Effect of supranutritional maternal and colostral selenium supplementation on passive absorption of immunoglobulin G in selenium-replete dairy calves

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ABSTRACT

Selenium (Se) is an essential micronutrient for ruminant animals affecting both performance and immune functions. Adding 3 mg of Se/L (in the form of Na selenite) to colostrum has been shown to improve IgG absorption in Se-deficient newborn dairy calves. The objective of our study was to determine the effect of supranutritional maternal and colostral Se supplementation on IgG status of Se-replete dairy calves. The study design was a $2 \times 2 \times 2$ factorial design. During the last 8 wk before calving, dairy cows at a commercial dairy were fed either 0 (control cows) or 105 mg of Se-yeast once weekly (supranutritional Se-yeast-supplemented cows), in addition to Na selenite at 0.3 mg of Se/kg of DM in their ration. After birth, calves were fed pooled colostrum from control or supranutritional Se-yeast-supplemented cows to which 0 or 3 mg of Se/L (in the form of Na selenite) was added. Concentrations of whole-blood (WB) Se and serum Se measured at birth and at 48 h and 14 d of age, and serum IgG concentrations measured at 48 h and 14 and 60 d of age were determined. Calves born to Se-yeast-supplemented cows had higher WB-Se and serum-Se concentrations for the first 2 wk, and higher IgG absorption efficiency (62% at 48 h), resulting in higher serum-IgG concentrations (43% at 48 h and 65% at 14 d) and higher total serum-IgG content (50% at 48 h and 75% at 14 d), compared with calves born to control cows. Calves that received colostrum with added Na selenite had higher WB-Se concentrations for the first 2 wk, but only at 14 d of age were serum-Se concentrations, serum-IgG concentrations (53% higher), and total serum-IgG content (56% higher) higher, compared with calves that were fed colostrum without added Na selenite. Calves born to Se-yeast-supplemented cows that received colostrum from Se-yeast cows without added Na selenite had a

higher IgG absorption efficiency compared with all other treatment groups. Our results support that feeding cows supranutritional Se-yeast supplement during the dry period or spiking colostrum with Na selenite both improve IgG status of Se-replete calves.

Key words: dairy calf, immunoglobulin G, inorganic sodium selenite, organic Se-yeast, blood and colostral Se

INTRODUCTION

Selenium is an essential micronutrient for ruminant animals, affecting both performance (Stewart et al., 2012; Hall et al., 2013a,b) and immune functions (Hall et al., 2011a,b; Hujerjiletu et al., 2013). Severe Se deficiency results in nutritional myopathy or white-muscle disease, whereas subclinical Se deficiency causes muscular weakness of the newborn, immunosuppression, unthriftiness, reduced weight gain, and scours in calves (Koller et al., 1983). Adequate Se must be provided to prevent Se-responsive diseases. Provision of Se to the mother during gestation is an effective method to meet Se requirements in the newborn because Se efficiently crosses the placental barrier into fetal tissues and enters colostrum and milk (Rock et al., 2001; El Ghany-Hefnawy et al., 2007; Stewart et al., 2013).

Two means exist by which an animal gains immunity against an infectious disease. The first, termed passive immunity, includes antibodies transferred from the mother to her offspring via colostrum. These passively transferred antibodies provide immediate protection, but are eventually catabolized such that as protection wanes, the animal becomes susceptible to infection. The second, active immunization, involves administering an antigen to an animal, who responds by mounting a primary immune response. This response may be antibody mediated, cell mediated, or both. The disadvantage of active immunization is that protection is not conferred immediately. Once established, however, it is long lasting. Antibodies first become detectable about 1 wk

Received September 12, 2013.

Accepted March 15, 2014.

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after exposure and their concentration in the serum increases for 10 to 14 d before declining to low levels. The amount of antibody formed and the amount of protection conferred during the primary response is relatively small. Upon second exposure to the same antigen, the response is very different, occurring more quickly, with antibodies reaching higher levels that last much longer. Thus, any immune response mounted by a newborn animal must be a primary response with a prolonged lag period and resultant low concentration of antibodies. This delay means that newborn animals are susceptible to diseases that present little threat to adults. Therefore, antibodies provided in the colostrum during this vulnerable period are important for interim protection.

In ruminants, IgG1 is the predominant immunoglobulin isotype in colostrum, and it is derived from the mother's serum (Baumrucker et al., 2010). Naturally suckled calves ingest an average of 2 L of colostrum. The level of proteolytic activity in the digestive tract is low and further reduced by trypsin inhibitors in colostrum. Therefore, colostral proteins are not degraded but instead reach the small intestine intact. In the ileum, they are actively taken up by epithelial cells through pinocytosis and pass through these enterocytes into the lacteals. They eventually reach the systemic circulation, which allows the newborn to obtain a massive transfusion of maternal immunoglobulin. The period during which the intestine is permeable to proteins varies, but is highest immediately after birth, declines after 6 h, and decreases to relatively low levels by 24 h (Quigley and Drewry, 1998). Unsuckled animals normally possess low levels of immunoglobulin in their serum. Because of the nature of the absorptive process, peak serum immunoglobulin concentrations are normally reached between 12 and 24 h after birth. After absorption ceases, these passively acquired antibodies immediately begin to decline through normal catabolic processes. Failure of passive transfer predisposes a young animal to infection.

Current Food and Drug Administration (FDA) regulations limit the amount of dietary Se supplementation in ruminant animals to 0.3 mg/kg (as fed) of inorganic Na selenite or Na selenate, or organic Se-yeast, which is equivalent to 3 mg per beef cow per day (FDA, 2012). In a Japanese study (Kamada et al., 2007), Na selenite added directly to colostrum at 10× the maximum FDA-permitted level (3 mg of Se/kg of colostrum) increased IgG absorption (over 40% higher) in Se-deficient newborn dairy calves. For comparison, bovine milk normally contains 0.03 to 0.05 mg of Se/kg (normal reference range for bovine milk at the Center for Nutrition, Diagnostic Center for Population and Animal Health, Michigan State University, East Lan-

sing). Selenium was postulated to act directly on the intestinal epithelium to stimulate pinocytosis (Kamada et al., 2007). If Se in colostrum is beneficial in promoting intestinal IgG absorption, it would be fairly easy for producers to adopt a Se-drenching program by adding Na selenite directly to colostrum.

The objective of this study was to determine whether feeding cows supranutritional Se-yeast concentrations during the 8-wk prepartum period also increases serum-IgG concentrations. We evaluated whether feeding dairy cows supranutritional Se-yeast supplement once weekly during the 8-wk prepartum period, feeding calves colostrum from cows fed Se-yeast, or adding Na selenite directly to colostrum, alone or in combination, increases serum-IgG concentrations in Se-replete dairy calves. We hypothesized that in utero exposure to supranutritional Se concentrations acts synergistically with colostrum containing supranutritional Se concentrations to increase serum-IgG concentrations in Se-replete dairy calves.

MATERIALS AND METHODS

Animal Ethics Statement and Study Design

The experimental protocol was reviewed and approved by the Oregon State University Animal Care and Use Committee (Corvallis; ACUP Number 4156). The study was a $2 \times 2 \times 2$ factorial design, with 8 calves per treatment group. The study was conducted at a commercial dairy in Oregon (Columbia River Dairy LLC, Boardman, OR). During the last 8 wk before calving, Jersey dairy cows were fed either 0 (control cows) or 105 mg of Se-yeast once weekly (supranutritional Se-yeast-supplemented cows), in addition to Na selenite in their ration at 0.3 mg of Se/kg of DM. After birth, their calves were fed pooled colostrum from control or supranutritional Se-yeast-supplemented cows to which 0 or 3 mg of Se/L (in the form of Na selenite) was added. The organic Se source (Se-yeast; Prince Se Yeast 2000; Prince Agri Products Inc., Quincy, IL) had a guaranteed analysis of 2 g/kg of organically bound Se, with 78% being selenomethionine (**SeMet**). The inorganic Na selenite source (Na_2SeO_3 ; Retorte Ulrich Scharrer GmbH, Röthenbach, Germany) was 456 g of Se/kg, or 45.6% Se.

At 8 wk before their expected calving date, which was the same for all cows, pregnant dairy cows ($n = 49$) were selected to receive 105 mg of Se-yeast as a top dressing to their TMR. Cows were head locked when they started to eat their TMR at a bunk feeder. The Se-yeast aliquot was placed directly in front of each cow for individual consumption. The supplemental Se-yeast dosage (105 mg of Se/wk) was calculated to provide 15

mg of Se/d, which is equal to $5 \times$ the maximal FDA-permitted level of 3 mg of Se/d. As an example of dose calculations, 3 mg of Se/d is considered equivalent to 0.3 mg of Se/kg of diet (as fed; maximum dose according to FDA regulations). This dose is multiplied by 7 for the weekly amount of 21 mg and then by 5 to attain 1.5 mg of Se/kg in the diet (thus, 105 mg). This is $5 \times$ the FDA regulation for supplementing ruminant diets, but less than 5 mg/kg, which is considered to be the maximal tolerable level for ruminants (NRC, 2001).

Other dairy cows (control cows; $n = 26$) received only Na selenite in their TMR and represented cows receiving 0 mg of supplemental Se-yeast during the last 8 wk prepartum. The TMR was formulated to meet NRC (2001) recommendations for dry cows and contained supplemental Na selenite at 0.3 mg of Se/kg of DM. Before and during the 8-wk prepartum Se-yeast supplementation period, cows from control and Se-yeast-supplemented treatment groups consumed the TMR that contained supplemental Na selenite at 0.3 mg of Se/kg of DM.

Colostrum was collected within 2 h of calving from control and Se-yeast-supplemented cows and pooled. The first calves were assigned to groups fed colostrum from control cows until sufficient colostrum from Se-yeast-fed cows was available. Approximately 150 L of control colostrum was divided into aliquots and frozen in 2-L quantities for subsequent warm-water thawing and feeding to calves. As Se-yeast-supplemented cows calved, their colostrum was collected, pooled, and stored at 4°C. Calves were fed 2 L of colostrum within 2 h of birth and then 2 L of the same colostrum at 12 h of age. Directly before feeding, the Na selenite dose was added to colostrum at a final concentration of 3 mg of Se/L of colostrum, based on the results of Kamada et al. (2007).

The study design had to be altered because several Se-yeast-supplemented cows calved later than expected. As a result, we had insufficient colostrum in the Se-yeast-treated cow pool to feed all calves from control cows that needed to be fed colostrum from Se-yeast-fed cows. To address this challenge, we had to eliminate the treatment group “calves born to control cows and fed colostrum from supranutritional Se-yeast-supplemented cows to which Na selenite was added,” which changed the statistical design. The final study design and the number of calves within groups are shown in Figure 1.

Calves were housed in a common nursery pen for the first 24 h, and not fed anything apart from colostrum during this 24-h period. Calves were housed in individual calf hutches after 24 h and were all fed the same diet. Ear tags were used to identify the calves. Body weights of all calves were recorded within 2 h of calving, and at 14 and 56 d of age.

Blood and Colostrum Collection for Selenium Analyses of Cow and Calf Samples

Blood samples were collected from the jugular vein of cows 10 d before expected calving date (after 6 weekly Se-yeast treatments) into evacuated EDTA tubes (2 mL; final EDTA concentration 2 g/L; Becton Dickinson, Franklin Lakes, NJ) and stored on ice until they were frozen at -20°C to measure whole-blood (WB)-Se concentrations. Cows fed Se-yeast with WB-Se concentrations that were unlikely to reach 300 ng/mL ($n = 9$ of 49) were excluded from the study. Whole-blood and serum-Se concentrations [blood was also collected into evacuated tubes without EDTA (10 mL; Becton Dickinson) for subsequent harvesting of serum] were measured in cows again after parturition (at the time

Figure 1. The 7 calf treatment combinations are shown. During the last 8 wk before calving, dairy cows were fed either 0 (control cows) or 105 mg of Se-yeast once weekly (supranutritional Se-yeast-supplemented cows), in addition to Na selenite in their ration at 0.3 mg of Se/kg of DM. After birth, their calves were randomly assigned to treatment groups and were fed pooled colostrum from control or supranutritional Se-yeast-supplemented cows to which 0 or 3 mg of Se/L (in the form of Na selenite) was added. The number of calves in each treatment group is indicated.

of first milking). Whole-blood and serum-Se concentrations were similarly collected in calves at birth (within 2 h of birth and before colostrum feeding), and at 48 h and 14 d. Selenium concentrations in WB and serum were determined by a commercial laboratory (Center for Nutrition, Diagnostic Center for Population and Animal Health, Michigan State University), using an inductively coupled argon plasma emission spectrometry method with modifications, as previously described (Hall et al., 2012).

Several aliquots from the 2 colostrum pools were taken throughout the study and submitted to a commercial laboratory for Se analysis (Utah Veterinary Diagnostic Laboratory, Logan). Selenium was measured using an inductively coupled argon plasma emission spectrometry method (ELAN 6000; PerkinElmer, Shelton, CT) as previously described (Hall et al., 2013a). The Se concentration (mean $\pm$ SD) was 219 ± 4 ng/mL ($n = 2$) for colostrum from control cows without added Na selenite, and 384 ± 8 ng/mL ($n = 3$) for colostrum from Se-yeast-supplemented cows without added Na selenite. After adding Na selenite to colostrum, the Se concentration (mean $\pm$ SD) was $3,219 \pm 4$ ng/mL ($n = 2$) for colostrum from control cows, and $3,637 \pm 8.0$ ng/mL ($n = 2$) for colostrum from Se-yeast-supplemented cows (Table 1).

Blood and Colostrum Collection for IgG Analysis of Cow and Calf Samples

Jugular venous blood was collected from calves within 2 h of calving, and at 48 h, 14 d, and 60 d of age into evacuated tubes without EDTA (10 mL; Becton Dickinson) for subsequent harvesting of serum. The tubes were centrifuged at $850 \times g$ for 10 min at room temperature; serum was collected, transferred into 2.0-mL screw-cap self-standing microtubes (ISC BioExpress, Kaysville, UT) and stored at -20°C until used for IgG determination.

Concentrations of IgG in pooled cow colostrum or individual calf serum were quantified using a direct ELISA procedure. The protocol was adapted from a commercially developed assay (Bethyl Laboratories Inc., Montgomery, TX). In brief, 96-well plates (Reacti-Bind Thermo Scientific, Rockford, IL) were coated with 100 μL of 1 $\mu\text{g}/\text{mL}$ affinity purified rabbit anti-cow heavy and light-chain IgG (Bethyl Laboratories Inc.) diluted in 0.05 *M* carbonate-bicarbonate buffer (pH 9.6) and incubated for 1 h at room temperature. After incubation, plates were washed 6 times in Tween-Tris PBS (**T-TPBS**; 50 *mM* Tris, 0.14 *M* NaCl, and 0.05% Tween-20; pH 8.0). For long-term storage of plates at 4°C , the plates were incubated with 100 μL of StabilCoat (SurModics Inc., Eden Prairie, MN) at room tempera-

ture for 30 min. The StabilCoat was shaken out, plates were sealed, and stored at 4°C until needed for ELISA. For standards, purified cow IgG (10 mg/mL; Sigma, St. Louis, MO) was diluted in TPBS from 3.75 to 500 ng/mL. Calf serum samples from all 4 time points were diluted in TPBS at 1:200,000 and 1:400,000. Colostrum samples were diluted 1:800,000 and 1:1,600,000. High- and low-IgG controls were included in each assay. All standards, samples, and controls were plated in duplicate at 100 μL per well, and allowed to incubate for 30 min at 37°C . After incubation, plates were washed 6 times in T-TPBS. Horseradish peroxidase conjugated rabbit anti-cow heavy and light-chain IgG (1 mg/mL; Bethyl Laboratories Inc.) was added at a 1:25,000 dilution and allowed to incubate for 30 min at 37°C . Plates were then washed 6 times in T-TPBS, and 100 μL of 3,3',5,5'-tetramethyl benzidine (Sigma) was added to each well. Plates were kept in the dark and read at 655 nm until an absorbance of at least 0.650 optical density was reached in the 500-ng IgG standard well. The 3,3',5,5'-tetramethyl benzidine reaction was then stopped by adding 100 μL of 1 *N* H_2SO_4 and the plate was read at 450 nm. Results are reported as milligrams of IgG per milliliter.

The IgG concentration (mean $\pm$ SD) in pooled colostrum was 48.9 ± 6.9 ng/mL ($n = 2$) for colostrum from control cows and 26.7 ± 4.0 ng/mL ($n = 5$) for colostrum from Se-yeast-supplemented cows. Based on the formula used by Quigley et al. (1998), who estimated plasma volume in Jersey calves to be 9.71% of birth weight, we calculated total calf serum-IgG content (g), and IgG apparent absorption efficiency (%), using calf birth weights and calf serum-IgG concentrations at 48 h.

Statistical Analyses

Statistical analyses were performed using SAS software (version 9.2; SAS Institute Inc., Cary, NC). In calves, WB Se, serum Se, serum IgG, and total serum-IgG content, and BW were analyzed as repeated-measures-in-time using PROC MIXED, and IgG apparent absorption efficiency using PROC GLM. We had planned to analyze the results of the study as a $2 \times 2 \times 2$ factorial design with the 3 main effects (maternal Se-yeast supplementation, colostrum from Se-yeast-fed cows, and Na selenite added to colostrum), age at blood sampling, and all possible interactions as fixed effects. Because of insufficient colostrum from Se-yeast-fed cows, we had to revise our statistical analysis and use calf treatment (7 treatment combinations), age of blood sampling, and their interaction as fixed effects. Using the 7 treatment combinations, the effect of in utero Se exposure (cow) on newborn calves was estimated by comparing average values of calves from cows fed 0

Table 1. Effect of supranutritional maternal (cow; 0 or 105 mg of Se/wk) or colostral [Col.; from Se-yeast (Se-Y)-supplemented cows (no/yes) or col. supplemented with 0 or 3 mg of Se/L in the form of Na selenite (Na_2SeO_3)] Se supplementation on blood Se concentrations of Se-replete dairy calves

Item	Treatment ¹								Contrast, ³ <i>P</i> -value					
	0 mg of Se/wk			105 mg of Se/wk				SEM ²						
	No/0	No/3	Yes/0	No/0	No/3	Yes/0	Yes/3		Cow	Col.	Na_2SeO_3	Cow × Col.	Cow × Na_2SeO_3	Col. × Na_2SeO_3
Colostrum Se, ⁴ ng/mL	219	3,219	384	219	3,219	384	3,637							
Calves, no.	8	7	9	11	7	9	9							
Whole-blood Se, ⁵ ng/mL														
d 0	197	199	182	279	293	277	277	17	<0.001	0.77	0.06	0.25	0.21	0.27
d 2	216	288	191	261	397	303	355	18	<0.001	0.56	<0.001	0.59	0.65	0.18
d 14	169	225	173	207	267	246	246	15	<0.001	0.65	<0.001	0.59	0.24	0.05
Serum Se, ⁵ ng/mL														
d 0	64	49	45	81	92	72	71	10	<0.001	0.19	0.44	0.21	0.93	0.27
d 2	61	80	77	84	104	100	77	12	0.04	0.77	0.49	0.34	0.34	0.07
d 14	51	76	54	69	66	61	76	5	0.04	0.63	<0.001	0.45	0.06	0.72

¹During the last 8 wk before calving, dairy cows at a commercial dairy were fed either 0 or 105 mg of Se-Y once weekly in addition to Na_2SeO_3 at 0.3 mg of Se/kg of DM in their ration. After birth, their calves were fed pooled colostrum from control or Se-Y-supplemented cows to which 0 or 3 mg of Se/L (in the form of Na_2SeO_3) was added.

²The largest SEM of the 7 treatment groups is shown.

³Using the 7 treatment combinations, the effect of in utero Se exposure (cow) on newborn calves was estimated by comparing average values of calves from cows fed 0 versus 105 mg of Se-Y during the dry period. The effect of high Col.-Se exposure on newborn calves was estimated by comparing average values of calves receiving colostrum from cows fed 0 versus 105 mg of Se-Y during the dry period. The effect of pharmacological Na_2SeO_3 Col.-Se treatment on newborn calves was estimated by comparing average values of calves receiving colostrum to which 0 or 3 mg of Se/L (in the form of Na_2SeO_3) was added. The 3 remaining contrasts were used to estimate potential 2-way interactions between the 3 main effects (cow, Col., and Na_2SeO_3 treatment).

⁴Aliquots were taken from the 2 colostrum pools throughout the study to measure Se concentrations. The Se concentration (mean ± SD) was 219 ± 4 ng/mL ($n = 2$) for colostrum from control cows without added Na_2SeO_3 , and 384 ± 8 ng/mL ($n = 3$) for colostrum from Se-Y-supplemented cows without added Na_2SeO_3 . After adding Na_2SeO_3 to colostrum, the Se concentration (mean ± SD) was $3,219 \pm 4$ ng/mL ($n = 2$) for colostrum from control cows and $3,637 \pm 8.0$ ng/mL ($n = 2$) for colostrum from Se-Y-supplemented cows.

⁵Concentrations of whole-blood Se and serum Se were measured in calves at birth, at 48 h, and 14 d of age.

versus 105 mg of Se-yeast during the dry period. The effect of high colostrum Se exposure on newborn calves was estimated by comparing average values of calves receiving colostrum from cows fed 0 versus 105 mg of Se-yeast during the dry period. The effect of pharmacological (Na_2SeO_3) colostrum Se treatment on newborn calves was estimated by comparing average values of calves receiving colostrum to which 0 or 3 mg of Se/L (in the form of Na_2SeO_3) was added. The 3 remaining contrasts were used to estimate potential 2-way interactions between the 3 main effects (maternal Se-yeast supplementation, colostrum from Se-yeast-fed cows, and Na selenite added to colostrum). All comparisons were constructed using the ESTIMATE statement. The serum-IgG concentrations at birth were not included in the calculation because they were below the detection limit. An unstructured variance-covariance matrix was used to account for variation of measures within calves. The unstructured variance-covariance matrix provided the most parsimonious variance-covariance matrix based on the lowest value by the Akaike information criterion. Data are reported as least squares means $\pm$ standard error of the mean. All statistical tests were 2-sided. Statistical significance was declared at $P \leq 0.05$ and a tendency at $0.05 < P \leq 0.10$.

RESULTS

Of the 49 cows fed Se-yeast supplement for 8 wk before calving, 36 of their calves were used in this study. Nine cow/calf pairs were excluded 10 d before expected calving date (after 6 weekly Se-yeast treatments) because mothers had WB-Se concentrations that were unlikely to reach 300 ng/mL at the time of calving. Other exclusions included 1 cow that had a dead calf, 1 cow/calf pair that was lost during follow-up, and 1 cow that calved after the study concluded. In addition, 1 calf from Se-yeast-supplemented cows and 2 calves from control cows died within 48 h of calving; their data were not included in the analysis. None of the cows in the study had multiple calves. Cows supplemented with Se-yeast had 29% higher WB-Se concentrations at calving (336 ± 6 vs. 261 ± 8 ng/mL, respectively; $P < 0.001$) compared with control cows, and 69% higher serum-Se concentrations (118.7 ± 2.7 vs. 70.1 ± 2.8 ng/mL, respectively; $P < 0.001$).

Effect of Se Supplementation on Blood-Se and Blood-IgG Concentrations and BW in Calves at Birth and 48 h

Within 2 h of birth, and before they were fed colostrum, calves from Se-yeast-supplemented cows had 46% higher WB-Se concentrations compared with calves

from control cows (Table 1; 281 ± 7 vs. 193 ± 9 ng/mL, respectively; $P < 0.001$) and 50% higher serum-Se concentrations (Table 1; 79.1 ± 4.3 vs. 52.9 ± 5.2 ng/mL, respectively; $P < 0.001$), and 9% higher birth weights (Table 2; 29.7 ± 0.6 vs. 27.3 ± 0.8 kg, respectively; $P = 0.02$). Before they were fed colostrum, serum-IgG concentrations of calves were non-detectable.

At 48 h of age, and after colostrum administration, calves that received colostrum with added Na selenite had 43% higher WB-Se concentrations compared with calves that received colostrum without added Na selenite (347 ± 10 vs. 243 ± 8 ng/mL, respectively; $P < 0.001$); a difference similar to what was observed for calves from Se-yeast-supplemented cows at 48 h compared with calves from control cows (329 ± 9 vs. 232 ± 10 ng/mL, respectively; $P < 0.001$; Table 1). The effect of supranutritional maternal and colostrum Se supplementation were additive, as calves from Se-yeast-supplemented cows that received colostrum with added Na selenite had the highest WB-Se concentrations (376 ± 13 ng/mL).

The effects of supranutritional maternal and colostrum Se supplementation on serum-Se concentrations were less pronounced than for WB-Se concentrations (Table 1). Calves from Se-yeast-supplemented cows had 25% higher serum-Se concentrations compared with calves from control cows (91.3 ± 5.8 vs. 73.0 ± 6.6 ng/mL, respectively; $P = 0.04$), whereas calves that received colostrum with added Na selenite did not have significantly higher serum-Se concentrations compared with calves that were fed colostrum without added Na selenite (87.0 ± 7.1 vs. 80.7 ± 5.5 ng/mL, respectively; $P = 0.77$; Table 1).

Feeding colostrum from cows fed Se-yeast supplement did not increase WB-Se concentrations in calves, despite its higher Se content, compared with feeding colostrum from control cows (283 ± 10 vs. 291 ± 9 ng/mL, respectively; $P = 0.56$), which was also true for serum-Se concentrations (84.9 ± 6.8 vs. 82.3 ± 5.7 ng/mL, respectively; $P = 0.77$; Table 1).

Calves from Se-yeast-supplemented cows had 43% higher serum-IgG concentrations compared with calves from control cows (19.7 ± 1.7 vs. 13.8 ± 2.0 mg/mL, respectively; $P = 0.03$) and 50% higher total serum-IgG content (54.4 ± 4.4 vs. 36.2 ± 5.3 g, respectively; $P = 0.01$; Table 3). Calves that were fed colostrum with added Na selenite did not have significantly higher serum-IgG concentrations compared with calves that received colostrum without added Na selenite (18.2 ± 2.1 vs. 16.4 ± 1.6 mg/mL, respectively; $P = 0.50$), nor did they have significantly higher total serum-IgG content (49.5 ± 5.5 vs. 44.3 ± 4.2 g, respectively; $P = 0.46$; Table 3). Feeding colostrum from cows fed Se-yeast supplement did not significantly decrease serum-IgG

Table 2. Effect of supranutritional maternal (cow; 0 or 105 mg of Se/wk) or colostral [Col.; from Se-yeast (Se-Y)-supplemented cows (no/yes) or col. supplemented with 0 or 3 mg of Se/L in the form of Na selenite (Na_2SeO_3)] Se supplementation on BW of Se-replete dairy calves

Item	Treatment ¹					Contrast, ³ P-value				
	0 mg of Se/wk					105 mg of Se/wk				
	No/0	No/3	Yes/0	No/0	No/3	Yes/0	Yes/3	SEM ²	Cow	Col.
Calves, no.	8	7	9	11	7	9	9			
BW, kg										
d 0	26.0	27.9	27.9	27.3	26.7	31.9	33.0	1.4	0.02	<0.001
d 14	33.5	33.5	33.3	33.9	33.7	37.8	36.9	1.5	0.05	0.03
d 56	65.7	62.8	61.8	63.2	60.2	63.8	66.1	2.8	0.95	0.62

¹During the last 8 wk before calving, dairy cows at a commercial dairy were fed either 0 or 105 mg of Se-Y once weekly in addition to Na_2SeO_3 at 0.3 mg of Se/kg of DM in their ration. After birth, their calves were fed pooled colostrum from control or Se-Y-supplemented cows to which 0 or 3 mg of Se/L (in the form of Na_2SeO_3) was added.

²The largest SEM of the 7 treatment groups is shown.

³Using the 7 treatment combinations, the effect of in utero Se exposure (cow) on newborn calves was estimated by comparing average values of calves from cows fed 0 versus 105 mg of Se-Y during the dry period. The effect of high Col.-Se exposure on newborn calves was estimated by comparing average values of calves receiving colostrum from cows fed 0 versus 105 mg of Se-Y during the dry period. The effect of pharmacological Na_2SeO_3 Col.-Se treatment on newborn calves was estimated by comparing average values of calves receiving colostrum to which 0 or 3 mg of Se/L (in the form of Na_2SeO_3) was added. The 3 remaining contrasts were used to estimate potential 2-way interactions between the 3 main effects (cow, Col., and Na_2SeO_3 treatment).

⁴Body weights of calves were measured at birth, at 14 d of age, and at 56 d of age.

concentrations in calves, despite its lower IgG content, compared with feeding colostrum from control cows (14.6 ± 1.9 vs. 19.1 ± 1.7 mg/mL, respectively; $P = 0.08$), which was also true for total serum-IgG content (42.3 ± 5.1 vs. 49.8 ± 4.5 g, respectively; $P = 0.27$; Table 3).

The IgG absorption efficiencies are shown in Table 3. Calves from Se-yeast-supplemented cows that received colostrum from Se-yeast-supplemented cows without added Na selenite had a higher IgG absorption efficiency ($57.0 \pm 6.4\%$) compared with all other treatment groups. Calves from cows fed Se-yeast supplement had 62% higher IgG absorption efficiency than calves from control cows (35.9 ± 2.8 vs. $22.1 \pm 3.5\%$, respectively; $P = 0.004$). In contrast, calves receiving Na selenite added to colostrum did not significantly differ from calves receiving colostrum without added Na selenite (28.3 ± 3.6 vs. $31.3 \pm 2.8\%$, respectively; $P = 0.20$).

Effect of Se Supplementation on Blood-Se and Blood-IgG Concentrations and BW in Calves at 14 d of Age

At 14 d of age, calves from Se-yeast-supplemented cows had 24% higher WB-Se concentrations compared with calves from control cows (246 ± 8 vs. 199 ± 6 ng/mL, respectively; $P < 0.001$), and 13% higher serum-Se concentrations (67.9 ± 2.3 vs. 60.1 ± 2.8 ng/mL, respectively; $P = 0.04$; Table 1). Calves that received colostrum with added Na selenite had 28% higher WB-Se concentrations compared with calves that were fed colostrum without added Na selenite (241 ± 6 vs. 189 ± 8 ng/mL, respectively; $P < 0.001$) and 23% higher serum-Se concentrations (72.4 ± 2.8 vs. 58.7 ± 2.2 ng/mL, respectively; $P < 0.001$; Table 1). No significant effect was detected when feeding colostrum from Se-yeast-supplemented cows on WB- or serum-Se concentrations compared with feeding colostrum from control cows (Table 1).

Calves from cows fed Se-yeast had 65% higher serum-IgG concentrations compared with calves from control cows (8.6 ± 0.9 vs. 5.2 ± 1.0 mg/mL, respectively; $P = 0.01$), and 75% higher total IgG content (29.1 ± 2.9 vs. 16.6 ± 3.4 g, respectively; $P = 0.007$; Table 3). Furthermore, calves that received Na selenite added to colostrum had 53% higher serum IgG concentrations compared with calves that were fed colostrum without added Na selenite (8.9 ± 1.1 vs. 5.8 ± 0.8 mg/mL, respectively; $P = 0.02$), and 56% higher total serum-IgG content (29.9 ± 3.5 vs. 19.2 ± 2.8 g, respectively; $P = 0.02$; Table 3). No significant effect was detected when feeding colostrum from Se-yeast-supplemented cows on serum-IgG concentrations or content compared with feeding colostrum from control cows (Table 3).

Table 3. Effect of supranutritional maternal (cow; 0 or 105 mg of Se/wk) or colostral [Col.; from Se-yeast (Se-Y)-supplemented cows (no/yes) or col. supplemented with 0 or 3 mg of Se/L in the form of Na selenite (Na₂SeO₃)] Se supplementation on serum IgG status of Se-replete dairy calves

Item	Treatment ¹								Contrast, ³ <i>P</i> -value					
	0 mg of Se/wk				105 mg of Se/wk									
	No/0	No/3	Yes/0	No/0	No/3	Yes/0	Yes/3	SEM ²	Cow	Col.	Na ₂ SeO ₃	Cow × Col.	Cow × Na ₂ SeO ₃	Col. × Na ₂ SeO ₃
Colostrum IgG, ⁴ mg/mL	48.9	48.9	26.7	48.9	48.9	26.7	26.7							
Calves, no.	8	7	9	11	7	9	9							
Serum IgG, ⁵ mg/mL														
d 2	13.0	17.2	11.4	21.9	24.5	19.3	13.0	3.7	0.03	0.08	0.50	0.16	0.13	0.41
d 14	4.5	6.0	5.0	8.3	13.0	5.3	7.8	1.9	0.01	0.16	0.02	0.03	0.41	0.73
d 60	4.7	8.4	5.4	7.3	8.0	9.4	7.3	1.5	0.09	0.78	0.26	0.58	0.06	0.20
Serum IgG, ⁶ g														
d 2	32.6	45.7	30.2	56.5	64.3	58.0	38.6	9.8	0.01	0.27	0.46	0.33	0.08	0.31
d 14	14.9	19.0	16.1	26.7	42.7	19.2	27.9	6.3	0.007	0.28	0.02	0.07	0.40	0.81
d 60	30.0	49.1	32.5	41.7	46.0	57.4	46.6	7.8	0.06	0.49	0.22	0.30	0.06	0.22
IgG absorption efficiency, ⁷ %														
d 2	14.8	21.3	30.3	23.2	29.9	57.0	33.6	6.4	0.004	<0.001	0.20	0.38	0.14	0.02

¹During the last 8 wk before calving, dairy cows at a commercial dairy were fed either 0 or 105 mg of Se-Y once weekly in addition to Na₂SeO₃ at 0.3 mg of Se/kg of DM in their ration. After birth, their calves were fed pooled colostrum from control or Se-Y-supplemented cows to which 0 or 3 mg of Se/L (in the form of Na₂SeO₃) was added.

²The largest SEM of the 7 treatment groups is shown.

³Using the 7 treatment combinations, the effect of in utero Se exposure (cow) on newborn calves was estimated by comparing average values of calves from cows fed 0 versus 105 mg of Se-Y during the dry period. The effect of high Col.-Se exposure on newborn calves was estimated by comparing average values of calves receiving colostrum from cows fed 0 versus 105 mg of Se-Y during the dry period. The effect of pharmacological Na₂SeO₃ Col.-Se treatment on newborn calves was estimated by comparing average values of calves receiving colostrum to which 0 or 3 mg of Se/L (in the form of Na₂SeO₃) was added. The 3 remaining contrasts were used to estimate potential 2-way interactions between the 3 main effects (cow, Col., and Na₂SeO₃ treatment).

⁴Aliquots were taken from the 2 colostrum pools throughout the study to measure IgG concentrations. The IgG concentration (mean ± SD) was 48.9 ± 6.9 mg/mL (n = 2) for colostrum from control cows and 26.7 ± 4.0 mg/mL (n = 5) for colostrum from Se-Y-supplemented cows.

⁵Concentrations of serum IgG were measured in calves at birth, at 48 h, and at 14 and 60 d of age. The serum IgG concentrations at birth and before colostrum feeding were below the detection limit.

⁶Serum IgG (g) = calf serum volume (L) × calf serum IgG concentrations (g/L). The calf serum volume is based on the formulas used by Quigley et al. (1998), who estimated plasma volume in Jersey calves to be 9.71% of BW (kg).

⁷Apparent efficiency of absorption (%) = [serum IgG (g) at 48 h ÷ total IgG consumed (g)] × 100%, where total IgG consumed = volume of colostrum ingested (L) × colostral IgG concentration at 48 h (g/L).

The effects of maternal-Se supplementation on BW were similar at 0 and 14 d (Table 2). Calves from cows fed Se-yeast had higher BW compared with calves from control cows (35.6 ± 0.7 vs. 33.4 ± 0.8 kg, respectively; $P = 0.05$). Furthermore, calves that were fed colostrum from Se-yeast-supplemented cows had higher BW compared with calves that were fed colostrum from control cows (36.0 ± 0.8 vs. 34.6 ± 0.7 kg, respectively; $P = 0.03$). In contrast, calves that were fed colostrum with Na selenite added had BW similar to that of calves that received colostrum without added Na selenite (34.7 ± 0.8 vs. 34.6 ± 0.7 kg, respectively; $P = 0.94$).

Effect of Se Supplementation on IgG Concentration and BW in Calves at 60 d of Age

The beneficial effects of being a calf born to a cow fed Se-yeast supplement on serum-IgG concentrations and total serum-IgG content persisted until 60 d of age (Table 3). Calves from cows fed Se-yeast tended to have higher serum-IgG concentrations compared with calves from control cows (8.0 ± 0.7 vs. 6.2 ± 0.8 mg/mL, respectively; $P = 0.09$), and higher total serum-IgG content (47.9 ± 3.6 vs. 37.2 ± 4.2 g, respectively; $P = 0.06$). In contrast, calves that received Na selenite added to colostrum did not have significantly higher serum-IgG concentrations compared with calves that received colostrum without added Na selenite (7.9 ± 0.8 vs. 6.4 ± 0.7 mg/mL, respectively; $P = 0.26$), and total IgG contents were similar (47.3 ± 4.3 vs. 40.4 ± 3.5 g, respectively; $P = 0.22$). No significant effect was detected when feeding colostrum from Se-yeast-supplemented cows on serum-IgG concentrations or total serum-IgG content compared with feeding colostrum from control cows (Table 3). No treatment differences were observed for BW (Table 2).

DISCUSSION

Failure of adequate IgG transfer is of major importance because passive transfer of immunity is critical for protection against infectious diseases. Three major reasons exist for failure of adequate colostral transfer: (1) insufficient or poor-quality colostrum, (2) inadequate colostral intake by the newborn calf, or (3) failure of absorption from the intestine despite adequate intake of colostrum. In this study, we showed that exposure to high Se concentrations in utero from feeding cows supranutritional Se-yeast supplement increased IgG absorption efficiency in Se-replete calves, resulting in higher serum-IgG concentrations and total serum-IgG content at 48 h, compared with Se-replete calves born to control cows. Previously, we showed that supranutritional Se-yeast supplementation of Se-replete

Polypay ewes throughout pregnancy at an equivalent concentration to that received by dairy cows in the current study also had a higher total serum-IgG content in lambs at 48 h versus lambs from Polypay ewes receiving Se-yeast at the FDA-allowed concentration (Stewart et al., 2013). Both studies suggest that supranutritional maternal Se-yeast supplementation improves IgG status of their offspring.

The effect of supranutritional maternal Se-yeast supplementation on serum-IgG concentrations and content in Se-replete dairy calves has not been reported to our knowledge. In Se-deplete beef cows, maternal Se-yeast supplementation significantly increased serum-IgM, but not -IgG, concentrations in calves 24 to 36 h after birth (Awadeh et al., 1998), whereas in another study, maternal Na selenite supplementation significantly increased IgG, but not IgM, concentrations in calves at 24 h after birth (Swecker et al., 1995). In Se-replete dairy cows, maternal Se supplementation with additional Se-yeast or Na selenite at the current FDA upper limit recommendation of 0.3 mg/kg (as fed), showed no Se source-dependent differences in serum-IgG or -IgM concentrations in calves at 24 h after consuming colostrum (Koenig and Beauchemin, 2009). In our study, serum-IgG concentrations and total serum-IgG content were significantly higher for the first 14 d, and tended to be higher until at least 60 d of age, indicating that benefits of fetal exposure to high Se concentrations in late pregnancy persist for months after birth.

Feeding colostrum from Se-yeast-supplemented cows (higher Se concentration than control cow colostrum) or adding 3 mg of Na selenite/kg to the colostrum did not significantly increase serum-IgG concentrations or total serum-IgG content in Se-replete calves. The IgG concentration of the colostrum pool from Se-yeast-supplemented cows was lower than the concentration of the colostrum pool from control cows (26.7 vs. 48.9 ng/mL). We did not measure IgG concentrations of colostrum from individual cows before pooling their colostrum nor did we adjust our colostrum pools to have equal IgG concentrations, which is a limitation of our study. We did not conclude that feeding Se-yeast to cows decreases colostral-IgG concentration based on a single colostrum pool. Furthermore, we are not aware of any study in ruminants that shows that supranutritional Se supplementation decreases colostral-IgG concentration. To the contrary, Swecker et al. (1995) showed that Se-deplete beef cows given the FDA-allowed level of Se supplement (120 mg of Se/kg as salt-mineral mix) had greater colostral-IgG concentrations than did Se-deficient cows. Similarly, Awadeh et al. (1998) showed in Se-deplete beef cows that Se-yeast as well as Na selenite supplementation significantly increased colostral-IgG concentrations. Moreover, we previously

showed that supranutritional Se-yeast supplementation of Se-replete Polypay ewes at the dosages used in the current study increased colostral-IgG concentrations compared with Polypay ewes receiving Se-yeast at the FDA-allowed concentration (Stewart et al., 2013). It is unknown why supranutritional Se supplementation increases colostral-IgG concentration. Potential explanations are that supranutritional Se supplementation may alter the number of specific nutrient transporters or growth and vascularization of mammary tissues as hypothesized for intestinal tissues (Meyer et al., 2012).

In the current study, despite the lower IgG concentration in colostrum from cows fed Se-yeast supplement, this did not significantly decrease serum-IgG concentrations or total serum-IgG content in recipient calves. In fact, the IgG absorption efficiencies were highest in the 3 treatment groups fed colostrum from Se-yeast-supplemented cows (Table 3). Calves from Se-yeast-supplemented cows that received colostrum from Se-yeast-supplemented cows without added Na selenite had a higher IgG absorption efficiency ($57.0 \pm 6.4\%$) compared with all other treatment groups (Table 3). It is likely that serum-IgG concentrations and IgG content would have been higher if colostral-IgG concentrations in pooled colostrum from cows fed Se-yeast supplement were higher.

The effect of Na selenite added to colostrum on serum-IgG concentrations and total serum-IgG content in Se-replete calves was more complex. Similar to serum-Se concentration, we observed significantly higher serum-IgG concentrations and total serum-IgG content in calves fed Na selenite added to colostrum only at 14 d of age (Table 3). Kamada et al. (2007) reported that adding 3 mg of Na selenite/kg to colostrum increased plasma IgG concentrations in Se-deficient dairy calves by 42% ($P < 0.04$) at 48 h, and by 24% (nonsignificant) at 14 d. In our study, the group of calves from control cows receiving colostrum from control cows was the treatment group most similar to those in the Kamada et al. (2007) study; adding 3 mg of Na selenite/kg to colostrum increased serum-IgG-concentrations in calves by 32% at 48 h, and by 33% at 14 d (Table 3). Overall, adding 3 mg of Na selenite/kg to colostrum increased serum-IgG concentrations in Se-replete dairy calves by 11% (nonsignificant) at 48 h, and by 43% ($P = 0.02$) at 14 d.

Selenium has been postulated to act directly on intestinal epithelium to activate pinocytosis (Kamada et al., 2007). It is also possible that supranutritional concentrations of Se delay turnover of specialized intestinal epithelium, prolonging the pinocytosis process. The period during which the intestine is permeable to proteins varies, but is highest immediately after birth, declines after 6 h, and decreases to relatively low levels

by 24 h (Quigley and Drewry, 1998). This is because the fetal intestinal epithelial cells, which are capable of engulfing soluble proteins such as immunoglobulins in the intestinal lumen and discharging them into the lateral spaces, are replaced by a more mature cell population. The loss of the gut protein-absorptive function in the neonate is called gut closure. We have shown in weaned beef calves that the WB-neutrophil gene expression profile for thioredoxin reductase (**TrxR**) genes is altered (TrxR1 was upregulated and TrxR2 was downregulated) with Se supplementation (Hall et al., 2013b). Both genes use NADPH as a cofactor to reduce thioredoxin and, thus, regulate cellular redox status (*TrxR1* in the cytosol and nucleus, and *TrxR2* primarily in the mitochondria). A recent review on mammalian TrxR outlines the importance of these selenoproteins in a wide range of cellular functions, in both health and disease states, and emphasizes their complexity (Arnér, 2009). For example, TrxR alters activity of transcription factors and decreases apoptosis (Arnér, 2009). We postulate that supranutritional Se supplementation delays apoptosis and turnover of fetal intestinal epithelium, thus prolonging pinocytosis.

Exposure to high Se concentrations in utero from feeding supranutritional maternal Se-yeast supplement increased WB-Se and serum-Se concentrations in Se-replete calves until at least 14 d of age. In contrast, colostrum from Se-supplemented cows, despite having higher Se concentration, did not alter WB-Se and serum-Se concentrations in calves fed this colostrum. Before beginning Se-yeast supplementation, cows were fed Na selenite in their ration at 0.3 mg of Se/kg of diet DM and were in an adequate nutritional status for Se, as evidenced by WB-Se concentrations of 245 ng/mL (range of 200 to 271 ng/mL). For comparison, the normal reference interval for WB-Se concentrations of adult cows at the Michigan State University diagnostic laboratory is 120 to 300 ng/mL (Hall et al., 2011a). The effect of supranutritional maternal Se-yeast supplementation on WB-Se and serum-Se concentrations in Se-replete dairy calves has not been reported, to our knowledge. In Se-deplete beef cows, maternal Se-yeast supplementation improves WB-Se concentrations in their calves within the first 36 h after birth (Awadeh et al., 1998; Gunter et al., 2013). Our results indicate that the primary route by which maternal Se supplementation increases WB-Se concentrations of calves is in utero transfer, whereas colostral Se transfer is rather ineffective at increasing WB-Se concentrations in calves because the amount of Se that can be transferred is limited.

Feeding calves colostrum with Na selenite added at the pharmacologic concentration of 3 mg of Se/L (approximately 10× higher colostral-Se concentra-

tions than that in colostrum from cows fed Se-yeast supplement) increased WB-Se concentrations in calves, similar to what was measured in calves born to mothers fed Se-yeast supplement during the last 8 wk before parturition. This enabled calves from control cows to have similar WB-Se concentrations as calves born to cows fed Se-yeast supplement until at least 14 d of age. Furthermore, supranutritional maternal and colostrum Se supplementation acted synergistically on WB-Se concentrations in that calves born to mothers who were fed 105 mg of Se/wk as Se-yeast supplement during the last 8 wk before parturition, and who received colostrum with added Na selenite, had additive increases in WB-Se concentration.

The effect of Na selenite added to colostrum on serum-Se concentrations in Se-replete calves was more complex. We observed significantly higher serum-Se concentrations in calves fed Na selenite added to colostrum only at 14 d of age (Table 1). Serum-Se concentrations in calves from control cows that were fed Na selenite added to colostrum were 49 ± 10 ng/mL at birth, 80 ± 12 ng/mL at 48 h, and 76 ± 5 ng/mL at 14 d (Table 1), demonstrating that serum-Se concentrations increased in response to colostrum Na selenite. Similarly, Kamada et al. (2007) showed that Na selenite added to colostrum increased plasma-Se concentrations in Se-deficient dairy calves from approximately 27 μ g/kg at birth, to 68 μ g/kg at 48 h, to 50 μ g/kg at 14 d. Furthermore, Abdelrahman and Kincaid (1995) showed that Se-deficient dairy cows who received a rumen bolus designed to release 3 mg of Se/d as Na selenite starting 60 d before calving (vs. no rumen bolus) produced calves with plasma-Se concentrations at birth of 34 versus 28 ± 2 ng/mL, respectively, and at 42 d, plasma-Se concentrations of 50 versus 40 ± 2 ng/mL, respectively. The normal reference interval for serum-Se concentrations of neonatal calves at the Michigan State University diagnostic laboratory is 50 to 70 ng/mL (Stowe and Herdt, 1992).

The increase in serum-Se concentration in response to feeding colostrum with added Na selenite was limited to control calves. Calves from cows that received Se-yeast supplement did not show an increase in serum-Se concentrations in response to adding Na selenite to colostrum. These calves had serum-Se concentrations of 82 ± 6 ng/mL at birth, 90 ± 9 ng/mL at 48 h, and 71 ± 5 ng/mL at 14 d of age, suggesting that an upper limit is reached for serum-Se concentrations, which cannot be raised even with supranutritional Se supplementation of colostrum. In support, Koenig and Beauchemin (2009) supplemented Se-replete dairy cow diets with additional Se-yeast or Na selenite at 0.3 mg/kg of DM, and showed that calves from cows fed Se-yeast for 8 wk before calving had higher serum-Se concentrations

at birth compared with calves from cows fed Na selenite (94 vs. 75 ± 5 ng/mL, respectively), yet serum-Se concentrations did not exceed approximately the same upper limit that we found in our study.

As for an explanation of why adding Na selenite to colostrum increases WB-Se but not serum-Se concentrations in calves exposed to high Se concentrations in utero, one must first consider Se distribution in blood. The WB Se is mainly found in red blood cell hemoglobin and plasma albumin as SeMet, and in red blood cell-bound glutathione peroxidase, plasma selenoprotein P, and plasma glutathione peroxidase in the form of selenocysteine (**SeCys**; Deagen et al., 1993). Whereas SeMet can be incorporated into any protein in place of methionine, functional selenoproteins require SeCys for proper activities. The distribution of Se in the serum or plasma of 21 healthy people showed that $53 \pm 6\%$ was associated with selenoprotein P, $39 \pm 6\%$ with glutathione peroxidase, and $9 \pm 4\%$ with albumin (Harrison et al., 1996). When inorganic Se is given to animals, SeCys is the main selenocompound formed (Whanger, 2002). No known pathway exists in animals for synthesis of SeMet from inorganic Se (Whanger, 2002). When dietary intake of Se is deficient, most absorbed Se, regardless of chemical form, is used for synthesis of SeCys-containing selenoproteins such as glutathione peroxidase; none goes into the SeMet pool unless this is the dietary form ingested [reviewed in Janghorbani et al. (1999)]. As dietary Se intake increases and animals become Se-replete, the selenite-exchangeable pool reaches saturation, and the rate of methylation and excretion of Se increases (Janghorbani et al., 1999). Consumption of SeMet-containing supplements such as Se-yeast leads to saturation of both pools, with a much higher Se content in the SeMet-containing proteins (Janghorbani et al., 1999). Selenoproteins such as plasma glutathione peroxidase and selenoprotein P do not respond to increasing flux of selenide (Se^{2-}) over a wide range of Se intakes (Janghorbani et al., 1999). As a result, adding Na selenite to colostrum will not increase serum-Se concentrations in calves that are exposed to high Se-concentrations in utero.

Feeding cows supranutritional Se-yeast supplements during the last 8 wk prepartum increased BW of Se-replete dairy calves until 14 d of age (Table 2). It was previously reported in dairy cows with unknown Se status that maternal administration of vitamin E and Na selenite at 3 and 1.5 wk before calving did not affect BW (Lacetera et al., 1996). In Se-deplete beef cattle, Se supplementation of cows did not affect their calves birth weights (Ammerman et al., 1980; Hidirolou et al., 1987; Awadeh et al., 1998) or BW gains (Awadeh et al., 1998). Previously, we showed that supranutritional supplementation of ewes with Se-yeast improves lamb

growth (Stewart et al., 2012). Performance was better in lambs from ewes receiving Se-yeast at 5 times the FDA-permitted level (equivalent to levels fed dairy cows in the current study) compared with lambs from ewes receiving Se-yeast at the maximum FDA-allowed concentration. In yr 1, lambs had 9% higher birth weights (similar to calves in the current study) and weighed 8% more at weaning (120 d of age). In yr 2, lambs were 10% heavier at 60 d of age. The difference in the results of our 2 studies can be explained by the fact that calves in the current study were limit fed, whereas Se-yeast-supplemented ewes nursed their lambs ad libitum.

It is worth noting that the effects of Se status on calf health are not limited to enhanced passive transfer of maternal immunoglobulins. As reviewed by Enjalbert (2009), other measures of nonspecific and specific immunity in calves born to cows supplemented with Se are enhanced. We have recently shown higher antibody titers postimmunization, greater neutrophil total antioxidant potential, and lower levels of inflammatory gene expression in weaned beef calves fed supranutritional concentrations of Se (Hall et al., 2013b). In the transitional period between weaning and movement to a feedlot (Hall et al., 2013a), and in the feedlot, calves previously fed the highest-Se-supplemented forage levels had higher BW, greater slaughter weights, and better immune functions (Hall et al., 2013b). Our studies suggest that supranutritional Se supplementation improves not only passive immunity, but also enhances active immunity and production as calves age.

Although the cost for purchasing comparable dosages of Se-yeast is higher than that for Na selenite, the higher purchasing costs are offset by the labor cost associated with giving each calf Na selenite in its colostrum. Furthermore, the chance for errors in dosing calculations is real with Na selenite, and the handling of Na selenite is not safe for untrained individuals. A more economical and safer alternative is to fertilize forages with Na selenite to increase their organic Se content (Hall et al., 2011a). We will examine this alternative in future studies.

CONCLUSIONS

The objective of this study was to determine whether feeding cows a supranutritional Se-yeast supplement during the last 8-wk prepartum period, feeding calves colostrum from cows fed supranutritional Se-yeast concentrations, or adding Na selenite directly to colostrum, alone or in combination, increases serum-IgG concentrations and total serum-IgG content in Se-replete dairy calves. We conclude that feeding cows a supranutritional Se-yeast supplement or adding phar-

macological dosages of Na selenite to colostrum both increase serum-IgG concentrations and total serum-IgG content in Se-replete calves. Effects were significant at more time points in calves from cows that received supranutritional Se-yeast supplement. Further studies are needed to determine the mechanism for this effect as well as to determine whether other forms of organic Se are as effective as Se-yeast (e.g., Se-fortified forage).

ACKNOWLEDGMENTS

Appreciation is expressed to Jeff Wendler and Columbia River Dairy LLC (Boardman, OR) for the use of their dairy herd, calves, and facilities for the conduct of these experiments. This research was funded in part by a grant from the Oregon Beef Council (Portland, OR; J. A. Hall and G. J. Pirelli, principal investigators) and in part by Animal Health and Disease Project Formula Funds (Oregon State University, Corvallis; J. A. Hall, principal investigator).

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