Effects of maternal selenium supply and plane of nutrition during gestation on passive transfer of immunity and health in neonatal lambs


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ABSTRACT: To investigate the influence of maternal Se supply and plane of nutrition on lamb morbidity, mortality, and passive transfer of IgG, pregnant ewe lambs were used in 2 experiments with 2 × 3 factorial treatment arrangements. Supplementation of Se began at breeding and was either adequate Se (ASe, 9.5 μg/kg of BW) or high Se (HSe, 81.8 μg/kg of BW) in Exp. 1 or ASe (11.5 μg/kg of BW) or HSe (77.0 μg/kg of BW) in Exp. 2. On d 50 or 40 of gestation for Exp. 1 or 2, respectively, ewes were assigned randomly to 1 of 3 nutritional planes: 60% (RES), 100% (control, CON), or 140% (HI) of NRC requirements. This resulted in the following treatments: ASe-RES, ASe-CON, ASe-HI, HSe-RES, HSe-CON, and HSe-HI. Upon parturition, lambs were separated from their dams and serum samples obtained. Lambs were fed artificial colostrum for the first 20 h and then placed on milk replacer and grain pellets until completion of the study (Exp. 1, 57 d; Exp. 2, 21 d). Twenty-four hours after parturition, lamb serum samples were collected for IgG analysis. All lambs were reared similarly and morbidity and mortality assessed. Main effects were considered significant when \( P \leq 0.05 \). In Exp. 1, there was a Se × plane of nutrition interaction \( (P \leq 0.01) \) for lamb morbidity from birth to weaning and for 24-h IgG concentration. Lambs from ASe-RES and HSe-HI ewes were treated more frequently \( (P < 0.01) \) for respiratory and gastrointestinal disease, and lambs from HSe-HI ewes had the smallest \( (P < 0.01) \) 24-h serum IgG concentration. In Exp. 1, lambs from HI ewes also had the greatest \( (P < 0.01) \) mortality rates from birth to weaning compared with lambs from CON and RES ewes. In Exp. 2, there was an effect \( (P < 0.01) \) of maternal plane of nutrition with lambs from RES ewes having increased 24-h IgG compared with lambs from CON and HI ewes. There was no effect of maternal Se supplementation on lamb 24-h IgG in Exp. 2; however, there was a Se × plane of nutrition interaction \( (P < 0.01) \) for morbidity. From birth to 21 d of age, lambs from ASe-CON ewes had fewer \( (P < 0.01) \) treatment days compared with lambs from any of the other treatment groups. There also tended \( (P = 0.08) \) to be an effect of maternal Se supplementation on lamb mortality with increased mortality observed in lambs from HSe ewes. Results from the studies show a restricted maternal plane of nutrition can increase lamb serum IgG concentration. Selenium results were not consistent between the 2 experiments and may be due to differences in maternal Se.

Key words: developmental programming, immunoglobulin G, lamb, maternal nutrition, passive immunity, selenium

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INTRODUCTION

Maternal nutrition during gestation may play a pivotal role in neonatal health through altered colostrum volume and composition including IgG production, which is needed for early immunocompetence. Wallace et al. (2005) reported decreased colostrum yield in ewes offered increased complete dietary intake during pregnancy compared with controls. Swanson et al. (2008) reported decreases in colostrum volume, total nutrients, and IgG content in ewes fed differing planes of nutrition during pregnancy. Other forms of maternal stress, such as restraint with a nose snare, have been shown to decrease IgG concentrations and increase piglet morbidity and mortality (Tuchscherer et al., 2002).

Developmental programming infers alterations in fetal development due to external stimuli, such as maternal nutrition (Godfrey and Barker, 2000). Fang et al. (2002) proposed that oxidative stress due to overnutrition results in the production of reactive oxygen species during late pregnancy when metabolic demands are greater. Dietary supplementation of Se, an antioxidant, has been shown to enhance humoral immune function and increase IgG absorption (Knight and Tyznik, 1990; Kamada et al., 2007). Despite intensive research in the field of developmental programming, little research has focused on the effects of Se supplementation in general and supranutritional levels in particular in conjunction with changing maternal nutritional plane during pregnancy on morbidity, mortality, and passive transfer of IgG in offspring.

The objectives of this study were to examine serum IgG concentrations and subsequent morbidity and mortality in lambs raised independently of their over- and undernourished dams that received either adequate or supranutritional levels of dietary Se. We hypothesized that maternal over- and undernutrition may decrease passive transfer of IgG in the neonate, increase morbidity and mortality rates, and that the addition of Se to the maternal diet may offset some of these effects.

MATERIALS AND METHODS

Animal care and use was approved by the Institutional Animal Care and Use Committee at North Dakota State University (NDSU), Fargo, and the USDA, ARS, US Sheep Experiment Station (USSES) in Dubois, ID. A full description of the breeding and feeding programs has been previously published (Swanson et al., 2008; Meyer et al., 2010) but will be described briefly in the sections below.

Animals and Treatments

Exp. 1. At the USSES, 160 Rambouillet ewe lambs (age = 240 ± 17 d; mean BW = 52.1 ± 0.9 kg) were equally divided into 2 breeding groups. Within each breeding group, ewes were divided among 8 pens (n = 9 to 11/pen), estrus was synchronized within each breeding group, and a single Rambouillet ram was placed in each pen of ewes for 72 h (1 ram/pen). Marking paint was placed on the brisket of each ram to facilitate identification of ewes that the rams attempted to breed. Subsequently, marked ewes were assigned randomly to treatment pen (n = 2), and Se treatments were assigned randomly to pens. Selenium was provided to high-Se (HSe) ewes in the form of Se-enriched yeast (Diamond V, Cedar Rapids, IA) and treatments were adequate Se (ASe; 9.5 μg/kg of BW) vs. HSe (81.8 μg/kg of BW; supranutritional) and were delivered 1 time daily in pelleted form as a top dressing (100 g/ewe). Several research projects have been conducted in our laboratory using this amount of Se with no signs of toxicity (Neville et al., 2008; Swanson et al., 2008; Carlson et al., 2009). During breeding, and 36 and 29 d after breeding, for breeding group 1 and 2 respectively, ewes were fed (2.04 kg/ewe daily) a diet consisting of 47% alfalfa hay, 20% corn, 20% sugar beet pulp pellets, 8% malt barley straw, and 5% concentrated separator byproduct (DM basis). For breeding groups 1 and 2, pregnancy was determined 36 and 29 d after breeding, respectively, using transrectal ultrasound. Eighty-two pregnant ewes were identified and shipped (1,584 km; approximately 14.5 h transit time) to the Animal Nutrition and Physiology Center (ANPC) at NDSU for the remainder of the experiment. From breeding groups 1 and 2, 45 and 37 ewes were selected, respectively. Ultimately, 40 and 42 ewes remained in the ASe and HSe treatment groups, respectively. Upon arrival at NDSU, ewes remained on their assigned Se treatments. Ewes were individually housed in 0.91 × 1.2 m pens in a temperature controlled (12°C) and ventilated facility for the duration of the study. Lighting within the facility was automatically timed to mimic daylight patterns. On d 50 of gestation, ewes were assigned randomly to 1 of 3 nutritional planes: 60% (RES), 100% (control, CON), or 140% (HI) of nutrition requirements (NRC, 1985) except for Se. This resulted in a randomized design with a 2 × 3 factorial arrangement of treatments: ASe-RES (n = 14); ASe-CON (n = 13); ASe-HI (n = 13); HSe-RES (n = 14); HSe-CON (n = 14); and HSe-HI (n = 14). All diets were fed once daily in a completely pelleted form (0.48-cm diam. pellets; Table 1). Ewes had free access to water and a trace mineralized salt block containing no added Se (99% maximum NaCl, 96% minimum NaCl, and verified minimum amounts of the following: 2,000 mg of Mn/kg, 1,000 mg of Fe/kg, 1,000 mg of Mg/kg, 500 mg of S/kg, 250 mg of Cu/kg, 100 mg of Co/kg, 80 mg of Zn/kg, and 70 mg of I/kg; Roto Salt Co., Penn Yan, NY). Nutrient requirements were based on NRC (1985) recommendations for 60-kg BW, pregnant ewe lambs during mid to late gestation (weighted ADG of 140 g/d). Intake of the respective diets was calculated based on BW, ME requirements, and supplement ME and Se concentrations and published in detail elsewhere (Meyer et al., 2010, 2011; Neville et al., 2010). Feed refusals were collected daily to calculate intake (feed offered – feed refused), but ewes generally...
and HSe (65 μg/kg of BW) were bred and assigned to treatments as described in Exp. 1. Selenium treatments were ASe (3.5 μg/kg of BW; ASe, 11.5 μg/kg of BW; and HSe (65 μg/kg of BW). In contrast to Exp. 1, Se intakes: ASe, 11.5 μg/kg of BW; HSe, 77.0 μg/kg of BW) were provided to HSe ewes in the form of Se-enriched wheat millrun that was produced locally by the USSES and was provided to HSe ewes in the form of Se-enriched wheat sourced from increased Se arable lands near Pierre, SD. Ewes were fed a total mixed ration (2.45 kcal of ME/kg, 10.4% MP; DM basis) during this period to achieve an ADG of 135 g/d (NRC, 2007). Pregnancy was determined 31 d after breeding as in Table 1. Analyzed dietary composition, % DM

<table>
<thead>
<tr>
<th>Ingredient, % of dietary DM</th>
<th>Basal pellet</th>
<th>Se pellet</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beet pulp, dehydrated</td>
<td>36.5</td>
<td>36.5</td>
</tr>
<tr>
<td>Alfalfa meal, dehydrated</td>
<td>22.3</td>
<td>22.3</td>
</tr>
<tr>
<td>Ground corn</td>
<td>16.2</td>
<td>16.2</td>
</tr>
<tr>
<td>Soybean hulls</td>
<td>18.0</td>
<td>18.0</td>
</tr>
<tr>
<td>Soybean meal</td>
<td>7.0</td>
<td>4.9</td>
</tr>
<tr>
<td>Se-enriched yeast</td>
<td>—</td>
<td>2.1</td>
</tr>
</tbody>
</table>

Adequate-Se or HSe pellets were fed to ewes in the ASe and HSe treatments, respectively, to meet the ME content appropriate for their plane of nutrition treatments so that feed was offered to the 60, 100, and 140% nutritional planes. The HSe pellet was used in combination with the ASe pellet as needed to meet the targeted HSe and ME content for each ewe. When the HSe pellet could not meet the HSe content for RES- or CON-fed ewes without exceeding the desired nutritional plane, the concentrated-Se pellet, with purified selenomethionine as its Se source, was used to augment the Se supply. Feed refusals were collected and ewe BW measured as described previously for Exp. 1.

### Lamb Care Postpartum

Initial care of lambs in both Exp. 1 and Exp. 2 was similar. All births were observed, and lambs were immediately removed from their dams before suckling and cared for in a separate, clean room. Lambs were dried with a towel and date, time of birth, sex, and birth weight were recorded. Within 15 min after birth (0 h, before nursing), blood samples (6 mL) were collected via jugular vein to obtain serum. Time of blood sampling was recorded and blood was placed at 4°C until processed (centrifugation at 1,500 × g for 30 min at 4°C). After centrifugation, serum samples were stored at −20°C until IgG analysis. The navel of each lamb was clipped to 5 cm with a surgical scissors and dipped into 7% iodine tincture. Lambs received 1 mL of Ultra-bac CD (Clostridium perfringens types C and D; Pfizer Animal Health Inc., New York, NY) subcutaneously.

### Artificial Colostrum and Milk Replacer

Lambs in both Exp. 1 and Exp. 2 were removed from their dams and fed artificial colostrum and milk replacer. The amount of artificial colostrum was based on birth weight to achieve consumption of 10.6 g of IgG/kg of BW during the first 20 h postpartum. The dosage of IgG was calculated to provide 50 g of IgG/4.7 kg of lamb BW based on previous reports using a similar product (Quigley et al., 2002). Bovine source IgG colostrum was fed in 7 feedings over the first 20 h postpartum (19.1 mL/kg for the first 2 feedings and 25.5 mL/kg for 5 subsequent feedings), with the initial feeding provided within 30 min postpartum. Artificial colostrum was offered by bottle, with any colostrum not sucked administered via stomach tube to ensure the full dosage of IgG was obtained. The 2 experiments differed only in source of the artificial colostrum. In Exp. 1, artificial colostrum was made in 15-L batches. Each batch contained 2.571 kg of lamb milk replacer (Super Lamb Instant Milk Replacer, Merrick’s Inc., Middleton, WI) and 1.928 kg of ImmunoLin (bovine serum IgG product, 50% IgG, APC Inc., Ankeny, IA) dissolved

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**Table 1.** Diet composition and calculated nutrient composition of diets fed to gestating ewe lambs (DM basis) while at North Dakota State University (Exp. 1)

<table>
<thead>
<tr>
<th>Ingredient, % of dietary DM</th>
<th>Basal pellet</th>
<th>Se pellet</th>
</tr>
</thead>
<tbody>
<tr>
<td>OM</td>
<td>93.8</td>
<td>93.8</td>
</tr>
<tr>
<td>CP</td>
<td>14.4</td>
<td>14.1</td>
</tr>
<tr>
<td>NDF</td>
<td>38.9</td>
<td>39.5</td>
</tr>
<tr>
<td>ADF</td>
<td>25.4</td>
<td>25.7</td>
</tr>
<tr>
<td>Starch</td>
<td>13.2</td>
<td>12.9</td>
</tr>
<tr>
<td>Ca</td>
<td>0.93</td>
<td>0.84</td>
</tr>
<tr>
<td>P</td>
<td>0.24</td>
<td>0.24</td>
</tr>
<tr>
<td>Se, mg/kg</td>
<td>0.77</td>
<td>40.4</td>
</tr>
<tr>
<td>Calculated ME,2 Mcal/kg</td>
<td>2.63</td>
<td>2.65</td>
</tr>
</tbody>
</table>

1 | Diamond V Mills Inc., Cedar Rapids, IA; 2,000 mg of Se/kg. 2Estimated using values obtained from the NRC (1985).

Ewes were housed at ANPC as described in Exp. 1. Body weight was measured every 14 d, and diets were adjusted accordingly.

**Exp. 2.** At the USSES, 178 Rambouillet ewe lambs (age = 240 ± 17 d; mean BW = 52.1 ± 6.2 kg) were bred and assigned to treatments as described in Exp. 1. Selenium treatments were ASe and HSe treatments, respectively, to meet the ME content appropriate for their plane of nutrition treatments so that feed was offered to the 60, 100, and 140% nutritional planes. The HSe pellet was used in combination with the ASe pellet as needed to meet the targeted HSe and ME content for each ewe. When the HSe pellet could not meet the HSe content for RES- or CON-fed ewes without exceeding the desired nutritional plane, the concentrated-Se pellet, with purified selenomethionine as its Se source, was used to augment the Se supply. Feed refusals were collected and ewe BW measured as described previously for Exp. 1.

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**Lamb Care Postpartum**

Initial care of lambs in both Exp. 1 and Exp. 2 was similar. All births were observed, and lambs were immediately removed from their dams before suckling and cared for in a separate, clean room. Lambs were dried with a towel and date, time of birth, sex, and birth weight were recorded. Within 15 min after birth (0 h, before nursing), blood samples (6 mL) were collected via jugular vein to obtain serum. Time of blood sampling was recorded and blood was placed at 4°C until processed (centrifugation at 1,500 × g for 30 min at 4°C). After centrifugation, serum samples were stored at −20°C until IgG analysis. The navel of each lamb was clipped to 5 cm with a surgical scissors and dipped into 7% iodine tincture. Lambs received 1 mL of Ultra-bac CD (Clostridium perfringens types C and D; Pfizer Animal Health Inc., New York, NY) subcutaneously.

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into 10 L of tap water (40 to 45°C). Once dissolved, additional tap water was added to raise the volume to 15 L. In Exp. 2, a commercially available artificial co-lostrum product was used (Acquire, APC Inc.).

Lamb Care 24 h Postpartum Through the End of the Experiment

Lamb care procedures were similar in Exp. 1 and Exp. 2; they varied only in the length of the experiment. In Exp. 1, lambs were raised until weaning (57 ± 4 d of age), whereas in Exp. 2, lambs were raised until 19 d of age. In both experiments, at 24 h of age (post-partum), lambs were weighed and a 6-mL blood sample was collected via jugular vein to obtain serum for IgG analysis. Lambs were then placed in group pens and fed lamb milk replacer (Super Lamb Instant Milk Replacer, Merrick’s Inc.) until weaning. Initially, lambs sucked from a bottle until they were adapted to a group teat bucket feeding system, which occurred within 3 d after birth. From 3 d until weaning, lambs had free access to creep feed (55% corn, 25% soybean meal, 12.5% oats, and 7.5% supplement, J & S Farmers Mill, Barnesville, MN), alfalfa leaves, and fresh water in addition to milk replacer. Lambs in Exp. 1 received a 1-mL booster of Ultrabac-CD (clostridium perfringens types C and D, Pfizer Animal Health Inc.) subcutaneously at 3 wk of age.

All lambs were reared similarly in a temperature-controlled (21.1°C), and ventilated facility for the duration of the study. Lambs were examined daily, and signs of illness prompted treatment. Necropsies were performed by an accredited veterinary diagnostic laboratory (NDSU Veterinary Diagnostic Laboratory, Fargo, ND) for all lambs that died during the trial. Morbidity was assessed as number of days treated for respiratory or gastrointestinal symptoms, whereas mortality was calculated as percentage that died.

IgG Analysis

Serum IgG concentrations were determined by radial immunodiffusion using a commercially available kit to detect bovine IgG (VMRD Inc., Pullman, WA). All samples were run in triplicate and compared against a known standard. The limit of detection for the low-level antigen assay was 0.5 to 4.0 g/L and was 4.0 to 32.0 g/L for the remainder of the samples.

Statistical Analysis

In Exp. 1, 4 ewes were removed from the study because 3 (ASe-CON, ASe-HI, and HSe-CON) were not pregnant due to loss of pregnancy, and 1 (ASe-RES) did not consume the diet. Ewes carried singles (n = 70) and twins (n = 8); therefore, fetal number was included in the model. If fetal number was clearly not significant (P ≥ 0.20), it was removed from the model. Five lambs were removed from analysis of morbidity, mortality, and IgG due to missed or inaccurate colostrum feeding (ASe-RES, ASe-CON = 2, ASe-HI, HSe-HI).

In Exp. 2, twins (n = 6) and their dams (n = 3) were removed from the data set and only ewes carrying singletons (n = 80) were used in the analysis. One
ewe was also found to no longer be pregnant and was removed from the study.

For both experiments, data were analyzed as a completely randomized design with a $2 \times 3$ factorial arrangement of treatments using GLM procedures (SAS Inst. Inc., Cary, NC). The model contained level of Se (ASe vs. HSe), nutritional plane (RES, CON, and HI), and all interactions. Lamb sex was initially included in the model, but was removed if not significant ($P \geq 0.20$). Morbidity data were analyzed using GLIMMIX procedures of SAS using the model described above. When interactions were present ($P \leq 0.10$), means were separated by LSD. Main effects were considered significant when $P \leq 0.05$ and approached significance when $P \geq 0.05$ and $P \leq 0.10$.

**RESULTS**

**Exp. 1**

Maternal gestation lengths and lamb birth weights were previously published by Swanson et al. (2008), but will be briefly described. Gestation length was decreased ($P < 0.01$) in ewes on the HI plane of nutrition compared with the RES and CON planes of nutrition (Table 3). Birth weight was decreased ($P < 0.01$) in lambs from RES and HI compared with CON ewes, whereas birth weights from RES and HI ewes did not differ (Table 3). There was no effect of Se on gestation length or lamb birth weight.

Lamb morbidity and mortality rates are shown in Table 3. There was no effect of Se on lamb morbidity through 21 d of age; however, morbidity was affected ($P = 0.01$) by ewe nutritional plane with lambs from dams on HI plane of nutrition having increased morbidity compared with lambs from RES and CON dams. For morbidity from birth to weaning (57 d of age), there was a Se × nutrition interaction ($P < 0.01$), with HSe decreasing morbidity in lambs from RES ewes but increasing morbidity in lambs from HI ewes.

At weaning there was a nutrition × sex interaction ($P < 0.01$) on morbidity, with female lambs from RES ewes and male lambs from CON and HI ewes being treated more frequently (Figure 1A). Moreover, there was a nutrition × litter size interaction ($P < 0.01$) on morbidity at weaning. Singleton lambs born to RES ewes had the least morbidity whereas twin lambs born to RES ewes had the greatest morbidity (Figure 1B).

There was no effect of Se or nutritional plane on lamb mortality from birth to 21 d of age (Table 3). However, lamb mortality was increased ($P < 0.01$) for lambs from HI ewes from birth to weaning.

Table 3. Effect of maternal Se supplementation and plane of nutrition on mean gestation length, lamb birth weight, and lamb morbidity and mortality rates (Exp. 1)

<table>
<thead>
<tr>
<th>Item</th>
<th>Se treatment</th>
<th>Nutrition treatment</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Item</td>
<td>ASe</td>
<td>HSe</td>
<td>SEM</td>
</tr>
<tr>
<td>Gestation length, d</td>
<td>149.3</td>
<td>148.5</td>
<td>0.4</td>
</tr>
<tr>
<td>Birth weight, kg</td>
<td>4.4</td>
<td>4.2</td>
<td>0.1</td>
</tr>
<tr>
<td>Morbidity 21 d</td>
<td>0.4</td>
<td>0.4</td>
<td>0.1</td>
</tr>
<tr>
<td>Morbidity 57 d</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Mortality 21 d</td>
<td>6.1</td>
<td>5.1</td>
<td>5.4</td>
</tr>
<tr>
<td>Mortality 57 d</td>
<td>16.0</td>
<td>12.8</td>
<td>5.9</td>
</tr>
<tr>
<td>IgG (Exp. 1), g/L</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>IgG (Exp. 1), g/L</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
</tbody>
</table>

*Within a row, means without a common superscript letter differ ($P \leq 0.05$).
*Within a variable, interactive means without a common superscript letter differ ($P \leq 0.05$).
*Selenium treatments were daily intake of organically bound Se; adequate Se (ASe; 9.5 μg/kg of BW) vs. high Se (HSe; 81.8 μg/kg of BW).
*Plane of nutrition treatments were 60% of control (RES), 100% of NRC requirements for gestating ewe lambs (control, CON), and 140% of control (HI).
*Probability values for effects of Se, nutrition (Nut), and their interaction.
*n = 13, 12, 14, 13, and 14 for ASe-RES, ASe-CON, ASe-HI, HSe-RES, HSe-CON, and HSe-HI, respectively.
*Days treated for respiratory and gastrointestinal illness according to protocol.
*Calculated as percentage that died.
*ASe-CON and HSe-RES differ at $P = 0.08$; ASe-HI and HSe-CON differ at $P = 0.06$. 

3694 Hammer et al.


Figure 1. Effects of maternal plane of nutrition and lamb sex (A) or litter size (B) on lamb morbidity until weaning (d 57) in Exp. 1. There was a main effect of nutrition ($P < 0.01$) for both variables. For maternal nutritional plane, bars marked with different letters (a–c) indicate different least squares means ± SEM, $P \leq 0.05$. Maternal nutritional intake treatments were 60% of control (RES; $n = 26$), 100% of requirements for gestating ewe lambs (CON; $n = 23$), and 140% of control (HI; $n = 24$).

(P < 0.01) 24-h serum IgG compared with twins (16.0 and 21.3 ± 1.2 g/L, respectively).

**Exp. 2**

Maternal gestation lengths and lamb birth weights were previously published by Meyer et al. (2010), but will be briefly described. There was a Se × nutrition interaction ($P = 0.01$), with HSe-RES ewes having increased gestation length compared with the remainder of the groups (Table 4). There also tended ($P = 0.08$) to be a Se × nutrition interaction for lamb birth weight with lambs from ASE-RES ewes having decreased ($P < 0.01$) birth weights compared with lambs from HSe-CON and ASe-HI ewes.

Lamb morbidity and mortality rates are shown in Table 4. There was a Se × nutrition interaction ($P < 0.01$) for lamb morbidity from birth to 21 d with lambs from ASe-CON ewes having decreased ($P < 0.01$) treatment days compared with other groups. There was no effect of maternal plane of nutrition or lamb sex on lamb mortality from birth to 21 d of age; however, there tended ($P = 0.08$) to be an effect of maternal Se supplementation, with increased mortality observed for lambs from HSe ewes.

Lamb 24-h IgG concentrations from Exp. 2 are shown in Table 4. There was an effect ($P < 0.01$) of maternal plane of nutrition with lambs from RES ewes having increased ($P \leq 0.02$) IgG compared with lambs from CON and HI treatments. There was no effect of maternal Se supplementation on lamb 24-h IgG.

**DISCUSSION**

To our knowledge, this is the first report of passive transfer of IgG where the offspring were raised independently of their nutritionally challenged dams and thus removed from lactational effects. All lambs were fed colostrum replacer to achieve 10 g of IgG per unit of BW and, thus, the difference in IgG absorption is independent of maternal colostrum production. Differences in colostrum yield and IgG concentration from stressed dams have been reported previously (Nardone et al., 1997; Wallace et al., 2005; Swanson et al., 2008) and, therefore, it is important to uncouple neonatal from lactational differences.

**IgG**

These experiments support the hypothesis that gestational diet affects serum IgG concentrations in neonatal lambs. In both experiments, lambs from RES ewes had increased serum IgG concentrations at 24 h compared with lambs from ewes on CON and HI treatments. In contrast, maternal overnutrition and the addition of Se to the maternal diet decreased serum IgG in Exp. 1, but not Exp. 2. There was no effect of Se on lamb serum IgG concentration at 24 h in Exp. 2; however, there was a Se × nutrition interaction in Exp. 1 with lambs from RES ewes having the greatest IgG concentration and lambs from HSe-HI ewes having the smallest serum IgG concentration.

Previous data from Kamada et al. (2007) reported that Se supplementation directly to colostrum increased calf serum IgG concentration; however, the authors also noted that at greater Se inclusion, IgG absorption was impaired. The authors speculated that the effect of Se on IgG absorption was pharmacological and not nutritional and could not be explained by any known actions of Se. It is difficult to make direct comparisons between the current studies and the experiment by Kamada et al. (2007) because of varying mechanisms in the way Se was provided to the animals and Se status of the offspring. In the present studies, Se was supplemented in the maternal diet and the resulting offspring were not Se deficient at birth (Meyer et al., 2010; Neville et al., 2010), whereas Kamada et al. (2007) reported offspring
serum Se concentrations of <30 μg/kg and added supplemental Se directly into the colostrum, thus avoiding the maternal digestive and metabolic pathways. Increases (Rock et al., 2001), no change (Lacetera et al., 1996, 1999), and decreases (Boland et al., 2005) in offspring serum IgG concentrations have all been reported because of maternal Se supplementation. Boland et al. (2005) fed ewes supplemental Se for 7 wk before lambing and noted decreased IgG absorption in lambs from supplemented ewes, even though colostrum intake and total IgG intake were similar among treatments. In contrast, Rock et al. (2001) fed ewes supplemental Se for 7 wk before lambing and noted decreased IgG absorption in lambs from supplemented ewes, even though colostrum intake and total IgG intake were similar among treatments. Although the mechanism leading to altered IgG absorption in offspring from Se-supplemented dams is not known, altered thyroid hormone status may provide an explanation. Cabello et al. (1983) reported that fetal infusion of thyroid hormones resulted in decreased IgG absorption in lambs. Also, Awadeh et al. (1998) reported greater T3 concentrations at birth in calves born to cows supplemented with 60 mg of organic Se/kg compared with 60 mg of Na-selenite/kg; however, there was no difference in calf serum IgG concentration. It should be noted, that there were differences in colostral IgG concentrations between the 2 treatment groups and even though no differences in calf serum IgG were reported, failure to account for colostral IgG concentration and colostral intake may have masked treatment differences. It is clear from the literature that factors such as Se source and animal Se status can influence results. In the current studies, the differing results between the 2 experiments may be due to the change in Se source and amount fed. Ewes in Exp. 1 were fed 81.8 μg/kg of BW of a Se yeast supplement, whereas ewes in Exp. 2 were fed 77 μg/kg of BW of Se-enriched wheat millrun.

### Morbidity and Mortality

Morbidity rates were quite small in both experiments, with an average of 1.5 treatment days across all treatments. In Exp. 1 there initially was only an effect of maternal nutrition on lamb morbidity with lambs from HI ewes having increased treatment days. However, by weaning there was a Se × nutrition interaction on lamb morbidity. Interestingly, maternal Se supplementation increased lamb morbidity in lambs from CON ewes in this experiment. Although there was no effect of nutrition on lamb mortality in Exp. 2, offspring from Se-supplemented ewes in Exp. 2 had decreased IgG concentrations, which may have masked treatment differences.

### Table 4. Effect of maternal selenium supplementation and plane of nutrition on mean gestation length, lamb birth weight, and lamb morbidity/mortality rates (Exp. 2)

<table>
<thead>
<tr>
<th>Item</th>
<th>Se treatment1</th>
<th>Nutrition treatment2</th>
<th>P-value3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gestation length, d</td>
<td>ASe</td>
<td>HSe</td>
<td>RES</td>
</tr>
<tr>
<td>ASe</td>
<td>—</td>
<td>—</td>
<td>148.5</td>
</tr>
<tr>
<td>HSe</td>
<td>—</td>
<td>—</td>
<td>149.9</td>
</tr>
<tr>
<td>Birth weight, kg</td>
<td>ASe</td>
<td>—</td>
<td>4.0d</td>
</tr>
<tr>
<td>HSe</td>
<td>—</td>
<td>—</td>
<td>4.5we</td>
</tr>
<tr>
<td>Morbidity, %</td>
<td>ASe</td>
<td>—</td>
<td>1.1d</td>
</tr>
<tr>
<td>HSe</td>
<td>—</td>
<td>—</td>
<td>0.5de</td>
</tr>
<tr>
<td>Mortality, %</td>
<td>0.0</td>
<td>7.5</td>
<td>3.0</td>
</tr>
<tr>
<td>IgG (Exp. 2), g/L</td>
<td>14.5</td>
<td>14.2</td>
<td>11.1</td>
</tr>
</tbody>
</table>

1Selenium treatments were daily intake of organically bound Se; adequate Se (ASe; 11.5 μg/kg of BW) vs. high Se (HSe; 77.0 μg/kg of BW).
2Nutritional plane treatments were 60% of control (RES), 100% of NRC requirements for gestating ewe lambs (control, CON), and 140% of control (HI).
3Probability values for effects of Se, nutrition (Nut), and the interaction.
4n = 13, 14, 13, 13, 14, and 13 for ASe-RES, ASe-CON, ASe-HI, HSe-RES, HSe-CON, and HSe-HI, respectively.
5Days treated for respiratory and gastrointestinal illness according to protocol through d 21.
6Calculated as percentage that died.

All within a row, means without a common superscript letter differ (P ≤ 0.05).

Within a variable, interactive means without a common superscript letter differ (P ≤ 0.05).

a,bWithin a row, means without a common superscript letter differ (P ≤ 0.05).
ewes tended to have greater mortality rates. Because of these experiments being conducted in a climate-controlled facility and the low morbidity and mortality rates, further analysis is needed to observe morbidity and mortality rates of offspring subject to in utero nutritional modifications in a production setting where they would be challenged by environmental conditions as well as increased exposure to pathogens. Muñoz et al. (2009) reported no difference in lamb mortality when dams were supplemented with Se. Although this was a large, multi-farm production study, lambs were allowed to nurse from their dams so effect of Se supplementation on lactation must be considered.

**Gestation Length and Birth Weight**

Shortened gestation lengths and lighter birth weights have been reported to decrease IgG concentrations and increase mortality in lambs (Cabello and Levieux, 1981; Gama et al., 1991; Christley et al., 2003). In the current experiments, maternal nutrition affected gestation length and birth weight. In Exp. 1, HI ewes had shorter gestation lengths, and lambs born to HI ewes had lighter birth weights, and greater mortality. It should be noted, however, that lambs from RES ewes also had decreased birth weights; however, they had increased IgG concentrations and no change in mortality compared with lambs from CON ewes.

In Exp. 2, a Se × nutrition interaction was observed for gestation length, lamb birth weight, and lamb morbidity. Lambs from ASe-RES tended to be lighter than HSe-CON and ASe-HI; however, ASe-RES did not have shorter gestation lengths compared with CON. Even though lambs from ASe-RES ewes were lighter at birth, lambs from RES ewes had increased IgG concentrations. However, lambs from ASe-RES did have increased morbidity compared with ASe-CON.

The present data suggest that maternal nutrition during pregnancy affects neonatal health and the ability of the neonate to acquire passive immunity of IgG. These studies are unique in that offspring were raised in a climate-controlled facility, and thus effects of maternal colostrum and milk production are removed. Lambs and calves absorb macromolecules like IgG nonspecifically from the intestine during the first day of life (Sawyer et al., 1977; Stott et al., 1979). This period of nonspecific absorption decreases over time in a linear fashion (Stott et al., 1979). The mechanism leading to this change in absorption is not fully understood but it is believed to be related to energy (glucose) availability and maturation of the small intestine (Comline and Silver, 1970; Smeaton and Simpson-Morgan, 1985).

Although the exact mechanism leading to the differing IgG concentrations reported in the current study was not examined, we hypothesize that the period of absorption may have been altered. Glucose concentrations at birth were not reported but lambs from nutrient-restricted dams have demonstrated altered glucose and insulin responses at 107 to 250 d of age (Ford et al., 2007; Vonnahme et al., 2010), suggesting that altered glucose concentrations may have delayed gut closure in lambs from restricted dams. Furthermore, nutrient restriction in adult rats, mice, and hamsters caused a decrease in enterocyte proliferation and migration along the crypt-villus axis (Ferraris and Carey, 2000). Although the effect of maternal nutrient restriction on lamb enterocyte migration has not been reported, Reed et al. (2007) reported alterations in fetal jejunal protein content and decreased protein:DNA ratio, suggesting a smaller cell size in the intestine of lambs from restricted ewes. A change in energy availability to the intestine or change in enterocyte maturation may alter the period of nonspecific absorption and cause the altered IgG concentrations observed in the current study.

If offspring are programmed in utero in a way that alters acquisition of passive immunity, health and survival can be affected. Factors that affect the well-being of offspring ultimately become economically relevant to the producer. Therefore, research to clarify the interaction of Se on lamb acquisition of IgG is needed as is research to understand the mechanism of action leading to increased serum IgG concentrations in lambs from nutrient-restricted dams.

**LITERATURE CITED**


