance and comparison of averages through contrast, using SAS 9.1 software (SAS Institute Inc., Cary, NC, USA).

Results and discussion

Growth performance

The effects of dietary treatment on lamb growth and DMI are presented in Table 2. There were no differences ($P > 0.05$) in ADG and feed conversion. Several studies have shown an increase in ADG with Na_2SeO_3 injections (Spears *et al.* 1986, Castellan *et al.* 1999) or no response when supplemented with the Se boluses release (Gunter *et al.* 2003) or directly in cattle feed (Lawler *et al.* 2004) and lambs (Vignola *et al.* 2009). Contrary to our results, Kumar *et al.* (2009) found a positive effect on growth performance of the lambs. The different responses are associated more with concentrations in the tissues; it is the process of dosage. A severe deficiency is not reflected in the ADG, but an additional moderate deficiency may

be reflected in ADG (Stowe & Herdt 1992). The DMI has an effect in all periods of the study, where supplementation with Na_2SeO_3 improved DMI by 13% (1.26 vs. 1.115). Lawler *et al.* (2004) found no effect on the feed intake with Na_2SeO_4 administered. Referring to Mg, over the period of 14 to 28 days, MgO supplementation improved consumption by 3.4%. This value isolated in previous studies in cattle found no differences in this variable (Ramirez *et al.* 1998, Ramirez & Zinn 2000).

Table 2
Influence of magnesium and selenium supplementation on growth performance response of feedlot lambs

Source	0.18% Mg + 0.1 µg/g Se	0.32% Mg + 0.1 µg/g Se	0.18% Mg + 0.3 µg/g Se	0.32% Mg + 0.3 µg/g Se	SEM
Lambs per treatment	16	16	16	16	-
Initial weight, kg	24.05	24.60	23.83	24.53	2.05
ADG, kg					
day 1 to 28	0.271	0.267	0.219	0.246	0.07
day 14 to 28	0.237	0.242	0.238	0.241	0.07
day 1 to 42	0.264	0.252	0.223	0.240	0.06
DMI, kg/day					
day 1 to 28 ^a	1.19	1.18	1.06	1.08	0.04
day 14 to 28 ^{ab}	1.24	1.28	1.11	1.15	0.04
day 1 to 42 ^a	1.26	1.24	1.11	1.12	0.05
DMI/ADG					
day 1 to 28	4.53	5.11	5.21	4.55	1.52
day 14 to 28	5.58	6.43	4.96	4.94	1.90
day 1 to 42	4.90	5.34	5.18	4.84	1.33

*Initial and final live weight reduced 10.5% to account for fill (gastrointestinal content), ^aSe effect $P < 0.001$,

^bMg effect $P < 0.05$

Carcass and meat quality

Significant differences were not present with the exception that commercial and biological dressing percentage were improved ($P < 0.1$, Table 3) with the supplement of Na_2SeO_3 as a source of Se. These differences were due to the higher proportion of muscle tissue in the region of the legs ($P < 0.02$, Table 4). Lawler *et al.* (2004) and Vignola *et al.* (2009) found that dietary Se had no effect on carcass dressing percentage. Other authors (Gabryszuk *et al.* 2009) administered Se, Zn (zinc) and vitamin E orally to growing ram-lambs which induced a decreased fat content in leg, fat thickness on loin-eye and fat thickness over ribs. However, in this research the carcass dressing percentage was evident, due to increased development of tissues that made up the legs in the groups supplemented with Se. A possible reason is that the mineral potential can stimulate hypertrophy in type 1 fibers of skeletal muscles (Rannem *et al.* 1995). It is known that Se has a specific activity of enzymes, which converts Se source from trisulfide selenoglutathion, which is degraded in the liver to form selenide (Schrauzer 2000). The selenide is finally used for the synthesis of selenoproteins like glutathione peroxidase. This enzyme, when integrated with skill, improves muscle and protects against peroxidation. Decreased activity of malondialdehyde and increased activity of glutathione peroxidase in muscle tissue increase cellular activity (Zhan *et al.* 2007). Referring to Mg, in the period from 14 to 28 days, MgO supplementation improved DMI by 3.4%.

Table 3
Influence of magnesium and selenium supplementation on carcass characteristics of feedlot lambs

Source	0.18 % Mg + 0.1 µg/g Se	0.32 % Mg + 0.1 µg/g Se	0.18 % Mg + 0.3 µg/g Se	0.32 % Mg + 0.3 µg/g Se	SEM
Live weight, kg	41.43	41.83	39.10	40.88	3.21
Fasting live weight, kg	36.2	37.55	34.4	35.02	3.63
Carcass hot weight, kg	21.38	21.22	20.84	21.12	1.61
Carcass cold weight, kg	20.90	20.6	20.44	20.68	1.61
Commercial dressing, % ^a	50.49	49.23	52.58	50.68	1.58
Biological dressing, % ^a	57.99	54.90	59.44	59.47	1.13

^aSe effect $P < 0.05$

Table 4
Influence of magnesium and selenium supplementation on carcass proportions of feedlot lambs

Source	0.18 % Mg + 0.1 µg/g Se	0.32 % Mg + 0.1 µg/g Se	0.18 % Mg + 0.3 µg/g Se	0.32 % Mg + 0.3 µg/g Se	SEM
Carcass length, cm	65.16	65.33	66.20	64.66	2.43
Fat thickness over, mm	2.58	2.48	2.48	2.50	0.27
Carcass width, cm	76.66	75.83	74.80	75.25	1.85
Buttock width, cm	59.66	59.51	61.10	60.25	1.63
Fore shank width, cm	24.41	25.42	25.00	24.83	1.81
Leg length, cm	29.00	28.83	28.60	28.16	1.06
Leg width, cm	32.08	31.66	30.80	31.50	2.77
Saddle weight, kg	4.62	4.58	4.31	4.57	0.44
Breast weight, kg	1.43	1.41	1.46	1.38	0.19
Ribs weight, kg	3.30	3.21	3.00	3.03	0.51
Loin weight, kg	4.26	4.61	3.27	4.01	1.10
Legs weight, kg ^a	5.08	4.80	6.09	5.54	0.56

^aSe effect $P < 0.02$

Table 5
Influence of magnesium and selenium supplementation on muscle minerals concentration (as wet tissues) of lamb meat

Source	0.18 % Mg + 0.1 µg/g Se	0.32 % Mg + 0.1 µg/g Se	0.18 % Mg + 0.3 µg/g Se	0.32 % Mg + 0.3 µg/g Se	SEM
Selenium, µg/g					
Neck	0.168	0.134	0.174	0.171	0.077
Loin	0.169	0.180	0.192	0.146	0.065
Magnesium, mg/g					
Neck	0.211	0.196	0.168	0.270	0.045
Loin	0.191	0.213	0.195	0.215	0.035

ns, $P > 0.05$

Concentrations of Se and Mg among treatments showed no difference (Table 5) in muscle, which is attributed to the method of administration in the diet and the concentration levels used in this experiment. Combs & Combs (1986) reported an increase in the absorption and storage of selenomethionine vs. sodium selenite (inorganic Se), followed by the incorporation of selenomethionine into the protein. However, this physiological event is evident in non-ruminants with the lack of transformation of the microelement in the rumen. The USDA (2006)

recommends the ingestion of 55 µg Se/day, with a maximum acceptable concentration of 400 µg Se/day. The average Se in muscle tissue of neck and loin in this study was 1.66 µg Se/g. However, the proportion of 100 g of lamb meat consumed should be covering the minimum requirement. Similarly, Cabrera *et al.* (2010) found a Se content ranged between 0.42 and 1.30 µg Se/g in wet tissues of steers. Referring to Mg, the requirement of the USDA (2006) is 350 mg/d. The average concentrations of Mg in neck muscle and loin of this study were 0.7 mg/g and an amount of 100 g of meat is not sufficient to cover the minimum requirement. It is difficult to achieve this concentration with dietary supplementation, as animal behaviour would be affected and therefore it should seek other sources or varieties of foods to meet the necessary requirement of Mg at different stages of human life.

Table 6
Influence of magnesium and selenium supplementation on long fatty acids in lamb meat

Source	0.18 % Mg + 0.1 µg/g Se	0.32 % Mg + 0.1 µg/g Se	0.18 % Mg + 0.3 µg/g Se	0.32 % Mg + 0.3 µg/g Se	SEM
Total fatty acid, %					
Neck					
C 14:0 ^a	1.96	2.27	2.38	1.98	0.29
C 16:0 ^b	23.81	25.78	25.57	24.67	1.45
C 16:1 n-7	2.85	3.11	2.90	2.73	0.44
C 18:0	16.95	16.30	17.05	17.00	1.72
C 18:1 n-9	44.88	43.16	43.23	44.09	2.04
C 18:2 n-6	9.06	8.63	8.85	9.05	1.59
C 18:3 n-3	0.46	0.73	0.00	0.46	0.69
Loin					
C 14:0	1.75	2.08	2.31	1.94	0.33
C 16:0 ^c	23.43	24.89	25.69	24.10	2.02
C 16:1 n-7	2.58	3.54	2.74	2.54	0.83
C 18:0	16.56	15.94	15.83	16.24	1.05
C 18:1 n-9	43.02	41.76	42.55	43.17	2.73
C 18:2 n-6	11.49	11.19	9.81	10.83	1.80
C 18:3 n-3	1.14	1.23	1.05	1.14	1.03

^aInteraction Mg×Se $P<0.01$, ^bInteraction Mg×Se $P<0.05$, ^cInteraction Mg×Se $P<0.1$

Table 6 shows the concentrations of fatty acids in neck and loin tissue. In the region of neck, C 14:0 and C 16:0 fatty acids showed an interaction, treatment with 0.32 % Mg+0.1 µg Se/g increased, C 14:0, 37% in neck and 18.8% in loin; C 16:0, 8.3% in loin and 6.2% in neck. Supplementation with MgO and Na₂SO₃ decreased the percentage concentration of these fatty acids: C 14:0 (17% in neck and 16% in loin), C 16:0 (5.9% in neck and 6.2% in loin). This difference was only noticeable in these saturated fatty acids. Annett *et al.* (2011) observed that injection Se (50 mg Se per lamb), as barium selenite, increased ($P<0.05$) the level of 20:4 n-6 in lamb meat but resulted in lower ($P<0.001$) levels of 22:6 n-3. However, Se had no effects on any of the health attributes of lamb meat. Apparently, there may be a physiological mechanism that these minerals interact with the synthesis or availability of fatty acids. The average concentrations of C 16:0 and C 18:0 (Table 6) were higher among the saturated fatty acids and the concentration of C 18:1 n-9 was higher in the unsaturated group.

Table 7
Influence of magnesium and selenium supplementation on physicochemical characteristics of lamb meat

Source	0.18 % Mg + 0.1 µg/g Se	0.32 % Mg + 0.1 µg/g Se	0.18 % Mg + 0.3 µg/g Se	0.32 % Mg + 0.3 µg/g Se	SEM
Neck color					
L ^b	39.27	36.54	41.16	40.78	3.26
a ^c	9.30	10.56	8.21	8.45	2.12
b	10.54	10.35	10.80	9.94	1.84
Loin Color					
L	35.00	37.75	35.94	35.96	3.26
A	9.68	9.65	10.51	9.53	1.46
b	10.41	10.39	10.39	9.95	1.51
Raw shear force					
Neck	3015.43	2301.79	2057.40	2784.67	1208.80
Loin	2529.02	2971.13	2172.86	2509.08	820.90
Cooked meat toughness					
Neck	2848.15	2687.19	2125.92	2615.17	1592.40
Loin	1832.49	2172.86	2971.13	2075.05	1146.30
pH					
Neck	6.03	6.08	6.16	6.0	0.32
Loin	5.87	5.74	5.83	5.79	0.36
Water holding capacity potential					
Neck ^a	42.00	38.66	67.00	51.16	13.47
Loin	39.83	40.50	46.00	36.66	11.49
Water activity					
Neck	0.96	0.96	0.97	0.96	0.01
Loin	0.97	0.95	0.95	0.96	0.04
Emulsion capacity					
Neck	76.11	74.22	90.40	87.92	29.71
Loin	78.41	75.91	94.71	87.23	30.62
Peroxide index					
Neck	3.38	3.31	2.78	3.60	0.77
Loin	5.56	5.30	5.52	4.90	0.67

^aSe effect $P < 0.005$, ^bSe effect $P < 0.05$, ^cSe effect Se $P < 0.1$

Table 7 shows the average values of the coordinate L* neck which increased with supplementation of Se ($P < 0.05$), while the coordinate a* fell 16 points with supplementation of Se ($P < 0.1$). The coordinate b* showed no significant differences in any of the treatments. Vignola *et al.* (2009) found no differences in the colour of lamb meat when a supplement of Na₂SeO₃ or selenium enriched yeast were at a concentration of 0.3 µg/g. Tenderness, expressed as shear strength, is one of the parameters that can indicate meat quality (hardness) and in this parameter, as one of the determinants of the degree of acceptability by the consumer (Clare *et al.* 1997), no difference among treatments was found. It is considered that the pH can have an effect on the hardness. Some authors (Hopkings *et al.* 1995) describe three final pH ranges: normal (<5.8), intermediate (5.9-6.2) and high (>6.3), in which the meat presents a different degree of maturation. The pH was not different among treatments, although its value has great influence on meat colour. Hopkins *et al.* (1995) found a significant correlation between negative values of L* and b* and pH of the muscle. Zhan *et al.* (2007) indicated that the function of Se to improve the meat quality was through enhancing its antioxidative

ability to protect against deterioration reactions during lipid peroxidation. Water retention potential (WRP) values are expressed as mL of 0.6 M NaCl retained in 100 g of meat. Pearce *et al.* (2011) suggested that the final pH can have a significant influence on the WRP of the flesh as it determines the electric charges of proteins and therefore their ability to retain water. In our case, neck WRP had a Se effect ($P<0.01$) but there were no significant differences in neck and loin pH (Table 7). Water activity showed no differences among treatments. The average neck and loin muscle were 0.965 and 0.959 specifically. The raw meat Aw was considered within a normal range and was approximately 0.97-0.99 (Hernández-Cruz *et al.* 2009). Peroxide value mean was 4.3 and there were no differences.

Sensory Characteristics

Sensorial analysis (Table 8) was affected by the treatments. Taste, juiciness and hardness of the neck muscle increased (28, 40 and 23.5%) with Mg supplementation. With respect to the muscle of the loin, the odor decreased (18%, $P<0.01$) with Mg supplementation. The smoothness of the neck was also improved (23.5%, $P<0.05$) with supplementation of Se. Swigert *et al.* (2004) reported that pork supplemented with Mg had higher juiciness scores. The variations recorded at the different attributes vary considering the type of muscle, the amount and solubility of connective tissue, their spatial distribution and chemical composition. However, all meat samples, regardless of treatment, received a score higher than six. Variations registered for the different attributes have been considered the type of muscle, the amount and solubility of connective tissue, their spatial distribution and chemical composition. Meat from the *Longissimus lumborum* muscle was tenderer, better tasting and more acceptable than meat from *brachiocephalic* muscle.

Table 8
Influence of magnesium and selenium supplementation for sensory traits of meat from lambs

Source	0.18% Mg + 0.1 µg/g Se	0.32% Mg + 0.1 µg/g Se	0.18% Mg + 0.3 µg/g Se	0.32% Mg + 0.3 µg/g Se	SEM
General quality					
Neck	5.62	6.81	6.71	7.05	3.11
Loin	8.12	9.00	8.72	7.36	3.32
Flavour					
Neck ^c	5.06	6.93	5.75	6.82	3.51
Loin	8.25	8.71	8.07	7.23	3.54
Lamb odor intensity					
Neck	6.31	7.60	7.75	7.45	3.61
Loin ^{be}	8.35	8.12	10.02	6.92	3.13
Color					
Neck	6.76	8.15	6.73	6.73	3.22
loin ^e	8.33	9.16	9.65	7.64	3.12
Juiciness					
Neck ^a	4.62	6.64	5.63	7.72	3.24
Loin	8.57	8.23	6.89	8.15	3.35
Hardness					
Neck ^{cd}	5.14	6.72	6.84	8.00	3.73
Loin	9.45	9.93	8.55	8.42	3.84

^aMg effect $P<0.0001$, ^bMg effect $P<0.01$, ^cMg effect $P<0.05$, ^dSe effect $P<0.05$, ^eInteraction Mg×Se $P<0.05$

In conclusion the incorporation of ascending concentrations of Se and Mg in the inorganic forms into growing lambs' diet improved some parameters. Specifically, Se supplement with Na₂SeO₃ (0.3 µg Se/g) enhanced DMI, commercial and biological yield of the carcass. Magnesium supplement with MgO (0.32%) did not improve the animal performance but it enhanced some characteristics in sensorial meat analysis.

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References

- AMSA (1995) Research guidelines for cookery, sensory evaluation and instrumental tenderness measurements of fresh meat. American Meat Science Association and National Livestock and Meatboard, Chicago, IL, USA
- Annett RW, Carson AF, Fearon AM, Kilpatrick DJ (2011) Effects of supplementation with fish oil and barium selenate on performance, carcass characteristics and muscle fatty acid composition of late season lamb finished on grass-based or concentrate-based diets. *Animal* 5, 1923-1937
- Balicka-Ramis A, Pilarczyk B, Ramisz A, Wieczorek M (2006) Effect of selenium administration on blood serum Se content and on selected reproductive characteristics of sheep. *Arch Tierz* 49, 176-180
- Behne D, Kyriakopoulos A (2001) Mammalian Selenium-Containing Proteins. *Annu Rev Nutr* 21, 453-473
- Cabrera MC, Ramos A, Saadoun A, Brito G (2010) Selenium, copper, zinc, iron and manganese content of seven meat cuts from Hereford and Braford steers fed pasture in Uruguay. *Meat Sci* 84, 518-528
- Cañeque V, Sañudo C (2001) [Methodology for the study of carcass quality and meat in ruminants.] Monografías INIA, Ganadera No.1. Ministerio de Ciencia y Tecnología [in Spanish]
- Capelo JL, Fernández C, Pedras B, Santos P, González P, Vaz C (2006) Trend in selenium determination specialisation by hyphenated techniques based on AAS or AFS. *Talanta* 68, 1442-1447
- Castellan DM, Maas JP, Gardner IA, Oltjen JW, Sween ML (1999) Growth of suckling beef calves in response to parenteral administration of selenium and the effect of dietary protein provided to their dams. *J Am Vet Med Assoc* 214, 816-821
- Clare TL, Jackson SP, Miller MF, Elliott CT, Ramsey CB (1997) Improving tenderness of normal and callipyge lambs with calcium chloride. *J Anim Sci* 75, 377-385
- Combs GF, Combs SB (1986) The role of selenium in nutrition. Department of Poultry and Avian Sciences and Division of Nutritional Sciences, Cornell University, Ithaca, NY, USA, 413-461
- Cozzi G, Prevedello P, Stefani AL, Piron A, Contiero B, Lante A, Gottardo F, Chevaux E (2011) Effect of dietary supplementation with different sources of selenium on growth response, selenium blood levels and meat quality of intensively finished Charolais young bulls. *Animal* 5, 1531-1538
- Faustman C, Chan WK, Schaefer DM, Havens A (1998) Beef color update: the role for vitamin E. *J Anim Sci* 76, 1019-1026
- Gabryszuk M, Horbańczuk K, Klewiec J (2009) Rearing, fattening performance and slaughter indicators of lambs after selenium, zinc and vitamin E supplementation. *Arch Tierz* 52, 309-320
- Gunter SA, Beck PA, Phillips JM (2003) Effects of supplementary selenium source on the performance and blood measurements in beef cows and their calves. *J Anim Sci* 81, 856-864
- Hernández-Calva LM, Guerrero-Legarreta MI, Pérez-Chabela ML, López-Arellano R, Ramírez-Bribiesca JE (2006) Interaction of Dietary Selenium and Magnesium Level on Digestive Function in Lambs fed High-concentrate Diets. *J Appl Anim Res* 31, 41-46
- Hernández-Cruz L, Ramírez-Bribiesca JE, Guerrero-Legarreta MI, Hernández-Mendo O, Crosby-Galvan mm, Hernández-Calva LM (2009) Effects of crossbreeding on carcass and meat quality of Mexican lambs. *Arq Bras Med Vet Zootec* 61, 475-483
- Hopkins DL, Ferrier GR, Channon HA, MacDonald BA (1995) Assessment of lamb meat quality in Sydney and Melbourne. In: *Proc New Zealand Soc Anim Prod* 55, 114-116

- Kumar N, Garg AK, Dass RS, Chaturvedi VK, Mudgal V, Varshney VP (2009) Selenium supplementation influences growth performance, antioxidant status and immune response in lambs. *Anim Feed Sci Tech* 153, 77-87
- Lawler TL, Taylor JB, Finley JW, Caton JS (2004) Effect of supranutritional and organically bound selenium on performance, carcass characteristics, and selenium distribution in finishing beef steers. *J Anim Sci* 82, 1488-1493
- Mateo RD, Spallholz JE, Elder R, Yoon I, Kim SW (2007) Efficacy of dietary selenium sources on growth and carcass characteristics of growing-finishing pigs fed diets containing high endogenous selenium. *J Anim Sci* 85, 1177-1183
- Mitsumoto M, Ozawa S, Mitsuhashi T, Koide K (1998) Effect of dietary vitamin E supplementation for one week before slaughter on drip, colour and lipid stability during display in Japanese Black steer beef. *Meat Sci* 49, 165-174
- Morrissey PA, Buckley DJ, Sheehy PJA (1994) Vitamin E and meat quality. *Proc Nutr Soc* 53, 289-297
- Mexican Norm official. PROY-NMX-FF-106-SCFI (2006) [Livestock products in lamb meat-carcass NMX-FF-106-SCFI-2006.] SAGARPA. Mexico [In Spanish]
- NRC (1985) Nutrient Requirements of Sheep. 6th rev. ed., Subcommittee on Sheep Nutrition, Committee on Animal Nutrition, Board on Agriculture, National Research Council, Washington, DC, USA
- NRC (2007) Nutrient Requirements of Small Ruminants. Sheep, goats, cervids, and new world camelids. National Research Council Committee in Nutrient Requirements of Small Ruminants, National Academy Press, Washington, DC, USA
- Pearce KL, Rosenvold K, Andersen HJ, Hopkins DL (2011) Water distribution and mobility in meat during the conversion of muscle to meat and ageing and the impacts on fresh meat quality attributes – A review. *Meat Sci* 89, 111-124
- Qin S, Gao J, Huang K (2007) Effects of different selenium sources on tissue selenium concentrations, blood GSH-Px activities and plasma interleukin levels in finishing lambs. *Biol Trace Elem Res* 116, 91-102
- Ramirez JE, Alvarez EG, Montaña M, Shen Y, Zinn RA (1998) Influence of dietary magnesium level on growth-performance and metabolic responses of Holstein steers to laidlomycin propionate. *J Anim Sci* 76, 1753-1759
- Ramirez JE, Zinn RA (2000) Interaction of dietary magnesium level on the feeding value of supplemental fat in finishing diets for feedlot steers. *J Anim Sci* 78, 2072-2080
- Rannem T, Ladefoged K, Hylander E, Christiansen J, Laursen H, Kristensen JH, Linstow M, Beyer N, Liguori R, Dige-Petersen H, Jensen BH, Jarnum S (1995) The Effect of Selenium Supplementation on Skeletal and Cardiac Muscle in Selenium-Depleted Patients. *J Parenter Enteral Nutr* 19, 351-355
- Rederstorff M, Krol A, Lescure A (2006) Understanding the importance of selenium and selenoproteins in muscle function. *Cell Mol Life Sci* 63, 52-59
- Reinhart RA (1988) Magnesium Metabolism. A Review with Special Reference to the Relationship Between Intracellular Content and Serum Levels. *Arch Intern Med* 148, 2415-2420
- Schrauzer GN (2000) Selenomethionine: A Review of Its Nutritional Significance, Metabolism and Toxicity. *J Nutr* 130, 1653-1656
- Sommer A, Chrenkova M, Chovanec J, Pajtas M, Polacikova M, Braun C (1997) [Influence of flue dust emissions containing excess Mg on the fermentation processes in the rumen: Balance of N, Ca, P, and Mg in ruminants.] In: VDLUFA. Kongreßband 1997, Leipzig, Germany, 155-158 [in German]
- Spears JW, Harvey RW, Segerson EC (1986) Effects of Marginal Selenium Deficiency and Winter Protein Supplementation on Growth, Reproduction and Selenium Status of Beef Cattle. *J Anim Sci* 63, 586-594
- Stowe HD, Herdt TH (1992) Clinical assessment of selenium status of livestock. *J Anim Sci* 70, 3928-3933
- Swigert KS, McKeith FK, Carr TC, Brewer MS, Culbertson MW (2004) Effects of dietary vitamin D₃, vitamin E, and magnesium supplementation on pork quality. *Meat Sci* 67, 81-86
- USDA (2006) <http://www.fas.usda.gov/2006/whatsnewaug06.asp> [last accessed 10.02.2013]
- Vignola G, Lambertini L, Mazzone G, Giammarco M, Tassinari M, Martelli G, Bertin G (2009) Effects of selenium source and level of supplementation on the performance and meat quality of lambs. *Meat Sci* 81, 678-685
- Zhan XA, Wang M, Zhao RQ, Li WF, Xu ZR (2007) Effects of different selenium source on selenium distribution, loin quality and antioxidant status in finishing pigs. *Anim Feed Sci Technol* 132, 202-211
- Zinn RA, Shen Y (1996) Interaction of dietary calcium and supplemental fat on digestive function and growth performance in feedlot steers. *J Anim Sci* 74, 2303-2309