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Late-gestation feed restriction reduces colostrum quality and lamb birth weight in Awassi ewes under semi-arid conditions

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Research Article

Keywords: Awassi sheep, Feed restriction, Late gestation, Negative energy balance, ketosis, Colostrum quality, Lamb birth weight

Posted Date: July 1st, 2026

DOI: https://doi.org/10.21203/rs.3.rs-10105491/v1

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Abstract

Awassi sheep are the dominant indigenous breed across Iraq, raised largely in semi-arid systems where feed shortage during late gestation is common, yet its consequences for the metabolism and productivity of Awassi ewes have seldom been quantified under field conditions. Eighty multiparous ewes near Najaf, Iraq, were allocated to receive either 60% or 100% of estimated requirements during the final two weeks of gestation and were monitored through lambing for blood metabolites, colostrum quality, and lamb birth weight. Restriction induced pronounced negative energy balance: β-hydroxybutyric acid and non-esterified fatty acids were markedly elevated in restricted ewes (both $P < 0.001$), and the majority exceeded the subclinical-ketosis threshold from one week before lambing onward, whereas controls did not. Colostrum quality was likewise reduced under restriction (Brix 19.77 vs 22.27%; $P < 0.001$), but this reduction was not uniform across litter types. It was concentrated in twin-bearing ewes, which produced the lowest-quality colostrum when restricted, whereas under full feeding twin- and single-bearing ewes did not differ. Lambs from restricted ewes were lighter irrespective of litter size. These findings indicate that adequate late-gestation nutrition preserves colostrum quality specifically in twin-bearing ewes and support targeted supplementation of such animals as a practical management priority in low-input, semi-arid production systems.

Introduction

Awassi sheep are the predominant indigenous breed in Iraq, where they are raised under low-input, semi-extensive systems characterized by seasonal feed scarcity and high ambient temperatures (Saeed et al., 2023). Fetal growth accelerates during the last 40 to 50 days of pregnancy (periparturient period), substantially raising maternal requirements for net energy and glucose (Plante-Dubé, Létourneau-Montminy, et al., 2025). When feed intake fails to meet these elevated demands, energy deficit predominates and ewes enter a state of negative energy balance (NEB) (Fiore et al., 2021).

Under NEB, adipose tissue is mobilized and non-esterified fatty acids (NEFA) are released into circulation (Lisuzzo et al., 2022). NEFA concentrations are particularly informative for monitoring energy status in late gestation, when rapid fluctuations in energy balance may not yet be reflected in body condition (Plante-Dubé, Bourassa, et al., 2025). The magnitude of NEFA elevation reflects the severity of metabolic imbalance and the degree of lipolysis required to meet the combined energy demands of the ewe and her conceptus (Pesántez-Pacheco et al., 2019). Hepatic oxidation of NEFA generates ketone bodies, principally β-hydroxybutyric acid (BHBA), the main clinical marker of ketosis and pregnancy toxemia in small ruminants (Araújo et al., 2020). BHBA threshold above 0.8 mmol/L is widely used to identify ewes at risk of subclinical ketosis or pregnancy toxemia (Souto et al., 2019). Pregnancy toxemia carries high case-fatality rates and is most prevalent in ewes carrying multiple fetuses under nutritional restriction (Ji et al., 2023).

The consequences of periparturient NEB extend beyond maternal health. Maternal undernutrition in late gestation can reduce colostrum quality and immunoglobulin concentration available to the neonate,

although reported effects vary across studies (Tillquist et al., 2025). Sustained NEFA elevation has been linked to hepatic lipidosis and fatty liver syndrome (Kang et al., 2025) as well as impaired immune function (Li et al., 2025). Lamb birth weight and neonatal survival are directly linked to maternal nutritional plane during gestation (Roca Fraga et al., 2018). In semi-arid systems with limited veterinary intervention and supplementary feeding, poor neonatal vigor represents a major source of economic loss(Santos et al., 2023).

Despite the recognized importance of periparturient nutrition, controlled studies documenting metabolic profiles and productive outcomes in Awassi ewes under field conditions in semi-arid Iraq remain scarce. Much of the available metabolic-profiling evidence derives from intensive dairy cattle systems (Mondal et al., 2026), and breed-specific data for Awassi under arid conditions are limited (Hassan, 2025). We hypothesized that ewes restricted to 60% of estimated nutrient requirements during the final two weeks of gestation would (i) develop greater periparturient NEB, indexed by elevated BHBA and NEFA (primary outcomes), and (ii) produce lower-quality colostrum and lighter lambs (secondary outcomes). We further hypothesized that twin-bearing ewes would be more metabolically compromised than singleton-bearing ewes, irrespective of feeding level. In addition, we quantified the relationship between metabolic status at lambing and colostrum quality and monitored lamb survival to Day + 14.

Materials and methods

Study location and production system

The study was conducted on a sheep farm in the Bahr Al-Najaf depression (approximately 31°58' N, 44°12' E; ~11 m above sea level), Najaf Governorate, Iraq, between December 2024 and May 2025; the area has a hyper-arid desert climate with mean annual temperature 25°C (summer up to 48°C), annual relative humidity ranging from 20% in summer to 64% in winter, annual rainfall of 134 mm.

Animals and experimental design

Eighty clinically healthy multiparous Awassi ewes in late gestation were enrolled. Ewes were stratified by parity and litter type (singleton vs. twin-bearing) and randomly assigned within divisions to one of two feeding groups using a random-number allocation procedure: a restricted group fed 60% of estimated requirements (R60; n = 40) or a fully supplemented control group fed 100% of estimated requirements (C100; n = 40). Each group contained 20 singleton-bearing and 20 twin-bearing ewes. Litter type was determined at enrollment by transabdominal B-mode ultrasonography performed by a single experienced veterinarian at approximately Day 50 of gestation. Parity ranged from 1 to 4 and the distribution was balanced between groups. Animals were individually identified by ear tag and managed in adjacent pens within the same housing unit, with separate feeding stations to permit individual feed-intake recording. The veterinarian performing body condition scoring and the laboratory analysts handling blood and

colostrum samples were blinded to group allocation; body condition scoring was performed without access to laboratory results or treatment records.

Feeding treatments

Estimated requirements for metabolizable energy and crude protein in late gestation were calculated for each ewe based on body weight and litter type according to NRC (2007) guidelines for small ruminants. The C100 group received a total mixed ration formulated to meet these requirements; the R60 group received the same ration in 60% of the daily amount, which proportionally reduced energy, crude protein, and mineral intakes by approximately 40%. The primary intent of the design was to manipulate energy supply, but the effects reported below should therefore be understood as effects of overall feed restriction with energy as the dominant factor, rather than as effects of isolated energy restriction. The ration was offered as two intermittent meals per day and comprised barley grain (30%), maize (20%), wheat bran (28%), soybean meal (20%), table salt (1%), and a limestone–digestive premix (1%) on an as-fed basis. Feed offered and refusals were weighed daily for each individual ewe; daily as-fed intake (kg/day) was calculated as offered minus refusals. Clean water was available ad libitum throughout the experimental period.

Sampling and measurements

Blood samples were collected at four timepoints relative to expected lambing: Day − 14, Day − 7, Day 0 (within 4 h of parturition), and Day + 7. Samples were drawn from the jugular vein into 10-mL plain vacutainer tubes, allowed to clot at room temperature for 30 min, centrifuged at 3000 × g for 15 min, and serum was aliquoted and stored at − 20°C until analysis. Serum BHBA and NEFA were measured using the Randox D-3-Hydroxybutyrate (Ketone) assay and the Randox NEFA assay, respectively (Randox Laboratories, Crumlin, UK); glucose, total protein, albumin, blood urea nitrogen (BUN), calcium, phosphorus, aspartate aminotransferase (AST), alanine aminotransferase (ALT), gamma-glutamyl transferase (GGT), triglycerides, and cholesterol were measured on a Roche Cobas c111 analyzer (Roche Diagnostics, Mannheim, Germany) using commercially available kits.

Body weight (kg) was recorded at each timepoint using a calibrated digital platform scale. BCS was assessed on a 1–5 scale in 0.25-unit increments by a single trained veterinarian. Colostrum was collected from each ewe within 2 h after the first nursing event by hand-milking a single ~ 5-mL sample from one half-udder into a sterile tube; one Brix reading per sample was taken using a digital refractometer (Atago PAL-1, Atago Co., Tokyo, Japan), an accepted refractometric proxy for ovine colostrum immunoglobulin G concentration (Hamer et al., 2023; Sarica and Aydoğdu, 2024). Lamb birth weight was recorded within 1 h of parturition using a calibrated digital scale. Lamb survival was monitored through Day + 14 post-partum and recorded at the litter level as a binary outcome.

Statistical analysis

All analyses were performed in R version 4.5.2 (R Core Team 2025). The pre-specified primary outcomes were serum BHBA, NEFA, colostrum Brix, and lamb birth weight; remaining variables were treated as exploratory.

Serially measured blood analytes, body weight, and BCS were analyzed by linear mixed models with ewe as a random effect to account for repeated measures. Two models were fitted for each variable: one testing feeding group, timepoint, and their interaction, and one testing litter type, timepoint, and their interaction; both included parity as a covariate, and the litter-type model additionally adjusted for feeding group. Model assumptions were assessed from residual and quantile–quantile plots, and right-skewed analytes were log-transformed before fitting. Where a significant interaction was detected, pairwise comparisons were made on estimated marginal means with Bonferroni adjustment (Supplementary Tables 2a, 2b).

Colostrum Brix, measured once per ewe, was analyzed by two-way ANOVA testing feeding group, litter type, and their interaction. Lamb birth weight, recorded as one value per ewe, was compared between feeding groups within each litter type using the Mann–Whitney U test. The proportion of ewes exceeding the subclinical-ketosis threshold (BHBA ≥ 0.8 mmol/L) and the proportion of litters surviving to Day + 14 were compared between groups by Fisher's exact test. Associations between colostrum Brix and blood analytes at lambing were assessed by Spearman rank correlation. Significance was set at $P \leq 0.05$.

Results

Effect of feeding level on the blood metabolic profile and production traits

Feed intake was lower in R60 than C100 (0.77 vs 1.24 kg/day; $P < 0.001$). Results of the linear mixed model for feeding level are summarized in Table 1 with temporal profiles of the main energy markers shown in Fig. 1.

Table 1
Effect of feeding level on the blood metabolic profile of periparturient Awassi ewes

Variable	R60	C100	SEM	p-Group
BHBA (mmol/L)	0.89	0.81	0.02	**< 0.001**
NEFA (mmol/L)	0.83	0.65	0.03	**< 0.001**
Glucose (mg/dL)	55.63	56.92	1.26	0.289
Total protein (g/dL)	7.20	7.18	0.07	0.674
Albumin (g/dL)	3.14	3.26	0.07	**0.008**
BUN (mg/dL)	23.31	25.04	0.92	**0.005**
Calcium (mg/dL)	10.44	10.62	0.14	**0.032**
Phosphorus (mg/dL)	6.07	5.97	0.15	0.200
AST (U/L)	93.89	93.42	2.06	0.699
ALT (U/L)	26.05	29.98	1.24	**< 0.001**
GGT (U/L)	39.05	39.73	1.49	0.615
Triglycerides (mg/dL)	24.86	24.97	1.36	0.884
Cholesterol (mg/dL)	69.10	65.24	1.75	**0.002**

Values are overall means. SEM = pooled standard error of the mean. p-Group = main effect of feeding level. Bold = p < 0.05.

R60 ewes had higher overall BHBA (0.89 vs 0.81 mmol/L; P < 0.001) and NEFA (0.83 vs 0.65 mmol/L; P < 0.001) than C100, with significant group × timepoint interactions (BHBA, P = 0.007; NEFA, P < 0.001). In R60, BHBA rose from 0.75 ± 0.03 mmol/L at Day − 14 to 0.96 ± 0.03 at Day − 7, was 0.97 ± 0.03 at lambing, and 0.88 ± 0.02 at Day + 7. In C100, BHBA peaked at lambing (0.87 ± 0.01) and was 0.77 ± 0.03 at Day + 7. The groups did not differ at Day − 14 (P = 0.936) but differed at Day − 7, lambing, and Day + 7 (all P ≤ 0.003). NEFA at Day − 14 was similar (R60 0.55 ± 0.02; C100 0.58 ± 0.02); R60 peaked at lambing (0.98 ± 0.04) versus 0.72 ± 0.02 in C100, and the groups differed at all timepoints after Day − 14 (P < 0.001).

Among the remaining analytes, BUN, calcium, and ALT were higher in C100, albumin was lower in R60, and cholesterol was higher in R60 (Table 1); glucose, total protein, phosphorus, AST, GGT, and triglycerides did not differ between groups. Significant group × timepoint interactions were detected for BUN (P = 0.002) and cholesterol (P = 0.017). AST, ALT, and GGT increased over time (P < 0.001) without a significant group × timepoint interaction. Body weight and BCS did not differ between groups (BCS, P = 0.050).

Prevalence of subclinical-ketosis risk

The proportion of ewes with BHBA ≥ 0.8 mmol/L is shown in Supplementary Table 3. Groups did not differ at Day − 14 (R60 35.0% vs C100 32.5%) but differed at Day − 7 (85.0% vs 50.0%). At lambing the proportions did not differ (82.5% vs 77.5%). At Day + 7 they differed (80.0% vs 40.0%;).

Effect of litter type on the blood metabolic profile and production traits

Results of the litter-type model are presented in Table 2 (Fig. 2). Twin-bearing ewes had higher BHBA (0.90 vs 0.81 mmol/L; P < 0.001) and NEFA (0.80 vs 0.70 mmol/L; P < 0.001) than singleton-bearing ewes, with timepoint means (Supplementary Tables 1a, 1b). Twin-bearing ewes also had higher BUN and phosphorus, and lower glucose and cholesterol (Table 2); total protein, albumin, calcium, AST, ALT, GGT, and triglycerides did not differ by litter type. Significant litter × timepoint interactions were detected for glucose (P = 0.003), albumin (P = 0.002), GGT (P = 0.021), triglycerides (P = 0.018), and cholesterol (P = 0.001).

Table 2
Effect of litter type on the blood metabolic profile of periparturient Awassi ewes

Variable	Singleton	Twin-bearing	SEM	p-Litter
BHBA (mmol/L)	0.81	0.90	0.03	**< 0.001**
NEFA (mmol/L)	0.70	0.80	0.03	**< 0.001**
Glucose (mg/dL)	57.29	54.91	1.28	**0.015**
Total protein (g/dL)	7.19	7.19	0.07	0.978
Albumin (g/dL)	3.21	3.19	0.07	0.446
BUN (mg/dL)	23.45	25.17	0.94	**0.013**
Calcium (mg/dL)	10.57	10.48	0.15	0.213
Phosphorus (mg/dL)	5.95	6.12	0.15	**0.044**
AST (U/L)	92.97	94.58	2.03	0.226
ALT (U/L)	28.07	27.93	1.29	0.662
GGT (U/L)	38.98	39.93	1.49	0.209
Triglycerides (mg/dL)	24.90	24.94	1.36	0.880
Cholesterol (mg/dL)	69.72	63.71	1.74	**< 0.001**

Values are arithmetic means across all four sampled timepoints. SEM = pooled standard error of the mean. p-Litter = main effect of litter type from a linear mixed model. Bold = p < 0.05. Abbreviations as in Table 1.

Lamb birth weight and survival

Lamb birth weight is shown in Table 3. Lambs from C100 were heavier than those from R60 within both litter types (singletons 4.20 ± 0.29 vs 3.80 ± 0.23 kg, P < 0.001; twins 3.68 ± 0.19 vs 3.40 ± 0.27 kg, P = 0.002). Singletons were heavier than twins (P < 0.001). Lamb survival to Day + 14 was 80.0% (32/40) in R60 and 90.0% (36/40) in C100 (P = 0.348).

Table 3
Lamb birth weight (kg) by litter type and feeding group (Mean ± SD)

Litter type	R60	C100	p-value
Singleton	3.80 ± 0.23	4.20 ± 0.29	< 0.001
Twin-bearing	3.40 ± 0.27	3.68 ± 0.19	< 0.05

p-value: effect of feeding group within litter type (Mann-Whitney U test). Birth weight recorded as one value per ewe. Overall singleton vs. twin-bearing: p < 0.001.

Colostrum quality

Colostrum quality is presented in Table 4/Fig. 3. C100 had higher Brix than R60 (22.27 ± 2.22 vs 19.77 ± 2.91%; P < 0.001). There was no main effect of litter type (P = 0.254); the group × litter interaction was significant (P = 0.008). Within R60, twin-bearing ewes had lower Brix than singleton-bearing ewes (18.45 vs 20.65%); within C100, the two did not differ (22.74 vs 21.88%).

Table 4
Colostrum quality (Brix %) by feeding group and litter type (Mean ± SD)

Feeding group	Singleton	Twin-bearing
R60	20.65 ± 2.83	18.45 ± 2.57
C100	21.88 ± 2.65	22.74 ± 1.50

Two-way ANOVA: p-Group < 0.001; p-Litter = 0.254; p-Interaction = 0.008. Overall: R60 = 19.77 ± 2.91 Brix %; C100 = 22.27 ± 2.22 Brix %.

Correlations between colostrum quality and blood parameters at lambing

Correlations are shown in Table 5. NEFA at lambing was negatively correlated with colostrum Brix (rho = − 0.305; P = 0.006), and glucose at lambing was positively correlated (rho = 0.246; P = 0.028). BHBA (rho = 0.016; P = 0.885) and BCS (rho = 0.147; P = 0.192) were not significantly correlated. The full correlation matrix among blood parameters at lambing is shown in Supplementary Fig. 4.

Table 5
Pearson correlations between colostrum quality (Brix %) and blood parameters at lambing

Variable at lambing	rho	p-value
BHBA at lambing	0.016	0.885
NEFA at lambing	-0.305	**0.006**
BCS at lambing	0.147	0.192
Glucose at lambing	0.246	**0.028**

Spearman rank correlation coefficient (rho). Bold = p < 0.05

Discussion

This study demonstrates that restricting overall feed supply to 60% of estimated requirements during the final two weeks of gestation substantially worsens the metabolic status of periparturient Awassi ewes relative to full supplementation. The elevated BHBA and NEFA concentrations in R60, together with the higher prevalence of subclinical ketosis risk, confirm pronounced NEB in late-gestation Awassi ewes under semi-arid conditions (Plante-Dubé, Létourneau-Montminy, et al., 2025). The decline in colostrum quality fell most heavily on twin-bearing ewes, while adequate feeding removed it.The overall BHBA concentration in R60 (0.89 mmol/L) exceeded the subclinical-ketosis threshold of 0.8 mmol/L(Simões et al., 2021).

A week from parturition, 85% of R60 ewes surpassed this threshold versus 50% in C100. At lambing the difference narrowed, as most ewes in both groups were above 0.8 mmol/L by parturition although mean BHBA remained higher in R60, and re-emerged at Day + 7 (80.0% vs 40.0%). These proportions are consistent with metabolic profiles in Awassi ewes affected by pregnancy toxemia in Iraq (Khames Mustafa et al., 2023) and with the greater risk of twin-bearing animals under restriction (Turín et al., 2023).

The group × timepoint interactions for BHBA and NEFA in R60, NEFA continued to increase throughout lambing and remained elevated at Day + 7, suggesting that lipid mobilization continued into the postpartum period and that the metabolic debt of late gestation was not resolved at parturition(Velasquez-Munoz et al., 2023). Sustained elevation of NEFA has been associated with hepatic lipidosis (McFadden, 2020) and impaired immune function (Zubieta et al., 2021), and the increase in NEFA precedes that in BHBA, along the expected pathway from adipose mobilization to hepatic ketogenesis during NEB (Fan et al., 2024).

Twin-bearing ewes had higher BHBA and NEFA concentrations than singleton-bearing ewes, in line with the increased energetic requirements of multiple fetuses (Chen et al., 2024). This supports their greater susceptibility to NEB and pregnancy toxemia and advocates for the early identification and preferential supplementation of twin-bearing ewes in the final trimester (Dwyer et al., 2016).

Total protein remained within reference ranges in both groups, consistent with periparturient restriction acting primarily on energy and lipid metabolism rather than circulating protein status (Glembová et al., 2025). Glucose declined across timepoints in both groups without a group difference, consistent with the high glucose demands of the uteroplacental unit in late gestation overriding nutritional effects on circulating glucose (Trotta et al., 2023). BCS also declined in both groups with the advancing demands of late gestation and early lactation (Supplementary Fig. 2). In fat-tailed breeds such as Awassi, a substantial proportion of body energy is stored in the tail, so BCS reflects overall reserves only partially and is best interpreted alongside biochemical markers (Yagoubi et al., 2024).

Liver enzyme activities (AST, ALT, GGT) increased over the study period in both groups ($P < 0.001$; Supplementary Fig. 1). These increases were parallel across feeding groups, with no significant interaction between groups across time, and the only group difference was a higher overall ALT in C100. The postpartum rise therefore reflects normal periparturient and early-lactation pattern rather than restriction-induced hepatic injury. Circulating minerals nevertheless remained within acceptable ranges (Supplementary Fig. 3), implying that restriction worked predominantly on energy and lipid metabolism rather than mineral homeostasis (Ahmed et al., 2021).

Reported effects of late-gestation nutrition on colostrum quality are inconsistent, ranging from clear reductions under restriction to minimal effects (Tillquist et al., 2025). Colostrum Brix mean in R60 group fell below typical values, while C100 sat marginally above (Sarica and Aydoğdu, 2024). The significant interaction between group and litter (p-value < 0.05) showed that twin-bearing ewes produced the poorest colostrum under restriction, which indicate that adequate late-gestation feeding offsets the colostrum disadvantage of carrying twins.

NEFA at lambing was modestly negatively correlated with colostrum Brix (rho = − 0.305 Fig. 4) and glucose positively (rho = 0.246). Both associations point the same way poorer energy status tracking lower colostrum quality consistent with transition-cow reports linking NEB to declining immunoglobulin (Yang et al., 2022) and with the responsiveness of ewe colostrum to late-gestation nutrition (Castellaro et al., 2022). Excessive fat mobilization may alter mammary nutrient partitioning and hepatic function (McFadden, 2020). Lamb birth weight was higher in C100 for both litter types (Table 3), by approximately 400 g in singletons and 280 g in twins, increments associated with improved early survival and growth under rangeland conditions (Dwyer et al., 2016).

From a practical perspective, these results support strategic supplementation of late-gestation Awassi ewes during the final 2–3 weeks of gestation, particularly twin-bearing animals, as a feasible intervention for smallholder semi-arid production systems. The present study has several limitations. It was conducted at a single farm during one breeding season, limiting generalizability across regions, climates, and management systems. The design proportionally restricted total feed, so energy, protein, and mineral intakes fell in parallel and the findings reflect overall restriction with energy dominant rather than isolated energy restriction. Colostrum quality was assessed by Brix as a proxy for IgG without lamb serum IgG measurement.

Conclusion

Restricting late-gestation Awassi ewes to 60% of requirements induced pronounced negative energy balance, raising BHBA and NEFA, increasing the prevalence of subclinical ketosis risk, and lowering both colostrum quality and lamb birth weight relative to full feeding, with lipid mobilization persisting into early lactation. The effect on colostrum was concentrated in twin-bearing ewes and was abolished by adequate feeding, indicating that sufficient late-gestation nutrition can offset the colostrum disadvantage of carrying twins. These findings support strategic supplementation over the final 2–3 weeks of gestation, prioritizing twin-bearing ewes, as a practical intervention for low-input, semi-arid sheep systems.

Declarations

Acknowledgements

The authors thank the staff of the host farm in Najaf Governorate for providing access to animals and facilities, and the staff of the diagnostic laboratory at both Najaf veterinary hospital and the College of Medical Technology, The Islamic University, Najaf, for assistance with blood biochemistry analysis.

Ethical statement

Ethical approval was obtained from the Institutional Animal Care Committee of The Islamic University, Najaf, Iraq (permit number 38, dated 13 December 2024).

Funding

The authors did not receive support from any organization for the submitted work.

Competing interests

The authors declare no competing interests.

Author contributions

A.S.W.: conceptualization, data curation, formal analysis, investigation, visualization, methodology, validation, writing original draft preparation, writing review and editing; J.P.: methodology, writing and editing; R.K.: conceptualization, supervision, acquisition, resources, validation, data curation, formal analysis, writing review and editing. All authors have read and agreed to the published version of the manuscript.

Data availability

The datasets analyzed during the current study are available from the corresponding author on reasonable request.

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Figures

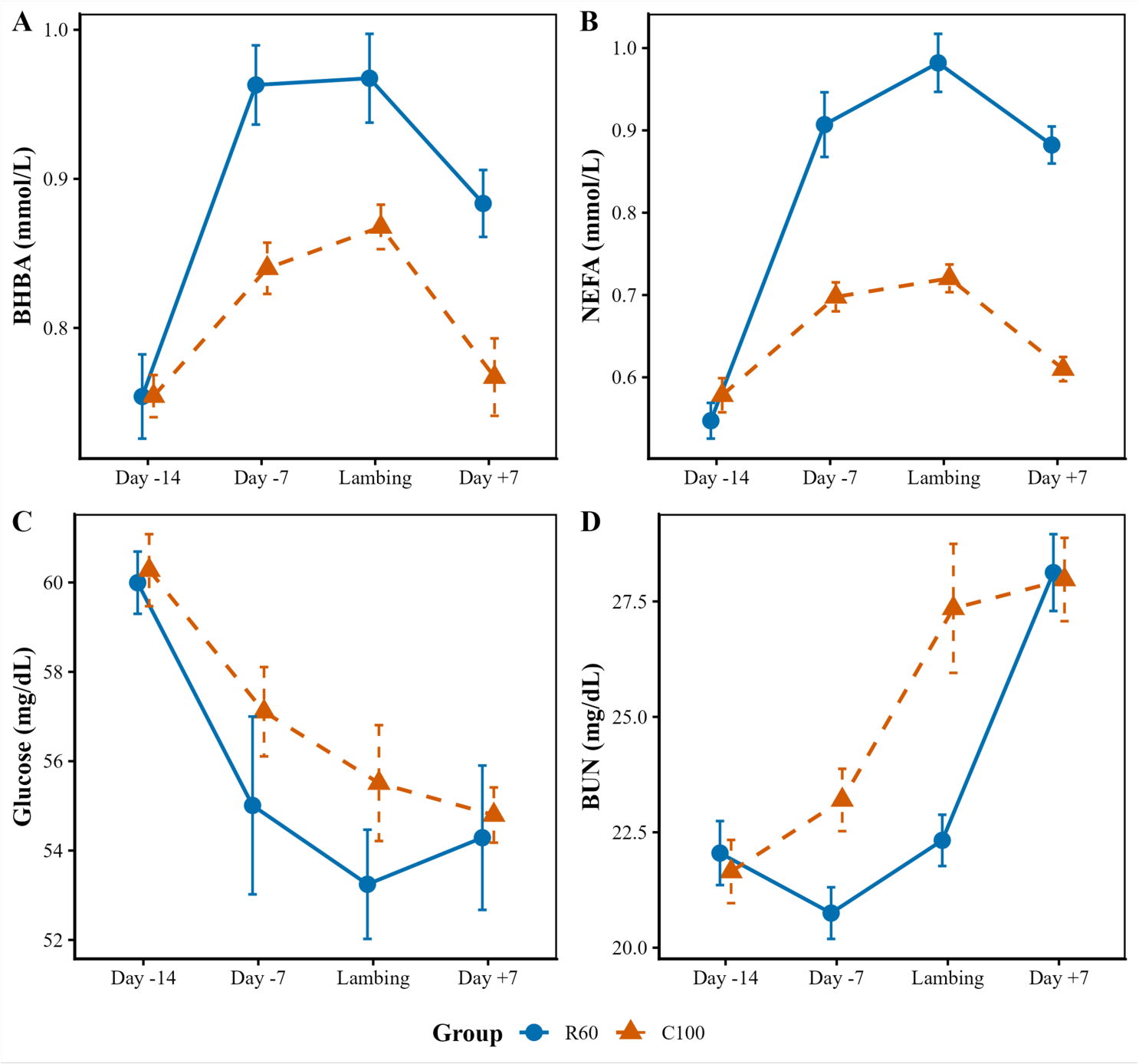


Figure 1

Blood energy and metabolic markers by feeding group across four periparturient timepoints (Day −14, Day −7, Lambing, Day +7). Values are arithmetic means ± standard error of the mean (SE); n = 40 ewes per group at each timepoint. (a) β-hydroxybutyric acid (BHBA, mmol/L); (b) non-esterified fatty acids (NEFA, mmol/L); (c) glucose (mg/dL); (d) blood urea nitrogen (BUN, mg/dL). Solid circles and solid lines: R60. Triangles and dashed lines: C100.

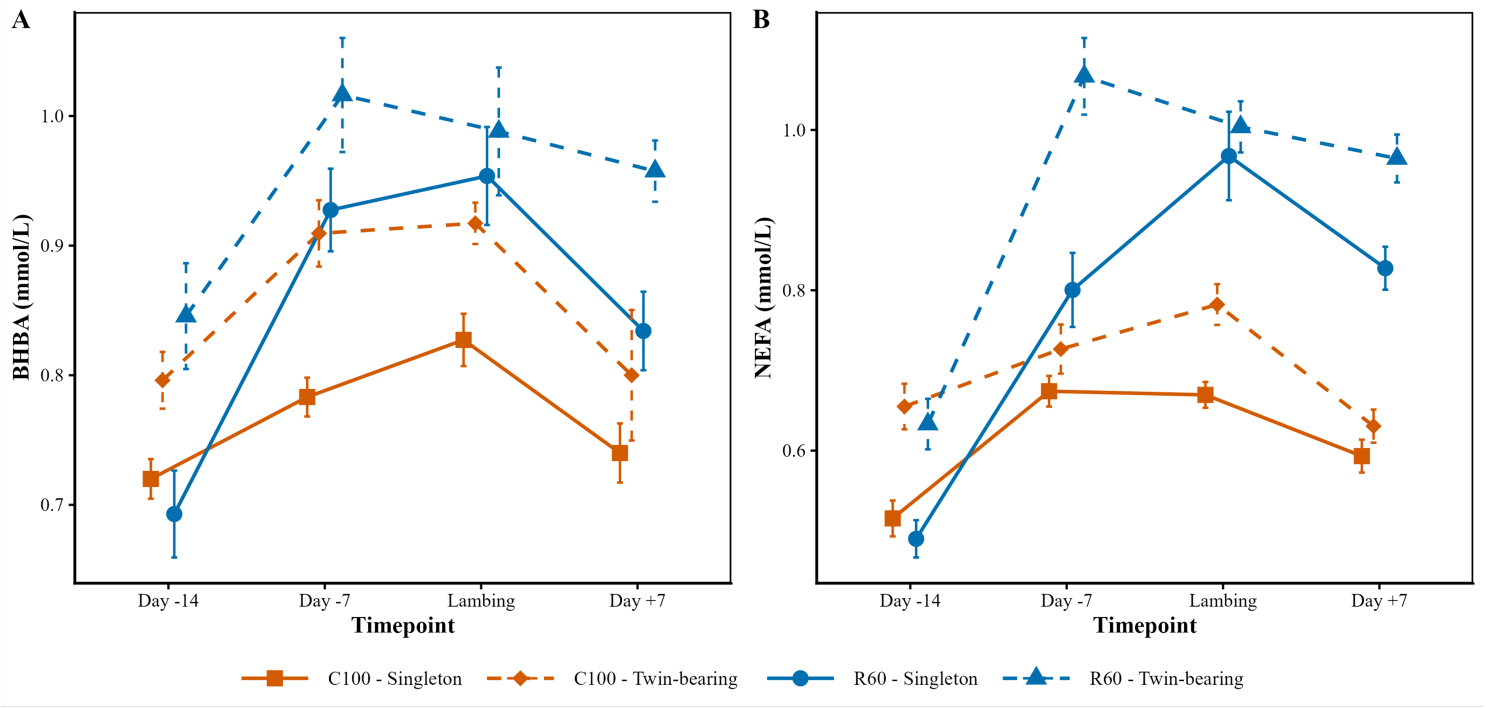


Figure 2

BHBA (mmol/L) and NEFA (mmol/L) by feeding group and litter type across four periparturient timepoints. Values are arithmetic means ± SE; n = 20 ewes per group × litter cell at each timepoint. (a) BHBA; (b) NEFA. Grey squares and solid lines: C100 – Singleton; grey diamonds and dashed lines: C100 – Twin-bearing; black circles and solid lines: R60 – Singleton; black triangles and dashed lines: R60 – Twin-bearing.

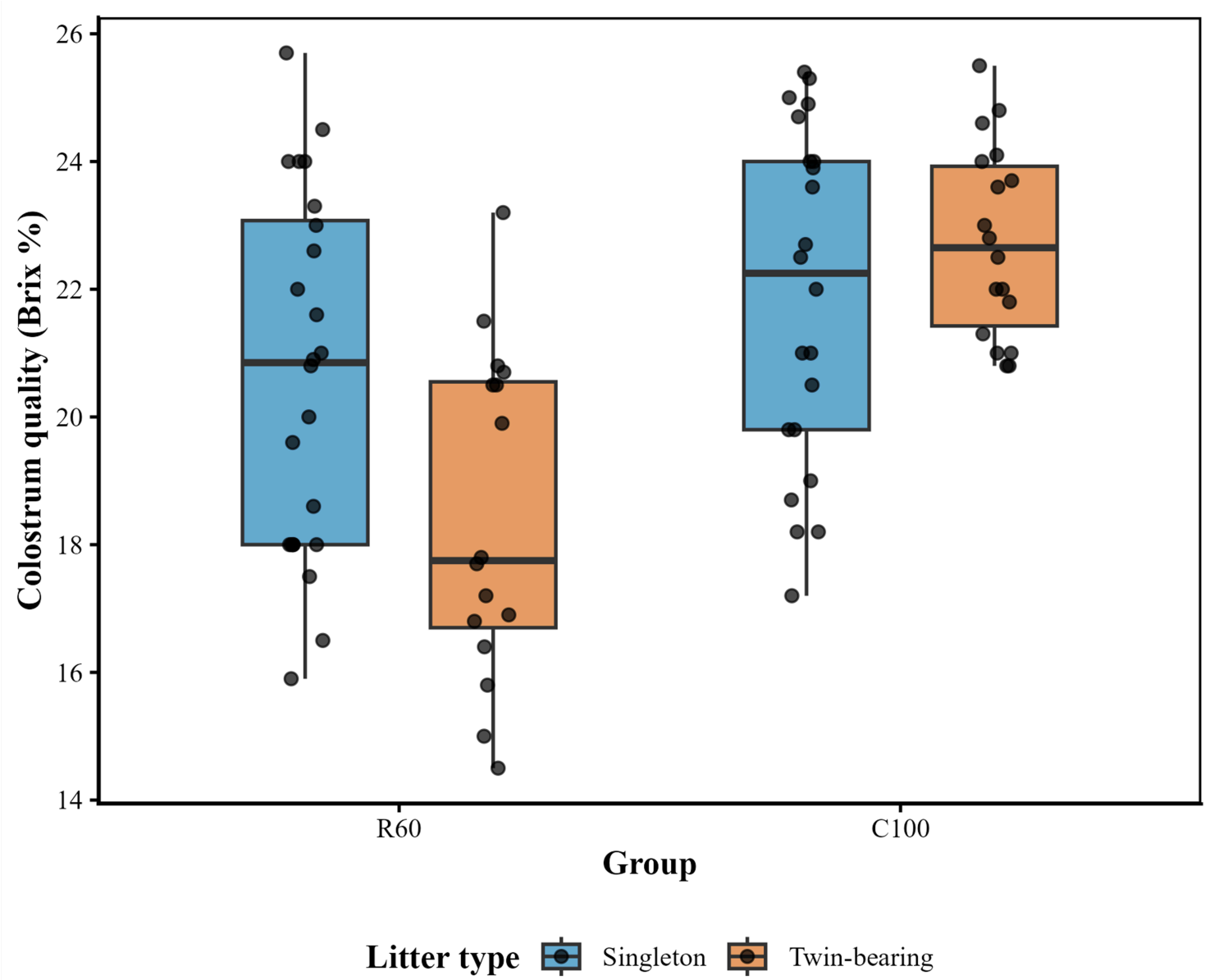


Figure 3

Colostrum quality (Brix %) by feeding group and litter type at lambing. Box-and-whisker plots with individual data points overlaid; n = 20 ewes per group × litter cell. White boxes: Singleton; grey boxes: Twin-bearing. Box: median and interquartile range; whiskers: 1.5 × IQR.

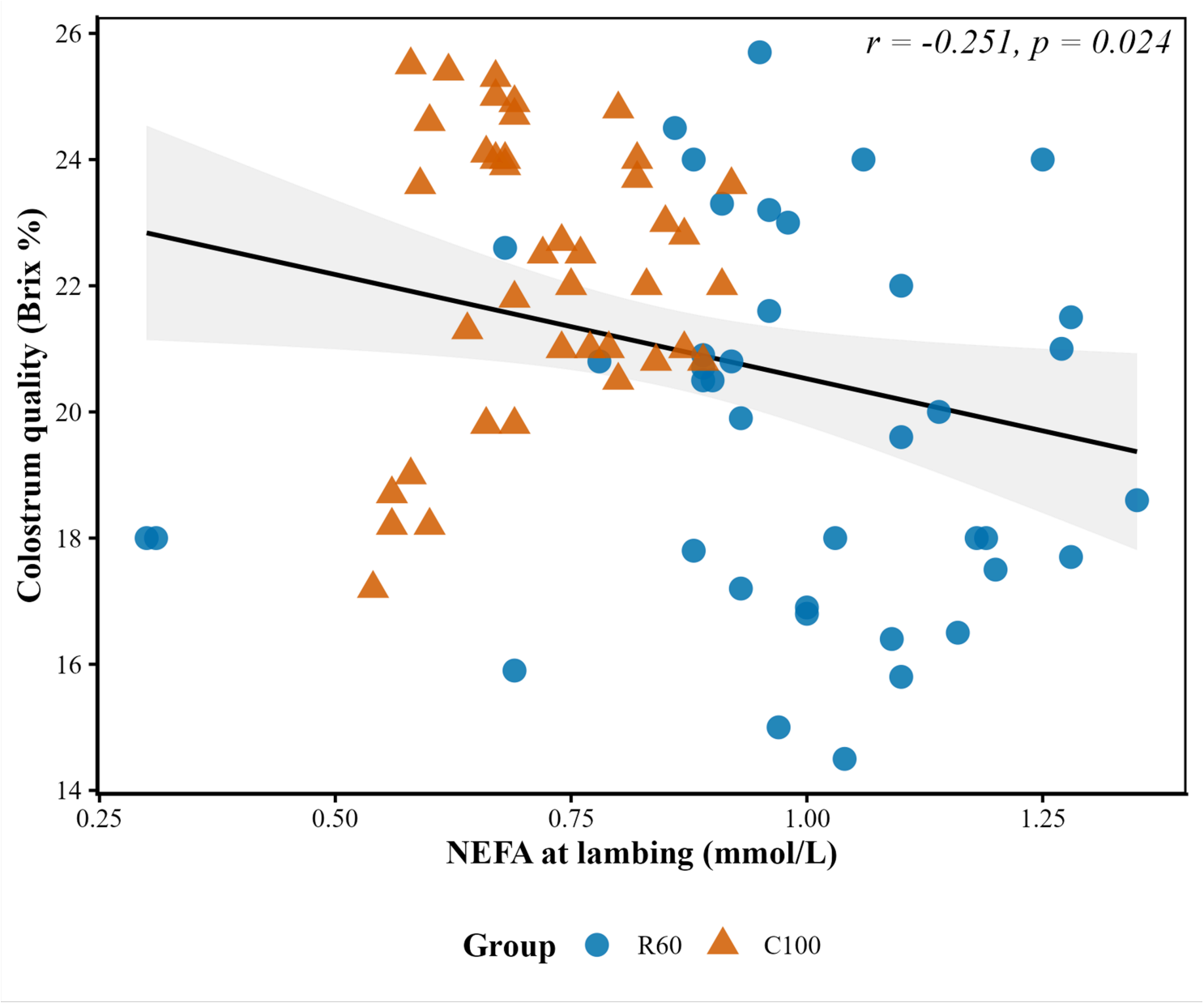


Figure 4

Scatter plot of the Pearson correlation between NEFA at lambing (mmol/L) and colostrum quality (Brix %); n = 80 ewes. Regression line and 95% confidence interval shown (r = −0.251; R^2 = 0.063; p = 0.024). The modest R^2 indicates that NEFA at lambing explains only a small fraction of between-ewe variance in colostrum Brix, although the negative direction of the association is statistically robust. Circles: R60; triangles: C100.

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