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The Dietary Inclusion of Magnesium Sulfate During Late Gestation Enhances Lambing Performance Without Compromising Neonatal Physiology or Behavior in Twin-Bearing Ewes

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Simple Summary

Neonatal mortality is a concern in sheep production. A prolonged lambing process may increase hypoxia, potentially causing neuronal damage and reducing maternal behavior, especially in lambs from hogget ewes. The use of dietary $MgSO_4$ in Finnish × Polwarth adult and hogget twin-bearing ewes reduces the duration of the expulsion phase without adversely affecting birth weight, neonatal behavior, or blood variables. The findings of this study suggest that dietary $MgSO_4$ may be a simple nutritional strategy to improve lambing in twin-bearing ewes.

Abstract

This study evaluated the effects of dietary magnesium sulfate ($MgSO_4$) addition in twin-bearing ewes during late gestation on the duration of lambing, neonatal behavior, and blood biochemical variables. Fifty-one hogget and 54 adult Finnish × Polwarth ewes were allocated to four groups based on age category (hogget or adult) and dietary addition ($MgSO_4$ addition or control). Ewes in dietary $MgSO_4$ treatments received 7 g of $MgSO_4$/ewe/day. Duration of the expulsion phase (DII), interval between lamb births (IL), and total lambing time (TL) were recorded. Meconium score (0–3), birth weight, time to stand (TS), time to first successful suck (SS), and rectal temperature at birth (T0) and at 3 h of life (T3) were measured. Blood samples were collected from lambs and analyzed for blood biochemical and acid–base variables. $MgSO_4$ addition did not affect individual or litter birth weight ($p > 0.05$), but the DII was lower in the lambs from $MgSO_4$ ewes ($p < 0.05$). A greater proportion of lambs born to dietary $MgSO_4$ ewes had higher meconium scores. The treatment did not affect the acid–base variables ($p > 0.05$); however, the age category had an effect on BEecf, HCO_3^-, tCO_2, lactate and glucose, and behavior variables ($p < 0.05$). Acidosis (pH < 7.20) occurred in lambs from control ewes. No differences were observed in T0, but lambs from control hoggets had lower T3 values ($p < 0.05$). In conclusion, in our conditions, dietary $MgSO_4$ addition in twin-bearing ewes during late gestation reduced the duration of the expulsion phase without affecting neonatal behavior or the main indicators of neonatal acid–base status. Further studies are needed to elucidate the mechanisms by which $MgSO_4$ influences the lambing process.

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1. Introduction

Perinatal mortality of lambs is a concern for the sheep industry worldwide. Some perinatal lamb deaths may be related to the maternal age category. It was reported that the main causes of perinatal mortality in lambs born to hogget ewes (yearling, primiparous ewes) were stillbirth (41.1%, twice that of adult ewes), starvation–mismothering (25%), and dystocia (16.8%), which increased lamb mortality compared with adult ewes [1]. This higher rate of lamb loss in primiparous ewes may be associated with complications during lambing. In this sense, primiparous ewes experience greater difficulties during lambing than multiparous ewes [2,3]. Similarly, a report in Corriedale describes that primiparous ewes had a longer expulsion phase and required approximately twice as much attention at parturition as multiparous ewes [4].

Delayed lambing can affect both the ewe and the lamb. Merino ewes that experienced a prolonged and difficult lambing process exhibited fewer maternal care behaviors [5]. Dutra & Banchero (2011) [6], using Texel × Polwarth lambs, found a correlation between increased parturition duration and hypoxic events. Some studies in lambs show that occlusion of the umbilical cord (before or during lambing) can cause asphyxia with hypercapnia and hypoxemia, lower pH, and increased blood lactate concentrations [7,8]. Dutra et al. (2007) [9] described that in lambs that died within the first week of life, hypoxic–ischemic episodes during parturition led to lesions in the central nervous system consistent with hypoxic–ischemic encephalopathy. Neuroprotectant substances are used to prevent or limit brain damage from hypoxemia in newborn humans and animals.

Several neuroprotectants were identified, including magnesium sulfate ($MgSO_4$). Goñi-de-Cerio et al. (2012) [10] demonstrated that magnesium sulfate decreased the number of apoptotic nerve cells after hypoxia generated by occlusion of the umbilical vein in newborn lambs. However, the inclusion of magnesium in the diets of pregnant ewes was inconsistent. The inclusion of $MgSO_4$ in the diet of pregnant Finnish × Polwarth adult ewes carrying twins for one week before parturition improved lamb birth weight and extended the pregnancy by one day [11]. $MgSO_4$ has recently been used in a negative dietary cation–anion difference for Merino ewes in late pregnancy, with no changes in survival, birth weight, or lamb viability [12]. However, despite these findings, it remains unclear what the effects of dietary $MgSO_4$ are on the lambing process and immediate neonatal conditions.

Therefore, the objective of this study was to evaluate the effect of including $MgSO_4$ in the diet of twin-bearing Finnish × Polwarth ewes during the final month of gestation on parturition and lamb outcomes, including birth weight, blood variables, and behavior. The hypothesis was that dietary magnesium sulfate addition during the last two weeks of gestation would improve the lambing process without adversely affecting the blood and/or behavioral variables of the lambs.

2. Materials and Methods

All animal work was conducted at the Experimental Sheep Unit of the National Institute for Agricultural Research (INIA) "La Estanzuela", Uruguay (latitude 34°19′57″ S, longitude 57°40′07″ W).

2.1. Animal Selection and Treatments

An experimental flock of 230 Finnish × Polwarth ewes was used. The estrus was synchronized with two doses of a synthetic analog of PGF2α seven days apart. The ewes were naturally mated with five Finnish × Polwarth rams (ratio of 1:46). The pregnancy (gestation and litter size) was confirmed by transabdominal ultrasound scanning at day 85 ± 5 of gestation. Only ewes carrying twins were used (54 adult ewes and 51 hogget ewes, yearlings, primiparous ewes). All ewes were shorn on day 120 of gestation. Throughout the gestation period, the ewes grazed improved pasture. The sample size was determined based on variability in the primary outcome variables reported in previous studies [11] and the availability of ewes carrying twins. No formal a priori sample size calculation was performed. The ewe was considered the experimental unit.

On day 140 of gestation, 105 twin-bearing ewes were allocated into four treatments (see Table 1) based on age category (adult or hogget), body weight (BW), and body condition score (BCs). All ewes were identified with a tag in the ear, and a correlative number was painted on the ribs (different colors for treatment).

Table 1. Treatment details for Finnish × Polwarth ewes.

	Dietary $MgSO_4$		**Control**	
Parity	Adult	Hogget	Adult	Hogget
n	30	23	24	28
BW (kg)	59.8 ± 5.8	52.6 ± 5.4	60.1 ± 3.2	52.7 ± 5.5
BCs	3.1 ± 0.3	3.1 ± 0.4	3.2 ± 0.3	3.1 ± 0.3
Diet	C + $MgSO_4$	C + $MgSO_4$	C	C

BW = body weight, BCs = body condition score, Diet: C = 200 g of soybean meal (CP: 45.6%; FAD: 10.0%; FND: 26.5%; EM: 2.16 Mcal) and alfalfa haylage ad libitum (CP: 18.3%; FAD: 38.2%; FND: 39.8%; EM: 2.05 Mcal), C + $MgSO_4$ = Diet C + 7 g $MgSO_4$/ewe/day.

All ewes were kept together in a large outdoor pen with free access to clean water and alfalfa haylage. At 8 a.m., each ewe was moved indoors into the individual pen and was offered diet C or C + $MgSO_4$. Once the ewe had eaten, it returned to the large pen. The blood Mg levels in this flock at late gestation were 2.64 ± 0.26 mg/dL (Minteguiaga et al., in press [13]), which is within the normal levels for the species. The Mg levels were not measured in this experiment. The selected dose of $MgSO_4$ was based on the recommended levels by Chester-Jones et al. (1989) [14] and NRC (2007) [15], as well as the levels previously used in pregnant ewes [11]. From day 144 of gestation, the ewes were monitored for 24 h, and those showing prodromal signs of lambing were housed in an individual pen. The experimental period was 13 ± 4 days.

2.2. Control of the Parturition Process

Each parturition process was observed. The duration of the expulsion phase (DII-second stage of labor) was determined (in minutes) from the time the head or the first limb was seen at the vulva until the lamb was fully expelled. The lambing interval (IL) was determined as the interval (in minutes) between the expulsion of the first lamb and the onset of the second birth. The total time to lambing (TL) was determined (in minutes) as the time between the onset of the first birth and the end of the second birth.

Post-partum measurements included birth weight and rectal temperature at birth (T0). The sex and meconium score (incremental scale, 0–3; 0 = no staining, 1 = mild staining, 2 = moderate staining, 3 = severe staining; modified by Brougham et al., 2020 [16]) were recorded, and the ear of one of the lambs was painted to indicate birth order.

At birth, a blood sample was collected from the lambs via jugular venipuncture (n = 210) during the apnea period (before the first breath) into pre-heparinized syringes

(with a rubber plug) for blood biochemical and acid–base studies (BD PresetTM, Becton, Dickinson and Company, Plymouth, UK). The blood was analyzed using a portable clinical analyzer (i-Stat1® Portable Clinical Analyzer, Abbot Laboratories, Abbott Park, IL, USA) with specific cartridges (CG4+®, Abbot Laboratories, Abbott Park, IL, USA) according to the manufacturer's recommendations. The following variables were determined: potential of hydrogen (pH), oxygen partial pressure (pO_2; mmHg), carbon dioxide partial pressure (pCO_2; mmHg), bicarbonate (HCO_3^-; mmol/L), oxygen saturation (saO_2; %), total carbon dioxide (tCO_2; mmol/L), base excess/deficit (BEecf; mmol/L), and lactate (mmol/L). The remaining sample was centrifuged at 5000 rpm, and plasma was extracted and frozen at −18 °C until analyzed. The glucose (mg/dL) was determined by the hexokinase-glucose-6-phosphate dehydrogenase method in a photometric system (Dimension® RxL Max Auto-Analyzer; Siemens Healthcare Diagnostics Ltd., Camberley, UK).

Lambs were further observed after birth to record their behavior. The time to standing (TS, lambs stand on all four limbs for more than 10 s) and the time of the first successful suck (SS, adapted from Matheson et al. (2011)) were recorded [17]. Three hours after birth, the rectal temperature (T3) was measured. The ewes and their lambs were kept in the pen until the second day of life; each lamb was identified with an ear tag, and the ewe number was painted on the ribs for easy identification in the field. From the second day of life, the lambs and their mothers were moved out to a pasture during the day and were confined at night.

2.3. Determinations

The sum of the birth weights of both lambs was defined as the litter birth weight. The relationship between lamb birth weight and maternal body weight (MBWP) was calculated as litter birth weight/ewe's BW and was expressed as a percentage.

2.4. Statistical Analysis

The model had a 2 × 2 factorial design. The data were analyzed using SAS® On-Demand for Academics 9.04 (SAS Institute Inc., Cary, NC, USA). The statistical model included treatment (dietary $MgSO_4$ or control), parity, and their interaction as fixed effects. For the birth weight analyses, the model included treatment, parity, the treatment × parity interaction, and lamb sex as fixed effects. Ewe was included as a random effect to account for the dependence between twin lambs born to the same ewe. For the lambing process variables in DII, the model includes treatment, parity, birth order, and their interaction as fixed effects. The variables IL and TL were recorded once per ewe; the model included treatment, parity, and their interaction as fixed effects, with BW included as a covariate. Least squares means were compared using the Tukey–Kramer adjustment.

Except for rectal temperature, all variables were analyzed using a mixed model (proc glimmix). Birth weight and the duration of diet administration were used as covariates in analyses of behavioral and blood variables. tCO_2, pO_2, lactate, and saO_2 were log10-transformed because their residuals did not meet the assumption of normality.

Rectal T0 and T3 were analyzed using a linear mixed model (proc mixed). The model included treatment, parity, time, and their interactions (treatment × parity, treatment × time, parity × time, and treatment × parity × time) as fixed effects. Birth weight was included as a covariate. The covariance structure for repeated observations was compound symmetric. Meconium score frequencies were compared among experimental groups using a chi-square test.

Correlation coefficients and linear regression analyses were used to assess relationships among variables. A p-value < 0.05 was used to identify statistically significant differences, and a p-value of $0.05 \leq p < 0.1$ was used to indicate statistical tendencies.

3. Results

The birth weight results are presented in Table 2. Lambs from adult ewes were heavier than those from hoggets ($p < 0.05$). The lambs from the HC group were 19.4% lighter than lambs from AC ewes, while lambs from HM ewes were 19.0% lighter than lambs from AM. The BW of adult ewes was higher than that of hoggets ($p < 0.05$). The MBWP did not differ between treatments or parity ($p > 0.05$). However, a significant treatment × parity interaction was observed ($p = 0.03$). A positive correlation was found between the BW and the birth weight of their lambs (r = 0.52; $p < 0.0001$).

Table 2. Birth weight and litter birth weight of lambs born to Finnish × Polwarth ewes (adults and hoggets) that received dietary $MgSO_4$ (7 g/d) or control (LS-means ± SEM).

	Dietary $MgSO_4$		**Control**		***p*-Value**		
	$AM_{(60)}$	$HM_{(46)}$	$AC_{(48)}$	$HC_{(56)}$	Parity	Treatment	Parity × Treatment
Birth weight (kg)	3.6 ± 0.1 ^{a}	2.9 ± 0.2 ^{ab}	3.6 ± 0.1 ^{a}	2.9 ± 0.1 ^{b}	<0.001	0.46	0.26
Litter birth weight (kg)	7.2 ± 0.2 ^{a}	5.7 ± 0.3 ^{b}	7.3 ± 0.2 ^{a}	6.2 ± 0.2 ^{b}	<0.01	0.48	0.08
MBWP (%)	12.7	9.9	13.0	10.8	0.65	0.12	0.03

BCs = body condition score, BW = body weight at parturition, MBWP = maternal body weight percentage, AM = lambs born to adult ewes receiving dietary $MgSO_4$, HM = lambs born to hoggets receiving dietary $MgSO_4$, AC = lambs born to control adult ewes, HC = lambs born to control hoggets. *p*-values indicate the effects of parity, treatment, and parity × treatment interaction. Differences were considered significant when $p < 0.05$. Different letters indicate a significant difference in the same row.

The results of the parturition process are presented in Table 3. The duration of the expulsion phase was shorter for the second than for the first lamb (birth-order effect, $p < 0.01$). The lambs born from ewes receiving dietary $MgSO_4$ were born faster than the lambs from control ewes ($p < 0.05$). The first lambs from the control ewes took 74 or 69% longer to be born than those from the ewes that received dietary $MgSO_4$ (adults and hoggets, respectively). The second lamb from the control ewes took more than twice as long to be born as those from the dietary $MgSO_4$ ewes. The TL did not differ between treatments ($p > 0.05$). The DII of the second lambs from control ewes took twice as long as the lambs from $MgSO_4$ ewes.

Table 3. Parturition process of Finnish × Polwarth ewes (adults and hoggets) that received dietary $MgSO_4$ (7 g/d) or control (LS-means ± SEM).

		Dietary $MgSO_4$		**Control**		***p*-Value**			
		AM	HM	AC	HC	Parity	Treatment	Parity × Treatment	Birth order
Birth Order	DII First (m)	7.2 ± 1.4	10.0 ± 1.5	12.5 ± 1.4	16.9 ± 1.4	0.26	<0.05	0.29	$p < 0.01$
	DII Second (m)	1.5 ± 1.4	1.4 ± 1.4	3.2 ± 1.4	2.9 ± 1.4				
	IL (m)	8.5 ± 2.1	8.1 ± 2.8	7.9 ± 2.1	6.6 ± 2.3	0.39	0.47	0.12	-
	TL (m)	24.7 ± 1.0	26.3 ± 1.0	32.3 ± 1.0	26.8 ± 1.1	0.51	0.13	0.14	-

DII = duration of the expulsion phase, IL = lambing interval, TL = total lambing: the time between the beginning of the first lambing and the end of the second lambing, AM = lambs born to adult ewes receiving dietary $MgSO_4$, HM = lambs born to hoggets receiving dietary $MgSO_4$, AC = lambs born to control adult ewes, HC = lambs born to control hoggets. For DII variables, *p*-values indicate the effects of parity, treatment, parity × treatment interaction, and birth order. For IL and TL, *p*-values indicate the effects of parity, treatment, and parity × treatment interaction. Differences were considered significant when $p < 0.05$.

The meconium score of lambs did not differ between treatments ($p > 0.05$). However, more lambs in the AC and HC treatments had lower scores than in the AM and HM treatments ($p < 0.05$; Figure 1). A positive correlation was found between the meconium score and the birth weight (r = 0.14, $p < 0.05$).

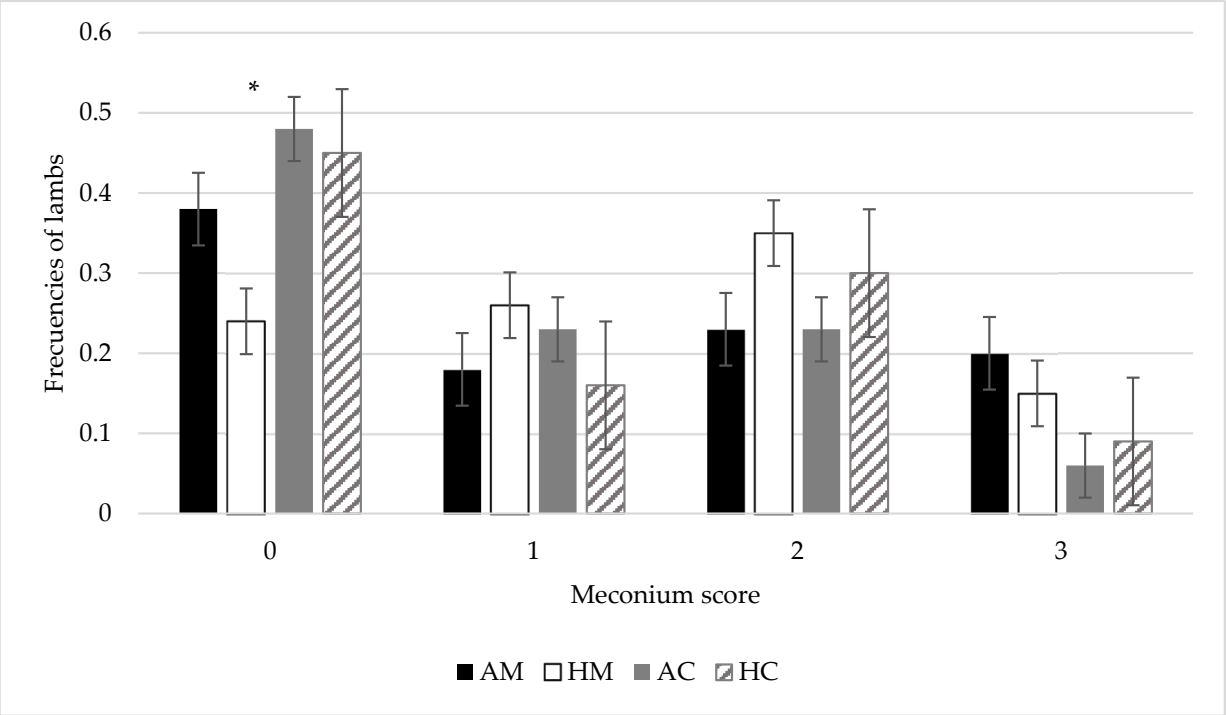


Figure 1. Meconium score of lambs from Finnish × Polwarth ewes (adults and hoggets) that received dietary $MgSO_4$ (7 g/d) or control. AM = lambs born to adult ewes receiving dietary $MgSO_4$, HM = lambs born to hoggets receiving dietary $MgSO_4$, AC = lambs born to control adult ewes, HC = lambs born to control hoggets. (*) $p < 0.05$.

Lamb behavior and rectal temperature are presented in Table 4; TS did not differ between treatments ($p > 0.05$). The lambs from adult ewes had lower TS than the lambs from hoggets ($p < 0.05$). The SS did not differ between treatments ($p = 0.69$), but the parity affected the SS time ($p < 0.05$). Lambs born to adult ewes (AM and AC) had lower SS than those born to hoggets (HM and HC; $p < 0.05$). T0 was not affected by treatment, parity, or their interaction ($p = 0.99$, $p = 0.95$, and $p = 0.23$, respectively). At T3, there was a treatment-by-parity interaction ($p = 0.04$). Among lambs from hoggets, those born to ewes that received dietary $MgSO_4$ had higher T3 than those from HC ewes ($p = 0.01$), whereas no treatment difference was observed among lambs born to adult ewes ($p = 0.85$). The repeated-measures analysis showed that rectal temperature increased from birth to 3 h of life (time effect, $p = 0.0004$). The treatment × time interaction was not significant ($p = 0.273$), indicating that the overall change in temperature over time did not differ between dietary treatments. A treatment × parity interaction was detected for T3 ($p = 0.046$). A positive correlation was found between T3 and birth weight (r = 0.2, $p < 0.01$).

Blood variables are presented in Table 5. The pH did not differ significantly between treatments ($p > 0.05$). The pH had a positive correlation with birth weight (r = 0.24, $p < 0.05$) and a negative correlation with TS (r = −0.2, $p < 0.05$) and glucose concentration (r = −0.23, $p < 0.05$). pCO_2, pO_2, BEecf, HCO_3^-, tCO_2, and saO_2 were not different between treatments ($p > 0.05$). However, BEecf, HCO_3^-, and tCO_2 were affected by parity ($p = 0.04$, $p = 0.02$, and $p = 0.01$, respectively).

Table 4. Behavior and rectal temperatures of lambs from Finnish × Polwarth ewes (adults and hoggets) that received dietary $MgSO_4$ (7 g/ewe/d) or control (LS-means ± SEM).

	Dietary $MgSO_4$		**Control**		***p*-Value**		
	$AM_{(60)}$	$HM_{(46)}$	$AC_{(48)}$	$HC_{(56)}$	Parity	Treatment	Parity × Treatment
TS (m)	28.4 ± 4.6	30.9 ± 5.2	25.8 ± 5.1	43.7 ± 4.8	0.04	0.25	0.62
SS (m)	64.2 ± 5.8	75.4 ± 7.3	61.3 ± 6.1	76.7± 6.0	0.04	0.69	0.72
T0 (°C)	39.3 ± 0.1	39.4 ± 0.1	39.4 ± 0.1	39.3 ± 0.1	0.95	0.99	0.23
T3 (°C)	39.6 ± 0.1 $_a$	39.6 ± 0.1 $_a$	39.4 ± 0.1 $_{ab}$	39.3 ± 0.1 $_b$	0.74	0.08	0.04

TS = time between the lambing and standing on four legs, SS = time between the lambing and the first successful sucking, T0 = rectal temperature at birth, T3 = rectal temperature at 3 h of life, AM = lambs born to adult ewes receiving dietary $MgSO_4$, HM = lambs born to hoggets receiving dietary $MgSO_4$, AC = lambs born to control adult ewes, HC = lambs born to control hoggets. *p*-values indicate the effects of parity, treatment, and parity × treatment interaction. Differences were considered significant when $p < 0.05$. Different letters indicate a significant difference only when there was an interaction between factors.

Table 5. Biochemical and acid–base variables at lambing in lambs from Finnish × Polwarth ewes (adults and hoggets) that received dietary $MgSO_4$ (7 g/ewe/d) or control (LSmeans ± SEM).

	Dietary $MgSO_4$		**Control**		***p*-Value**		
	$AM_{(60)}$	$HM_{(46)}$	$AC_{(48)}$	$HC_{(56)}$	Parity	Treatment	Parity × Treatment
pH	7.32 ± 0.01	7.30 ± 0.01	7.33 ± 0.01	7.36 ± 0.02	0.32	0.86	0.95
pCO_2 (mmHg)	61.2 ± 1.6	61.8 ± 2.0	61.5 ± 1.6	57.9 ± 2.0	0.31	0.47	0.32
pO_2 (mmHg)	9.1 ± 1.1	9.2 ± 1.1	9.4 ± 1.0	6.4 ± 1.1	0.86	0.58	0.83
BEecf (mmol/L)	5.9 ± 0.8	4.4 ± 1.0	7.0 ± 0.8	8.0 ± 1.0	0.04	0.96	0.7
HCO_3^- (mmol/L)	31.8 ± 0.7	30.5 ± 0.9	32.7 ± 0.7	33.0 ± 0.9	0.02	0.68	0.42
tCO_2 (mmol/L)	33.5 ± 1.0	32.1 ± 1.0	34.6 ± 1.0	34.5 ± 1.0	0.01	0.53	0.35
saO_2 (%)	7.4 ± 1.1	7.2 ± 1.2	7.8 ± 1.1	4.7 ± 1.2	0.97	0.64	0.82
Lac (mmol/L)	3.7 ± 0.2	5.1 ± 0.3	3.6 ± 0.2	4.6 ± 0.2	<0.01	0.22	0.46
Glucose (mg/dL)	20.4 ± 2.6	34.0 ± 3.1	22.7 ± 2.7	26.6 ± 3.3	<0.01	0.08	0.17

pH = potential of hydrogen, pCO_2 = carbon dioxide partial pressure, pO_2 = oxygen partial pressure, BEecf = base excess/deficit, HCO_3^- = bicarbonate, saO_2 = oxygen saturation, tCO_2 = total carbon dioxide, AM = lambs born to adult ewes receiving dietary $MgSO_4$, HM = lambs born to hoggets receiving dietary $MgSO_4$, AC = lambs born to control adult ewes, HC = lambs born to control hoggets. *p*-values represent the effects of parity, treatment, and their interaction.

The lactate concentrations were higher in the lambs born to hoggets than in the lambs from adult ewes ($p < 0.05$). Negative correlations were found between the lactate concentration and birth weight ($r = -0.22$; $p < 0.01$) and pH ($r = -0.58$; $p < 0.0001$). Positive correlations were found between lactate concentration and glucose ($r = 0.33$; $p < 0.0001$). The glucose concentrations were higher in the lambs from hoggets than in the lambs from adult ewes ($p < 0.05$). The glucose concentrations were positively correlated with total lambing duration ($r = 0.21$; $p = 0.0037$) and negatively correlated with pH (reported previously), BEecf ($r = -0.26$; $p = 0.0007$), HCO_3^- ($r = -0.21$; $p = 0.005$), and total CO_2 ($r = -0.22$; $p = 0.004$). No significant correlations were observed between glucose concentration and birth weight, duration of lamb expulsion, meconium score, rectal temperature, pCO_2, pO_2, or sO_2 ($p > 0.05$).

4. Discussion

The hypotheses tested were partially supported; the addition of $MgSO_4$ to the diet of ewes improved the parturition process and did not affect lamb behavior or blood variables; however, several blood variables differed by maternal parity. The most relevant finding was the reduction in the lamb expulsion duration of both lambs observed in hogget and adult ewes receiving dietary $MgSO_4$.

The reduction in lamb expulsion duration confirms previous results reported by Ataollahi et al. (2021) [18], who found that mineral supplementation with Ca and Mg to Merino ewes from one month before lambing tended to decrease the lamb expulsion duration. Several factors determine the duration of the lamb expulsion: birth weight, parity, litter size, and breed.

In this study, the inclusion of $MgSO_4$ did not affect lamb birth weight. These results are consistent with Munn et al. (2024) [12], who evaluated an anionic diet by adding $MgSO_4$ to the diets of Merino ewes and found no differences in birth weight. The levels of $MgSO_4$ inclusion were like those used in this study, but the supplementation period was longer. However, a previous experiment reported an improvement in birth weight (0.23 kg) in Finnish x Polwarth adult ewes in the last week of gestation [11]. In the present study, the lambs had a higher birth weight than the control lambs in the previous study (approximately 0.2 kg) [11]. The addition of $MgSO_4$ may affect birth weight when it is administered one week before lambing or in lambs that would otherwise have lower birth weight.

The temperature of the lambs at lambing is equal to the ewe's rectal temperature. In this work, the ewe's rectal temperature was not measured, and the rectal temperature of the lambs was not different at lambing. However, we found that lambs from HC ewes have the lowest T3 values. This temperature difference was statistically significant and less than 0.5 °C, yet it fell within the reference range for newborn lambs (37–39.6 °C) [19]. In our study, the lambs with the lowest T3 were from HC ewes; these were the ones that took the longest to stand up. These findings are consistent with Dwyer et al. (2006) [20], who observed that lambs that were slower to stand had lower rectal temperatures one hour after lambing. However, the rectal temperature of all lambs increased between the time of birth and 3 h; this increase is consistent with the findings of Stafford et al. (2006) [21], who reported a steady rise in rectal temperature in single and twin lambs between birth and 6 h of life.

The dietary inclusion of $MgSO_4$ in the ewes did not affect the lamb's mean pH; the means of the treatments were in the physiological range reported [22,23] at lambing. However, only control lambs (AC and HC treatments) had acidosis (defined as pH $\leq$ 7.20 [24]): 7.7% of the HC lambs and 2.0% of the AC lambs. In our work, the acidemic lambs were second in birth order, and, in addition to low pH, they had high pCO2, reduced BEecf, low pO2, and the concentrations of lactate were double those of the normal AC lambs (8.8 $\pm$ 2.6 vs. 4.6 $\pm$ 0.2 mmol/L, acidotic and normal lambs, respectively). Interestingly, acidosis only occurred in lambs from control ewes; this may be explained by the fact that the control lambs have a longer DII, spend more time in the birth canal, and have a reduced oxygen supply due to umbilical cord occlusion.

Both glucose and lactate are energy substrates for the ovine fetus. In our work, lambs from hoggets had higher concentrations of glucose and lactate compared with the lambs from adult ewes. At the time of lambing, the lactate concentrations in the lambs' blood were the same as those in the placenta but higher than those in maternal blood [25]. However, these authors did not specify whether the lambs in their experiment had difficulties at birth or had a normal delivery. Westgate et al. (2002) [26] found no difference in lactate concentration after inducing in utero hypoxia in lambs before birth; similarly, in our study,

lactate concentration was not related to the meconium score. In fetal arterial blood, a negative correlation between oxygen and lactate concentrations was reported [27]. Our work did not find this correlation, but the blood sample was taken from the jugular vein immediately after lambing.

Lambs with acidemia or hypoxia at birth may indicate that these lambs were born in distressed conditions. However, in our study, the meconium score for these lambs was $\leq$1. These findings suggest that the meconium score was ineffective as a distress indicator, as described by Westgate et al. (2002) [26], who induced hypoxia in preterm lambs and reported that the meconium score was inadequate for measuring fetal distress. In addition, more lambs from HC ewes (higher lactate and glucose) had lower meconium scores than those from the AM and HM treatments. This finding was unclear, but correlations between birth weight, litter birth weight, and the meconium score may explain it.

The blood glucose concentrations in newborn lambs are low and increase within the first 24 h of life [8]. In all groups, the concentrations were lower than those reported by other authors [6]. Hypoxia in the last days of gestation increased fetal blood glucose concentration and accompanied an increase in lactate concentration [28]. This finding was supported by Gardner et al. (2002) [22], who reported increases in blood glucose and lactate levels at 15 or 45 min after a hypoxic event; in our work, the lambs that had both conditions were the HC and HM lambs. These conditions did not affect behavior, but they did affect T3.

The behavioral variables (time to stand and time to first suck) did not differ between treatments, in agreement with the previous report [11]. However, parity affected both variables: lambs from hogget (HM and HC treatments) took longer to stand up and suck than lambs from adult ewes, regardless of maternal diet. This is consistent with Dwyer et al. (2003) [29], who reported that seek-under, suck attempt, and suck durations decrease as maternal parity increases. However, since the observed differences may be attributable to the ewe's age, they cannot be attributed entirely to the lambs, as maternal behavior and experience may be a key factor in these variables.

Time to stand varies widely across reports and breeds; lambs from primiparous Corriedale ewes took 10 min longer to stand than those in our experiment [4]. Other studies have reported that the twin lambs (Finnish $\times$ Rhamani) stood up at 12 min, which is half the time it took our lambs [30]. The lamb behavior was not altered by the addition of $MgSO_4$ to the dam. An interesting finding is the positive correlation between TS and the lactate concentrations; hence, the lambs with higher lactate concentrations stood later; however, no difference in SS was found.

5. Conclusions

In conclusion, in our conditions, the addition of $MgSO_4$ to the diet of twin-bearing ewes in late gestation reduces the expulsion phase of the lambs. The treatment does not alter blood variables or affect the behavior of newborn lambs.

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