LAMB MUSCLE SELENIUM CONCENTRATION PLATEAUS FOLLOWING 56 DAYS OF SELENIUM SUPPLEMENTATION

C.S. Schauer[1], J. Held[2], J. Daniel[2], J. Caton[3], P. Hatfield[4], R. Stobart[5], J.O. Hall[6], D.M. Stecher[1], D. Pearson[1], and D. Drolc[1]

[1]Hettinger Research Extension Center, NDSU, Hettinger, ND
[2]South Dakota State University, Brookings, SD
[3]North Dakota State University, Fargo, ND
[4]Montana State University, Bozeman, MT
[5]University of Wyoming, Laramie, WY
[6]Veterinary Diagnostic Laboratory, Utah State University, Logan, UT

Acknowledgements: We would like to thank the South Dakota Agricultural Experiment Station and the Four-State Ruminant Consortium for funding this project.

Impact Statement
Lambs supra-supplemented with selenium have skeletal muscle selenium concentrations at levels that may prevent lung, colorectal, and prostate cancer in humans. Providing supranutritional levels of selenium for up to 56 days enhances muscle selenium concentration, however, muscle selenium concentration appears to plateau following 56 days of supplementation. These results indicate that future research is necessary to determine the lamb-to-lamb variability in muscle selenium concentration associated with supra-selenium supplementation protocols. Additionally, efforts are needed to ascertain the likely level of demand for a high-selenium lamb product, and the marketing techniques required to deliver that product to the consumer.

Introduction

Selenium (Se) deficiency in humans is not considered to be an issue in the United States, however, recent research suggests that humans who consume in excess (2 to 4 fold) of the recommended dietary allowance (RDA = 55 μg Se/d) of Se may reduce their chance for developing lung, colorectal, and prostate cancer by 30, 50, and 70%, respectively (Clark et al., 1996). Although tablets of Se as selenite or high Se yeast are available, the American Dietetic Association encourages people to consume nutrients through food whenever possible, including meats and grains.

Taylor et al. (2002) documented that circulating plasma Se concentration of finishing beef steers was elevated by feeding high Se (60 to 70 $\mu g \bullet kg^{-1}$ BW $\bullet$ d^{-1}) wheat, hay, or sodium selenate supplement by d 21 of feeding. Additionally, Lawler et al. (2004) reported that beef steers fed feedstuffs naturally high in Se (65 $\mu g \bullet kg^{-1}$ BW $\bullet$ d^{-1}) had Se concentration in semitendinosus muscle greater than those fed control or selenate supplemented animals. The inability of the sodium selenate supplement to increase muscle Se concentration is likely linked to the organic sources of Se containing primarily selenomethionine, which accumulates in tissue to a greater extent than other forms of Se. Results by Lawler et al. (2004) were similar to those of Hintze et al. (2001), reporting that a moderate sized portion of high Se beef would supply the Se necessary to achieve the cancer protection benefits described by Clark et al. (1996). Research by Schauer et al. (2005) indicates that feeding supranutritional levels of selenoyeast for 56 days to lambs prior to harvest can increase lamb muscle Se levels to concentrations required to prevent cancer in humans. However, a plateau in muscle Se concentration has not been reached by feeding supranutritional levels of Se for up to 56 d. Research by Schauer et al. (2005) and Taylor (2005) reported a linear increase in muscle Se concentration for 56 d of supranutritional Se supplementation, indicating that muscle Se concentration may continue to increase as length of supra-supplementation of Se continues beyond 56 d. Although the four state region has soils high in Se, the variability of Se concentration in forages (and subsequently grazing livestock) indicate that a feeding program for finishing livestock is necessary to ensure animals of both low and high Se status can achieve the desired Se concentration in skeletal muscle (Lawler et al., 2002).

Research by Lawler et al (2004) indicates that hot carcass weight, longissimus muscle area, backfat thickness, marbling score, quality grade, and yield grade of beef steers was not affected by supra-Se supplementation during the finishing time period. However, kidney, pelvic, and heart fat tended to be higher for animals supplemented with high Se wheat compared to animals supplemented with high Se hay or sodium selenate. Similarly, Schauer et al (2005) reported no differences in carcass quality of finished lambs fed supranutritional levels of Se for up to 56 d.

Our four state team's goal is to develop feeding strategies for finishing lambs that increase the Se content of lamb skeletal muscle to levels that will provide for cancer protection in humans while utilizing locally grown forages and grains. The marketing of these lamb meats as high Se organic supplements will provide marketing cooperatives an opportunity to develop a niche market for high Se lamb meat, and provide the beef industry with a model of feeding Se to finishing beef steers for the development of additional niche marketing.

Materials and Methods

In year 2 of a two year study, a randomized complete design was used to evaluate the influence of duration of supra-Se supplementation in finishing rations on a) lamb skeletal muscle Se concentration; b) finishing period body weight gain and feed efficiency; and c) carcass characteristics. The North Dakota State University Institutional Animal Care and Use Committee reviewed and approved animal care and use protocols used during this study. One-hundred sixty wethers (78 ± 0.7 lbs initial BW) were stratified by weight and assigned randomly to one of 20 pens (8 lamb/pen) for an eight-four day finishing phase. Pens were then assigned to one of 5 treatments (4 replications/treatment); supra-selenium supplementation for the final 84, 56, 28, 14, or 0 days of feeding prior to harvest. Wethers were wormed on day 0. Diets were approximately 73% corn and 25% alfalfa provided daily at 8:00 am to ensure ad libitum intake (NRC, 1985; Table 1). Diets were isonitrogenous and isocaloric (Table 1). Feed offered was recorded daily and feed refusals collected and recorded when significant amounts of refused feed accumulated in the feeders. Selenium for supra-selenium supplementation treatments (14, 28, 56, and 84 days) was provided as selenoyeast to provide approximately 50 $\mu g \cdot kg^{-1}$ $BW \cdot d^{-1}$ Se (2.6 ppm ration concentration; Table 1). Initial and final weights were two-day weights, and single day interim weights were taken once every 28 days to aid in monitoring health and potential Se toxicity.

Blood (jugular venipuncture into EDTA) was collected on day 0 and 84 to determine the change in circulating Se status. Blood samples were centrifuged and plasma collected. Plasma samples were frozen at -30°C until analysis for Se. Wethers were harvested at Iowa Lamb Corp. in Hawarden, IA. Skeletal muscle samples (approximately 5 g of foreshank) were removed for the determination of Se concentration. Skeletal muscle samples were frozen at -30°C until analysis for Se. Skeletal muscle samples (0.3 - 0.5 g) and plasma samples were analyzed for Se by a commercial laboratory (Utah Veterinary Diagnostic Laboratory). Additionally, carcass characteristics were evaluated following harvest. Hot carcass weight (**HCW**), backfat, bodywall thickness, and ribeye area (**REA**) were measured. Yield and quality grade were determined subjectively by a USDA grader. Feed to gain ratios, ADG, and % boneless closely trimmed retial cuts (**%BCTRC**) were calculated. Dry matter intake (**DMI**), body weight (**BW**), feed:gain (**F:G**), ADG, blood and skeletal muscle Se concentration, and carcass characteristic data were analyzed as a randomized complete design with the GLM procedure of SAS (SAS Inst. Inc., Cary, NY) using pen as the experimental unit. The model included treatment. Orthagonal contrast statements included 1) Control vs supra-Se supplementation; 2) linear effect of supra-Se supplementation; and 3) quadratic effect of supra-Se supplementation.

Results

Length of supra-selenium supplementation did not affect performance measures of DMI, final weight, gain, F:G, and ADG ($P \geq 0.28$; Table 2), carcass characteristics (fat depth, body wall thickness, REA, and HCW; $P \geq 0.29$; Table 2) or carcass quality ($P \geq 0.31$; Table 2).

Initial and final plasma Se concentrations were similar for all lambs ($P \geq 0.06$; Table 3). Muscle Se (wet and dry) concentration increased quadratically ($P = 0.05$) as length of supra-Se supplementation increased (Table 3).

Discussion

Lamb performance, carcass characteristics, and carcass quality of lambs in this study were not affected by the length of supra-selenium supplementation. These results are similar to results in steers (Hintze et al., 2002; Lawler et al., 2004) and lambs (Schauer et al., 2005). Unlike the results reported by Schauer et al. (2005), we did not observe a decrease in DMI and HCW as length of supra-Se supplementation increased, suggesting the previous results for DMI and HWC may be misleading.

Muscle Se concentration in our trial quadratically increased ($P = 0.05$) as length of supra-selenium supplementation increased. These results are similar to results of other researchers for beef (Lawler et al., 2004) and sheep (Van Ryssen et al., 1989; Ehlig et al., 1967; Taylor, 2005). However, our trial indicates a plateau in muscle Se concentration may be reached, which has not been previously reported. Taylor (2005) reported that although gut tissue (kidney, lever, spleen, and duodenum) selenium concentration appeared to plateau after 56 d of supra-Se supplementation (2.9 ppm), he did not observe a similar plateau in muscle Se concentration. Similarly, Schauer et al. (2005) observed a linear increase in muscle Se concentration following 56 d of supra-Se supplementation (1.89 ppm), but did not observe a plateau in muscle Se concentration. These results suggest that supra-selenium supplementation for the purpose of enhancing muscle selenium concentration should be withheld for the final 56 days of lamb finishing.

North Americans acquire their daily Se requirement primarily from wheat grain and beef (Schubert et al., 1987; Holden et al., 1991; Hintze et al., 2001). A ¼ lb portion of lamb from lambs fed a supra-selenium supplemented diet would provide approximately 147, 146, 95, 64, and 42 µg Se/day (wet basis; 84, 56, 28, 14, and 0 day supra-selenium supplementation, respectively). While the 28 d supplemented treatment in this trial provided adequate selenium to meet the recommended dietary allowance for selenium in humans (RDA = 55 µg Se/day for females and 70 µg Se/day for males), the selenium concentration in lamb skeletal muscle tissue for the 84 and 56 day selenium supplemented treatment would provide approximately 200% of the RDA for selenium. This level falls within the range indicated by Clark et al. (1996; 2 to 4 fold the RDA) for humans to reduce their chance of developing lung, colorectal, and prostate cancer. Our results suggest that animals may prove to be an excellent "filter" for preventing Se toxicity in humans who are consuming high Se diets for the prevention of cancer. Because of the plateau in muscle Se concentration, humans may be prevented from consuming toxic levels of Se if red meat is the source of supra-Se in their diet.

Implications

Development of feeding protocols for achieving high selenium lamb will aid producers in developing a niche market for the sale of lamb as an organic selenium supplement, as well as adding value to locally grown forages through the finishing of lambs. Additionally, the beef industry may derive benefit from this research as a model of feeding beef cattle to achieve high selenium status for the purpose of niche marketing. Our results indicate the supplementing selenium during the finishing phase can result in a lamb product that is naturally high in selenium. Muscle selenium concentrations may plateau following 84 days of supra-selenium supplementation, indicating a need to concentrate the supra-supplementation of selenium into the final 84 days of finishing.

Literature Cited

Clark, L.C., G.F. Combs Jr., B.W. Turnbull, E.H. Slate, D.K. Chalker, J. Chow, L.S. Davis, R.A. Glover, G.F. Graham, E.G. Gross, A. Krongrad, J.L. Lesher Jr., H.K. Park, B.B Sanders Jr., C.L. Smith, and J.R. Taylor. 1996. Effects of selenium supplementation for cancer prevention in patients with carcinoma of the skin. A randomized controlled trial. Nutritional Prevention of Cancer Study Group. J. Am. Med. Assoc. 276:1957-1963

Ehlig, C.F., D.E. Hogue, W.H. Allaway, and D.J. Hamm. 1967. Fate of selenium from selenite or selenomethionine with or without vitamin E in lambs. J. Nutr. 92:121-126.

Hintze, K.J., G.P. Lardy, M.J. Marchello, and J.W. Finley. 2001. Areas with high concentrations of selenium in the soil and forage produce beef with enhanced concentrations of selenium. J. Agric. Food Chem. 49:1062-1067.

Hintze, K.J., G.P. Lardy, M.J. Marchello, and J.W. Finley. 2002. Selenium accumulation in beef: Effect of dietary selenium and geographical area of animal origin. J. Agric. Food Chem. 50:3938-3942.

Holden, J.M., S. Gebhardt, C.S. Davis, and D.G. Lurie. 1991. A nationwide study of the selenium contents and variability of white bread. J. Food Compos. Anal. 4:183-195

Lawler, T.L., J.B. Taylor, E.E. Grings, J.W. Finley, and J.S. Caton. 2002. Selenium concentration and distribution in range forages from four locations in the northern great plains. Proc. West. Sect. Amer. Soc. of Anim. Sci. 53:7-9.

Lawler, T.L., J.B. Taylor, J.W. Finley, and J.S. Caton. 2004. Effect of supranutritional and organically bond selenium on performance, carcass characteristics, and selenium distribution in finishing beef steers. J. Anim. Sci. 82:1488-1493.

NRC. 1985. Nutrient Requirements of Sheep (6^{th} Rev. Ed.). National Academy Press, Washington, DC.

Schauer, C.S. J. Held, J. Daniel, J. Caton, P. Hatfield, R. Stobart, L.P. Anderson, J.O. Hall, D.M. Stecher, D. Pearson, and D. Drolc. 2005. Development of high selenium lamb as a human health food. Western Dakota Sheep & Beef Day. 46:6-10

Schubert, A., J.M. Holden, and W.R. Wolf. 1987. Selenium content of a core group of foods based on a critical evaluation of published analytical data. J. Am. Diet. Assoc. 87:285-299.

Taylor, J.B. 2005. Time-dependent influence of supranutritional organically bound selenium on selenium accumulation in growing wether lambs. J. Anim. Sci. 83:1186-1193.

Taylor, J.B., T.L. Lawler, J.W. Finley, and J.S. Caton. 2002. Effect of high selenium feeds on selenium status in finishing beef steers. Proc. West. Sect. Am. Soc. Anim. Sci. 53:534-536.

Van Ryssen, J.B.J., J.T. Deagen, M.A. Beilstein, and P.D. Whanger. 1989. Comparative metabolism of organic and inorganic selenium by sheep. J. Agric. Food Chem. 37:1358-1363.

Table 1. Dietary ingredient and nutrient composition of lamb finishing diets

Ingredient	Feedstuff Se concentration, ppm	Diets[a]	
		Control	Selenium Diet
		%, DM basis	
Corn	0.12	73.09	72.85
Alfalfa	0.21	24.65	24.64
Trace Mineral[b]	---	0.44	0.44
Selenoyeast	614	---	0.24
CTC[c]	---	0.52	0.52
Limestone	---	0.87	0.87
Ammonium Chloride	---	0.44	0.44
Nutrient Composition of Diet			
CP, %		13	13
TDN, %		83	83
ADF, %		9.59	10.05
Ca:P		3.32	3.01
Selenium, ppm		0.57	2.60
Selenium intake, $\mu g \cdot kg^{-1}$ $BW \cdot d^{-1}$		4.34	50.17

[a]Control = no supra-selenium supplementation with selenoyeast; Selenium Diet = supplementation with selenoyeast for the final 14, 28, 56, or 84 days of finishing.
[b]Trace mineral: 95.5% NaCl, 3,500 ppm Zn, 2,000 ppm Fe, 1,800 ppm Mn, 350 ppm Cu, 100 ppm I, and 60 ppm Co.
[c]CTC (4G) was formulated to provide 48 g/ton chlortetracycline.

Table 2. The influence of supra-selenium supplementation on feedlot lamb performance and carcass characteristics

	Treatment[a]						*P*-value[c]		
Item	Control	14 day	28 day	56 day	84 day	SEM[b]	Control vs Supp.	Linear	Quadratic
Dry Matter Intake, lbs/hd/day	3.10	3.07	3.10	3.19	3.02	0.06	0.91	0.83	0.36
Final Weight, lbs	121	122	121	125	121	1.2	0.39	0.52	0.29
Gain, lbs	43	44	44	47	43	1.3	0.49	0.69	0.29
Average Daily Gain, lbs/day	0.52	0.53	0.52	0.56	0.52	0.02	0.41	0.59	0.31
F:G	6.04	5.80	6.00	5.72	5.89	0.15	0.28	0.43	0.57
Hot Carcass Weight, lbs	59	59	59	61	58	0.9	0.76	0.86	0.28
Fat Depth, in	0.18	0.21	0.18	0.19	0.18	0.02	0.82	0.74	0.78
Ribeye Area, in^2	2.6	2.5	2.5	2.6	2.7	0.1	0.58	0.25	0.09
Quality Grade[d]	3.0	3.0	3.0	3.0	3.0	0.03	0.62	0.49	0.56
Yield Grade	2.4	2.3	2.2	2.4	2.4	0.11	0.53	0.76	0.31
% BCTRC[e]	45.8	45.6	45.7	45.8	45.8	0.18	0.65	0.82	0.56

[a]Control = no supra-selenium supplementation with selenoyeast; 14 days = supplementation with selenoyeast for the final 14 days of finishing; 28 days = supplementation with selenoyeast for the final 28 days of finishing; 56 days = supplementation with selenoyeast for the final 56 days of finishing; 84 days = supplementation with selenoyeast for the final 84 days of finishing.
[b]Standard Error of Mean; n = 4 .
[c]*P*-value for Control vs supra-selenium supplemented treatments and linear and quadratic affect of supra-selenium supplementation.
[d]1 = utility; 2 = good; 3 = choice; 4 = prime.
[e]% boneless closely trimmed retail cuts (49.936-(0.0848*D5)-(4.376*E5)-(3.53*F5)+(2.456*G5)).

Table 3. The influence of supra-selenium supplementation on feedlot lamb muscle and plasma selenium concentration

	Treatment[a]						P-value[c]		
Item	Control	14 day	28 day	56 day	84 day	SEM[b]	Control vs Supp.	Linear	Quadratic
Initial plasma Se concentration, ppm	0.17	0.15	0.16	0.17	0.16	0.005	0.06	0.54	0.23
Final plasma Se concentration, ppm	0.26	0.28	0.26	0.25	0.26	0.025	0.92	0.53	0.89
Muscle Se concentration, ppm; DM	1.41	2.12	3.25	4.73	4.80	0.09	< 0.001	< 0.001	0.01
Muscle Se concentration, ppm; wet	0.37	0.56	0.84	1.29	1.30	0.03	< 0.001	< 0.001	0.05

[a]Control = no supra-selenium supplementation with selenoyeast; 14 days = supplementation with selenoyeast for the final 14 days of finishing; 28 days = supplementation with selenoyeast for the final 28 days of finishing; 56 days = supplementation with selenoyeast for the final 56 days of finishing; 84 days = supplementation for the final 84 days of finishing.

[b]Standard Error of Mean; n = 4 .

[c]*P*-value for Control vs supra-selenium supplemented treatments and linear and quadratic affect of supra-selenium supplementation.