Iranian Journal of Applied Animal Science

Effects of Sodium Butyrate and Lysophospholipid Supplementation during the Transition Period on Performance of Ile-de-France Ewes

Research Article

S. Mazareei[1], H. Jahani-Azizabadi[1*] and O. Azizi[1]

[1] Department of Animal Science, Faculty of Agriculture, University of Kurdistan, Sanandaj, Iran

Received on: 29 Apr 2025
Revised on: 19 Aug 2025
Accepted on: 12 Oct 2025
Online Published on: Dec 2025

*Correspondence E-mail: ho.jahani@uok.ac.ir

Online version is available on: www.ijas.ir
https://doi.org/10.71798/ijas.2025.1228575

ABSTRACT

The aim of this study was to investigate the effects of sodium butyrate (SB) and lysophospholipid (LPL), alone or combined, on performance and blood metabolites of Ile-de-France ewes during transition period. Sixty close-up pregnant Ile-de-France ewes (body weight=65±5 kg) were used in a 2 × 2 factorial experiment in a completely randomized design from 21 pre-partum to 21 days post-partum (n=15). Experimental treatments were: 1) control (without additives); 2) 0.5 g SB/kg BW/day; 3) 1 g LPL/head/day; or 4) SB + LPL. Results of present study showed that although SB or LPL alone had no significant impact on dry matter intake (DMI) compared to the control, their combination increased DMI (P<0.05) and neutral detergent fiber (NDF) digestibility (44.36% *vs.* 37.31%; P<0.05). Ewe body weight changes, colostrum brix value, and postpartum body temperature remained unaffected by SB and LPL supplementation. Serum analysis indicated SB elevated high-density lipoprotein (HDL) and alkaline phosphatase (ALP), while LPL increased malondialdehyde (MDA), albumin, and superoxide dismutase (SOD) (P<0.05). The SB + LPL group exhibited reduced glutathione peroxidase (GPX) activity (P<0.05). These results demonstrate that SB and LPL synergistically enhance feed intake and fiber digestion, potentially alleviating energy deficits in transition ewes. However, divergent effects on oxidative stress and lipid metabolism underscore the need for tailored supplementation protocols. Further studies should explore long-term impacts on metabolic resilience and offspring development.

KEY WORDS colostrum, ewe, lambs born weight, sodium butyrate, transition period.

INTRODUCTION

Ruminants near parturition, which transitioning from pregnant to lactating state, experience significant metabolic pressures (Babaei *et al.* 2019). The dramatic changes in nutrient requirements from pre- to post-partum are the primary reasons that makes the transition period such a metabolic challenge. During late pregnancy, the fetal metabolic rate is approximately twice that of the dam (Roche *et al.* 2010). After parturition, approximately 50% of the daily energy expenditure in lactating sheep and goats is devoted to the lactation process (Mazareei *et al.* 2024). In the initial weeks of lactation, ewes often fail to consume sufficient dry matter intake (DMI) relative to the increased energy demand required to support milk production, resulting in a negative energy balance (NEB). NEB can lead to decreased milk production (Carvalho *et al.* 2019), impaired health, and reduced reproductive performance (Mazareei *et al.* 2024). Most infectious diseases and metabolic disorders occur during this critical period. Ewes become particularly susceptible to developing metabolic diseases such as ketosis, mastitis, metritis, and displaced abomasum during the transition period (Havekes *et al.* 2020). Among the factors affecting production and reproduction performance in ani-

mals, feed and feeding management plays the most crucial role (Snyman and Olivier, 1999). Implementing various energy supply methods during the pre- and post-partum periods is recognized as a primary strategy to prevent metabolic diseases and enhance pregnancy efficiency (Walsh *et al*. 2011).

Butyrate is a short-chain fatty acid produced through anaerobic microbial fermentation in the rumen of ruminants, and large intestine of both humans and animals. It has the most potent nutritional effects among volatile fatty acids (Bedford *et al.* 2017). The microorganisms colonizing the gastrointestinal tract can influence feeding behavior, hormones secretion, nutrient digestion, absorption and metabolism, and the immune response (Nicola *et al.* 2023). Short-chain fatty acids, particularly butyrate, serve as immunomodulators and valuable energy source for colonocytes (Jianping, 2013). Numerous studies have demonstrated that butyrate influences gene expression, cell differentiation, promotes the growth and development of digestive tissue, modulates immune responses, reducing oxidative stress, possesses anti-inflammatory and antibacterial properties, and help control diarrhea (Bedford and Gong, 2018). Consequently, butyrate is believed to have beneficial effects on animal performance and health (Tan *et al.* 2014; Zhang *et al*. 2023a). While a few studies have investigated the effects of butyrate in transition cows, no research has been conducted specifically in transition ewes.

Lysophospholipids are derivatives of phospholipids from which a fatty acid has been removed by phospholipase A1 or A2 (Joshi *et al.* 2006). Due to the absence of one fatty acid, lysophospholipids exhibit enhanced emulsifying properties and can alter the conformation of membrane protein channels by increasing ion exchanges (Maingret *et al.* 2000). Additionally, they increase the number and size of membrane pores, thereby enhancingthe passage rate of macromolecules across the cell membrane. These mechanisms facilitate the transfer of nutrients both small particles like calcium ions and complex compounds such as polysaccharides thereby increasing nutrient availability and improving animal performance (Boontiam *et al*. 2017). Lysophospholipid such as Lysophosphatidylcholine, have been shown to enhance the anti-oxidative response of cultured neutrophils in mice (Yan *et al.* 2004). These findings underscore the capacity of lysophospholipids to modulate immunity (Tate *et al*. 2023).

To our knowledge there are no information about the effects of sodium butyrate (SB) and lysophospholipids (LPL), alone or in combination, on performance of ewes in transition period. We hypothesize that the use of SB and LPL will improve metabolic health and performance in transition ewes by enhancing nutrient utilization, and modulating immune responses. In addition, the simultaneous incorporation of both LPL and SB may provide synergistic effects that enhance cellular metabolism and improve the overall performance of ewes. Therefore, the objective of the current study was to assess the effects of SB and LPL on the performance of transition Ile-de-France ewes.

MATERIALS AND METHODS

Animals, diets, and experimental design

This study was conducted in Ajdad Mahidasht sheep breeding farm located in Mahidasht, Kermanshah, Iran. The experimental protocols were approved by the Animal Care and Use Committee of the University of Kurdistan in accordance with the guidelines of the Iranian Council of Animal Care (1995). Sixty transition Ile-de-France ewes (body weight=65±5 kg) from -21 days prepartum to 21 days postpartum, were used to evaluate the effects of SB and LPL in a 2 × 2 factorial experiment in a completely randomized design. Ewes were randomly assigned to four treatments (n=15 ewes per treatment) and housed in individual pens. Treatments were: 1) basal diet without additive (as Control), 2) basal diet plus 0.5 g SB per kg of BW per day, 3) basal diet plus 1 g LPL per head per day, 4) basal diet plus 0.5 g SB per kg of BW + 1 g LPL per head per day. The LPL complex used in this study was obtained from soybean lecithin using proprietary technology and contained 6% LPL, 43% other lipids (phospholipids and triglycerides), and 50% carrier, which was used as active ingredients and absorption accelerators. The SB used in this study was produced by Innovad® (Novyrate® C, Postbaan 69, 2910 Essen, Belgium). The LPL and SB treatments were mixed with the daily concentrate feed throughout the experimental period.

Ewes were fed twice daily (at 09:00 and 17:00 h) with the experimental diets (Table 1), formulated according to the nutrient requirement suggested by Natural Research Council (NRC, 2007). During the experiment, the animals were kept in individual pens and had *ad libitum* access to the diet and water.

Data and sample collection

The daily dry matter intake (DMI) of the ewes was recorded from 21 days before to 21 days after lambing. Immediately following parturition and the drying of the lambs, the ewes' weight (after the placenta execration), as well as the number and weight of the lambs delivered by each ewe, were recorded. To assess colostrum quality, a sample was taken immediately after parturition from the colostrum produced by each ewe (after emptying firs 5 mL, 10 mL was collected from each teat and mixed). The Brix value of the colostrum was measured using an automatic and water-resistant refractometer (ATAGO, Tokyo, Japan).

Table 1 Ingredients and concentrate composition of the basal diets

Ingredients (% of DM[1])	Basal diet	
	Close-up ewes	Dairy fresh ewes
Alfalfa hay	20	22
Wheat straw	10.4	-
Corn silage	24	22.5
Sugarcane bagasse	23.6	33
Beet pulp	2	3.5
Pregnant concentrate	20	-
Dairy ewes concentrate	-	19
Chemical composition (% of DM)		
Crude protein	11	13
Neutral detergent fiber	38.5	36.3
Metabolizable energy (Mcal/kg)	2.7	2.9
Concentrate composition (% of DM)		
Barley grain	27.3	36.5
Corn grain	25.4	29.5
Wheat bran	12.6	6.7
Soybean meal	20.6	15.1
Corn gluten meal	2.5	-
Meat and bon meal	3.3	5.4
Soaped fatty acids	3.8	-
Special permix for pregnant ewes	4.5	-
Special permix for dairy ewes	-	6.8

DM: dry matter.

The incidence of metabolic disorders during and after the parturition such as dystocia, abortion, retained placenta, metritis, etc., was recorded. To monitor health and identify potential internal issues, the rectal temperature of the ewes was measured at 24, 48 and 72 hours post-lambing using a digital thermometer. From day 7 after parturition, in the separate pens the lambs had free access to the starter feed in addition to maternal milk.

Blood samples were collected from the jugular vein 4 h after morning feeding on days -7, 0, +7, +14 and +21 relatives to lambing. Blood samples was drawn into two tubes: one containing ethylenediaminetetraacetic acid (EDETA) for whole blood sample, and the other containing a clot activator (VACUETTE® TUBE 1 mL CAT Serum Clot Activator 13x75) for serum samples. After allowing the blood to clot, samples were centrifuged at 3000 × *g* for 15 min to separate serum, which was then stored at −20 °C until analysis. Serum samples were analyzed to measure glucose (Glu), triglyceride (TG), cholesterol (Chol), high density lipoprotein (HDL), low density lipoprotein (LDL), very-low density lipoprotein (VLDL). Beta-hydroxybutyrate (BHB), albumin (Alb), total protein (TP), malondialdehyde (MDA), total antioxidant capacity, alkaline phosphatase (ALP), aspartate aminotransferase (AST) and alanine aminotransferase (ALT).

Whole blood samples were used to determine hemoglobin concentration and activities of superoxide dismutase (SOD) and glutathione peroxidase (GPX).

Ewes fecal samples were collected on days -7 and +21 relative to lambing (collected at 2 and 4 hours after morning feeding, and then samples of each sheep were mixed together). Samples were used to measure nutrient apparent digestibility using acid-insoluble ash (AIA) as an internal marker. At 21 days post-lambing, both ewes and lambs were weighed to assess lambs weight gain and changes in ewe body weight relative to the lambing day.

Chemical analyses

Feed and fecal samples were oven-dried at 60 °C for 72 h. Samples were ground to pass through a 1.5-mm sieve. The feed samples were analyzed for dry matter (DM), crude protein (CP), organic matter (OM), and ash following standard procedures (AOAC, 2000). Ash-free neutral detergent fiber (NDF) content of samples was determined using the method recommended by Van Soest *et al*. (1991). Nitrogen concentration in the samples was determined using the Kjeldahl method (Kjeltec 2300, Foss Tecator AB, Hoganas, Sweden). Acid insoluble ash (AIA) concentration of experimental diets and fecal samples were measured according to the method recommended by Van Keulen (1977).

Serum concentrations of Glu, TG, Chol, Alb, TP, ALP, AST and ALT were measured using special laboratory kits (Pars Azmun Laboratory, Tehran, Iran) and a spectrophotometer (JASCO, V-570) according to the manufacturer's instructions. Randox Laboratories kits were used to determine BHB, SOD, GPX and total antioxidant capacity. Malondialdehyde (MDA) concentration was measured using thiobarbituric acid (TBA) test and spectrophotometer (JASCO, V-570). The standard solution containing MDA was extracted from mixture with 20% trichloroacetic acid solution, 1.8% sodium dodecyl sulfate, and 0.8% thiobarbituric acid solution. The mixture was boiled for one hour, cooled, and n-butanol was added. The organic acid phase was collected after centrifugation at 4000 rpm for 10 minutes and read at a wavelength of 532 nm (Sanjadi and Nayeri, 2019).

Statistical analysis

This research was conducted in a completely randomized design (CRD) with 4 treatments and 15 replications in a 2 × 2 factorial arrangement. Data on changes in ewe's body weight, kg of lamb produced per ewe, lambs birth weight, lambs body weight at 21 days, and ewe's body temperature were analyzed using the GLM procedure of SAS (2004). Turkey's test was applied for mean comparisons. Data of DMI, nutrient apparent digestibility, blood biochemical and

anti-oxidant parameters were analyzed using MIXED procedure of SAS. Period and ewes within period and treatment were considered as random effects.

RESULTS AND DISCUSSION

The effects of alone and combined use of SB and LPL on the DMI of Ile-de-France ewes during the transition period are presented in Figure 1. The results indicated that the alone use of SB and LPL did not significantly affect DMI. However, the in combination use of SB and LPL resulted in a significant increase (P<0.05) in DMI.

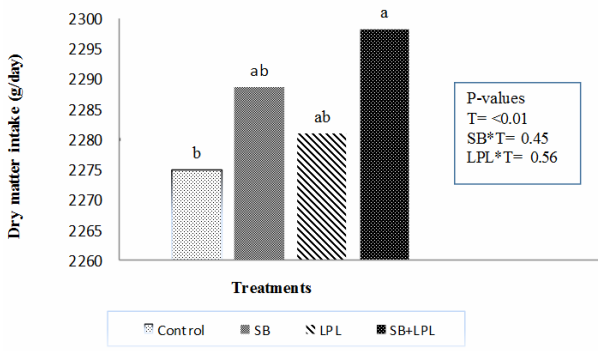

Figure 1 Effects of experimental treatments on DMI of Ile-de-France ewes during the transition period. Treatments were: 1) control, 2) SB: 0.5 g sodium butyrate (SB) per kg of BW per head per day, 3) LPL: 1 g/d lysophospholipid (LPL) per head per day, 4) SB + LPL: 0.5 g SB per kg of BW + 1 g LPL per head per day
[a,b] Means with different letters are significantly different (P<0.05)
T: time effect (sampling period); SB × T: interaction effect of SB and time and LPL × T: interaction effect of LPL and time

Table 2 summarized the effects of alone and in combination use of SB and LPL on nutrient apparent digestibility. The findings revealed that neither the alone nor the in combination use of SB and LPL had significant effects on apparent total tract digestibility of DM, OM, and CP compared to the control group. However, the combination of SB and LPL significantly increased CP digestibility (62.15% *vs*. 57.3%, P<0.05) relative to the SB group. Additionally, total tract NDF digestibility was significantly (P<0.05) higher in the SB + LPL group compared to both the control and SB groups (44.36% *vs*. 37.31% and 35.58%, respectively). The apparent digestibility of nutrient was influenced (P<0.01) by sampling time (sampling periods). Apparent nutrient digestibility in pre-partum period was higher than that of post-partum.

The effect of alone and in combination use of SB and LPL on performance of ewes and their offspring are detailed in Table 3. The experimental treatments did not significantly affect body weight changes in ewes. However, the SB group exhibited the least weight loss (-1.76 kg *vs*. -2.72 kg, -3.11 kg, and -3.14 kg for other treatments).

Results showed a numerical increase (P>0.05) in the kg of lambs produced per ewe compared to the control group. Lambs weight at 21 days post-birth was unaffected by either the alone and in combination use of SB and LPL. Furthermore, neither alone nor in combination use of SB and LPL significantly affected colostrum brix values in fresh ewes.

The effects of alone and in combination use of SB and LPL on body temperature in ewes, as an indicator of inflammation, are presented in Table 4. The results indicated that body temperature at 24, 48 and 72 hours post-lambing was not significantly affected by the experimental treatments.

Table 5 represents the effects of the alone and in combination use of SB and LPL on serum Glu and BHBA concentration in the Ile-de-France ewes during the transition period. Glucose (Glu) and BHBA are key indicators of the energy status of ewes during this phase. The results indicated that neither the alone nor in combination use of SB and LPL significantly affected blood Glu and BHBA concentration during transition period. However, the effects of treatments on these metabolites were influenced (P<0.01) by sampling time (sampling periods), with a notable interaction between LPL and sampling time observed for BHBA concentration.

The effect of alone and in combination use of SB and LPL on the blood lipid profile of Ile-de-France ewes during transition period is summarized in Table 6. The findings revealed that supplementation with SB and LPL did not significant alter serum concentration of TG, LDL and VLDL. In contrast, the combined use of SB and LPL (SB+LPL) resulted in a significant decrease (P<0.01) in serum Chol and HDL concentration compared to the SB group.

Additionally, supplementation with SB alone led to a significant increase (P<0.01) in HDL concentration relative to the control group. The serum concentration of Chol, TG, HDL, LDL, and VLDL were significantly influenced (P<0.01) by sampling time (sampling periods), with a significant interaction noted between LPL effects and sampling time.

The effect of alone and in combination use of SB and LPL on blood antioxidant parameters in Ile-de-France ewes during transition period are detailed in Table 7. The findings indicated that blood TAC was not significantly affected by the experimental treatments.

Furthermore, the treatments did not significant influence MDA concentration (except for alone LPL supplementation) or the activity of SOD (except for alone LPL supplementation), and GPX (except for in combination use of SB and LPL).

Table 2 Effect of experimental treatments on total tract nutrient apparent digestibility in transition Ile-de-France ewes

Item (%)	Treatments				SEM	P-value					
	1	2	3	4		SB	LPL	SB × LPL	T	SB × T	LPL × T
DM	46.22	43.49	44.37	46.56	1.93	0.91	0.81	0.35	<0.01	0.12	0.44
OM	48.07	43.63	48.79	50.28	1.66	0.51	0.11	0.19	0.01	0.15	0.76
CP	58.91^{ab}	57.30^{b}	60.64^{ab}	62.15^{a}	1.59	0.97	0.04	0.31	<0.01	0.28	0.42
NDF	37.31^{b}	35.58^{b}	38.15^{ab}	44.36^{a}	1.63	0.31	0.04	0.06	0.02	0.13	0.63

Treatments: 1) control; 2) 0.5 g sodium butyrate (SB) per kg of BW in day; 3) 1 g/d lysophospholipid (LPL) per head and 4) 0.5 g SB per kg of BW + 1 g/d LPL per head.
SB: main effect of SB; LPL: main effect of LPL; SB × LPL: interaction effect of SB and LPL; T: time effect (sampling period); SB × T: interaction effect of SB and time and LPL×T: interaction effect of LPL and time.
DM: dry matter; OM: organic matter; CP: crude protein and NDF: neutral detergent fiber.
The means within the same row with at least one common letter, do not have significant difference (P>0.05).
SEM: standard error of the means.

Table 3 Effects of sodium butyrate (SB) and lysophospholipid (LPL) on performance of transition Ile-de-France ewes and their lambs

Parameter	Treatments				SEM	P-value		
	1	2	3	4		SB	LPL	SB × LPL
Body weight changes of ewes (kg)	-2.72	-1.76	-3.11	-3.14	0.469	0.63	0.36	0.61
Lamb produced per ewe (kg)	5.96	6.74	6.11	6.35	0.268	0.35	0.82	
Lamb weight in days 21 (kg)	11.47	11.49	11.06	11.66	0.493	0.76	0.90	0.77
Colostrum brix value	29.00	26.00	29.00	30.00	0.710	0.41	0.12	0.11

Treatments: 1) control; 2) 0.5 g sodium butyrate (SB) per kg of BW in day; 3) 1 g/d lysophospholipid (LPL) per head and 4) 0.5 g SB per kg of BW + 1 g/d LPL per head.
SB: main effect of SB; LPL: main effect of LPL and SB × LPL: interaction effect of SB and LPL.
The means within the same row with at least one common letter, do not have significant difference (P>0.05).
SEM: standard error of the means.

Table 4 Effects of sodium butyrate (SB) and lysophospholipid (LPL) on body temperature (BT, ˚C) of Ile-de-France ewes

	Treatments				SEM	P-value					
	1	2	3	4		SB	LPL	SB × LPL	T	SB × T	LPL × T
BT (◦C)	38.9	39.7	38.8	39.2	0.26	0.55	0.76	0.37	0.11	0.53	0.87

Treatments: 1) control; 2) 0.5 g sodium butyrate (SB) per kg of BW in day; 3) 1 g/d lysophospholipid (LPL) per head and 4) 0.5 g SB per kg of BW + 1 g/d LPL per head.
SB: main effect of SB; LPL: main effect of LPL; SB × LPL: interaction effect of SB and LPL; T: time effect (sampling period); SB × T: interaction effect of SB and time and LPL × T: interaction effect of LPL and time.

Table 5 Effects of experimental treatments on the serum glucose and β-Hydroxybutyric acid (BHBA) concentration in transition Ile-de-France ewes

Parameter[1]	Treatments				SEM	P-value					
	1	2	3	4		SB	LPL	SB × LPL	T	SB × T	LPL × T
Glucose (mg/dL)	58.50	65.80	65.30	66.50	2.56	0.21	0.27	0.08	<0.01	0.70	0.41
BHBA[1] (mg/dL)	0.53	0.61	0.50	0.57	0.02	0.10	0.49	0.89	<0.01	0.70	0.02

Treatments: 1) control; 2) 0.5 g sodium butyrate (SB) per kg of BW in day; 3) 1 g/d lysophospholipid (LPL) per head and 4) 0.5 g SB per kg of BW + 1 g/d LPL per head.
SB: main effect of SB; LPL: main effect of LPL; SB × LPL: interaction effect of SB and LPL; T: time effect (sampling period); SB × T: interaction effect of SB and time and LPL × T: interaction effect of LPL and time.
The means within the same row with at least one common letter, do not have significant difference (P>0.05).
SEM: standard error of the means.

Table 6 Effects of experimental treatments on serum lipid profile of transition Ile-de-France ewes

Parameter[3]	Treatments				SEM	P-value					
	1	2	3	4		SB	LPL	SB × LPL	T	SB × T	LPL × T
Chol (mg/dL)	58.07^{ab}	61.87^{a}	58.87^{ab}	51.94^{b}	1.22	0.69	0.26	0.01	0.02	0.92	0.01
TG (mg/dL)	16.31	19.10	16.42	18.51	1.04	0.09	0.86	0.73	<0.01	0.86	0.05
HDL (mg/dL)	22.38^{b}	27.46^{a}	22.41^{ab}	21.28^{b}	0.63	0.35	0.16	<0.01	<0.01	0.40	<0.01
LDL (mg/dL)	31.97	31.13	33.03	27.67	1.09	0.21	0.62	0.07	<0.01	0.89	0.01
VLDL (mg/dL)	3.26	3.82	3.28	3.70	0.20	0.09	0.86	0.73	<0.01	0.86	0.05

Treatments: 1) control; 2) 0.5 g sodium butyrate (SB) per kg of BW in day; 3) 1 g/d lysophospholipid (LPL) per head and 4) 0.5 g SB per kg of BW + 1 g/d LPL per head.
SB: main effect of SB; LPL: main effect of LPL; SB × LPL: interaction effect of SB and LPL; T: time effect (sampling period); SB × T: interaction effect of SB and time and LPL × T: interaction effect of LPL and time.
Chol: cholesterol; TG: triglyceride; HDL: high density lipoprotein; LDL: low density lipoprotein and VLDL: very-low density lipoprotein.
The means within the same row with at least one common letter, do not have significant difference (P>0.05).
SEM: standard error of the means.

Table 7 Effects of experimental treatments on antioxidant indices of transition Ile-de-France ewes

Parameter	Treatments				SEM	P-value					
	1	2	3	4		SB	LPL	SB × LPL	T	SB × T	LPL × T
MDA (nmol/mL)	1.71^{b}	1.81^{ab}	2.14^{a}	1.70^{b}	0.11	0.37	0.40	0.04	0.02	0.06	0.04
SOD (U/L)	925.10^{b}	945.70^{b}	1264.90^{a}	996.80^{b}	26.81	0.03	<0.01	<0.01	<0.01	0.10	<0.01
GPX (U/L)	64.7^{a}	62.20^{a}	62.80^{a}	59.60^{b}	0.62	0.04	0.11	0.79	<0.01	0.79	0.50
TAC (mmol/L)	0.37	0.42	0.39	0.41	0.01	0.18	0.81	0.57	0.03	0.68	0.57

Treatments: 1) control; 2) 0.5 g sodium butyrate (SB) per kg of BW in day; 3) 1 g/d lysophospholipid (LPL) per head and 4) 0.5 g SB per kg of BW + 1 g/d LPL per head.
SB: main effect of SB; LPL: main effect of LPL; SB × LPL: interaction effect of SB and LPL; T: time effect (sampling period); SB × T: interaction effect of SB and time and LPL × T: interaction effect of LPL and time.
MDA: malondialdehyde; SOD: superoxide dismutase; GPX: glutathione peroxidase and TAC: total antioxidant capacity.
The means within the same row with at least one common letter, do not have significant difference (P>0.05).
SEM: standard error of the means.

Table 8 Effects of experimental treatments on liver function of transition Ile-de-France ewes

Parameter	Treatments				SEM	P-value					
	1	2	3	4		SB	LPL	SB × LPL	T	SB × T	LPL × T
TP (mg/dL)	6.92	7.30	7.30	7.26	0.09	0.41	0.41	0.14	<0.01	0.86	0.05
Alb (mg/dL)	3.01^{b}	3.11^{ab}	3.20^{a}	3.00^{b}	0.04	0.62	0.71	0.02	<0.01	0.34	0.07
Glob (mg/dL)	3.86	4.23	4.09	4.22	0.08	0.31	0.65	0.29	<0.01	0.76	0.13
ALP (U/L)	176.50^{b}	249.7^{a}	207.00^{ab}	151.00^{b}	7.98	0.73	0.18	<0.01	0.72	0.23	0.01
ALT (U/L)	21.77	20.02	21.17	19.72	0.55	0.19	0.70	0.80	0.02	0.86	0.42
AST (U/L)	109.90	119.00	118.90	119.20	2.72	0.41	0.42	0.32	<0.01	0.24	0.63

Treatments: 1) control; 2) 0.5 g sodium butyrate (SB) per kg of BW in day; 3) 1 g/d lysophospholipid (LPL) per head and 4) 0.5 g SB per kg of BW + 1 g/d LPL per head.
SB: main effect of SB; LPL: main effect of LPL; SB × LPL: interaction effect of SB and LPL; T: time effect (sampling period); SB × T: interaction effect of SB and time and LPL × T: interaction effect of LPL and time.
TP: total protein; Alb: albumin; Glob: globulin; ALP: alkaline phosphatase; ALT: alanine aminotransferase and AST: aspartate aminotransferase.
The means within the same row with at least one common letter, do not have significant difference (P>0.05).
SEM: standard error of the means.

The effects of treatments on TAC, MDA concentration and the activity of SOD and GPX were influenced (P<0.01) by sampling time (sampling periods), with significant interactions observed between LPL effects on MDA concentration and SOD activity over time.

The effects of SB and LPL supplementation on liver function in transition Ile-de-France ewes are presented in Table 8. The results indicated a significant decrease (P<0.02) in serum Alb concentration with the combination use of SB and LPL (SB+LPL), compared to the control and LPL groups. Additionally, while there were no significant effects observed for serum TP, Glob, ALT, or AST concentration for either treatment alone or in combination, both SB and LPL alone resulted in a significant (P<0.01) increase in the serum ALP concentration compared to the control group. The serum concentrations of TP, Alb, ALP, AST, and ALT were influenced (P<0.01) by sampling time (sampling periods), with significant interactions noted between LPL effects on TP, Alb, and ALP concentration over time.

Our findings indicated that DMI in the SB and LPL groups was numerically (P>0.05) higher than that of the control group. Notably, in combination use of SB and LPL (SB+LPL) significantly increased DMI compared to the control group. Research on the effects of SB and LPL on DMI and performance, specifically in ewes, is limited, and most studies focus on lambs. The enhanced DMI observed can be attributed to several mechanisms. Sodium butyrate (SB), a short-chain fatty acid, is recognized for its role in promoting gut health by enhancing the intestinal barrier integrity and stimulating the proliferation of beneficial gut microbiota (Nicola *et al.* 2023). This improvement in gut health can lead to better nutrient absorption and utilization, ultimately contributing to increased feed intake. Moreover, LPL has been shown to influence cellular signaling pathways that regulate appetite and energy metabolism, potentially further stimulate appetite and feed consumption (Eiras *et al.* 2004). Our findings demonstrated that it is likely that the synergistic effect of combining SB with LPL enhanced these benefits and led to a more significant increase in DMI. The postpartum period presents significant metabolic and nutritional demands as ewe transition from gestation to lactation. Our observation suggested that the combination use of SB and LPL may help meet these increased demands by improving DMI and promoting a more favorable metabolic state. Previous studies have reported significant in-

crease in lambs DMI with SB supplementation (Liu *et al.* 2019; Sun *et al.* 2024; Zhao *et al.* 2019). Similarly, Farahmandpour *et al.* (2023) reported that the addition of LPL to the diet of fattening lambs (0.75% of DM) resulted in a significant increase in DMI. Consistent with our findings, Huo *et al.* (2019) reported that the inclusion of LPL (0.5% of DM) led to increase in DMI of fattening male lambs. The variability in results across different studies may be related to several factors, including the source of LPL, the age of the animals, the dosage used, and the duration of LPL consumption. Further research is warranted to elucidate these factors and their impact on DMI and overall performance in ewes during the transition period.

The literature presents conflicting results regarding the effects of SB on nutrient digestibility. For instance, in contrast with our findings, Rice *et al.* (2019) reported that SB supplementation did not influence apparent total-tract nutrients digestibility. Conversely, Ren *et al.* (2018) found that tributyrin, a form of butyrate, significantly increased the NDF digestibility in adult small-tail ewes. In addition, Abdi-benemar *et al.* (2020) reported that while SB significantly increased CP digestibility in dairy calves, it had no significant effect on the digestibility of other nutrients. The effects of LPL supplementation in ruminants are not consistently uniform across studies. For example, Huo *et al.* (2019) reported that adding LPL to the diet increased the digestibility of DM, CP and OM, while decreasing NDF and ADF digestibility. Also, Baraz *et al.* (2024) reported a significant liner increase in CP digestibility with inclusion of LPL in the diet of dairy calves. Several factors may explain the lack of significant effects of SB and LPLs on DM, OM, and CP digestibility observed in our study. These include differences in diet, variations in dietary lipid sources, genetic factors, the types of LPL and enzymatic processes involved in LPL production, dosage differences, animal age (suckling *vs*. adult), and physiological state.

Zhang *et al.* (2023a) reported that butyrate promoted the growth and propagation of rumen bacteria, as well as the secretion of microbial enzymes, thereby enhancing fiber digestion. They observed an increase in the populations of key cellulolytic bacteria, including Ruminococcus flavefaciens, Ruminococcus albus, Bacteroides fibrisolvens, and Fibrobacter succinogenes, with butyrate supplementation. This increase supported improved ruminal fermentation and enhanced the digestibility of dietary NDF. Contrary to the finding of Zhang *et al.* (2023b), we did not observe significant increase in NDF digestibility with SB supplementation compared to the control group. The combined use of SB and LPL in current study may synergistically enhance the microbial population and activity responsible for fiber digestion. This synergistic effect is likely attributed to the improved availability of butyrate to the microbes and an overall enhancement of microbial function, leading to increased NDF digestibility. Lysophospholipids (LPL) could also alter microbial membrane permeability. Therefore, the presence of LPL might modify the membrane permeability of cellulolytic bacteria to SB.

Ewes feed intake and milk composition key factors influenced the lamb's birth weight and growth performance. In the present study, the observed numerical increase in kg of lambs produced per ewe especially with supplementation of SB and LPL may be attributed to improve nutrient use efficiency. Reis *et al.* (2021) reported that LPL supplementation enhanced growth performance and feed efficiency in dairy cows without increasing DMI. The non-significant differences in lamb weights at 21 days after birth observed in this study suggest that the treatments likely had no significant effect on their dams' milk production. One of the study limitations was that milk production and milk composition of fresh ewes was not recorded. Our findings showed that treatments did not have significant effects on ewes BW changes from partum to 21 day after parturition. Likely the results influenced by the high internal variation in groups. Lower decrease in BW in SB group compared to the control group may be related to effects of SB in an increase in feed conversion rate. Guilloteau *et al.* (2010) reported that SB supplementation resulted in an improvement in the feed conversion ratios. In addition, higher decrease in LPL and LPL+SB groups BW compared to the SB and control group likely due to increase in milk fat content. There is evidence that LPL supplementation can increase in milk fat content (Zhao *et al*. 2016; Porter *et al*. 2024).

The non-significant differences in lamb weights at 21 days postpartum observed in this study suggest that the treatments likely had no significant effect on their dams' milk production. One limitation of the study was that neither milk production nor milk composition of the freshly lambed ewes was recorded.

Our findings indicated that the treatments did not significantly affect ewes' BW changes from parturition to 21 days postpartum. This lack of significant effects may have been influenced by the high within-group variation. The SB group showed a smaller BW decrease compared to the control group, which might be attributed to SB's potential effect on improving feed conversion efficiency. Guilloteau *et al.* (2009) reported that SB supplementation improved feed conversion ratios. Conversely, the LPL and LPL + SB groups exhibited greater BW reductions compared to both the SB and control groups, possibly due to increased milk fat content. Existing evidence suggests that LPL supplementation can increase milk fat content (Zhao *et al*. 2016; Porter *et al*. 2024).

To date, no study has investigated the effect of SB and LPL supplementation on the colostrum quality of sheep,

with only a few studies for on dairy cow and non-ruminants. Contrary to our results, He *et al.* (2016) reported that SB supplementation altered colostrum composition (protein, lactose and triglyceride) and subsequently improved the growth performance of suckling piglets. However, similar to our findings, their study found no significantly effect of SB on colostrum brix value and immunoglobulin (Ig) concentration. In contrast, Kovács *et al.* (2023) demonstrated that magnesium butyrate supplementation increased colostrum production and the concentration of protein, IgG and lactose in the colostrum of pre-partum dairy cows which is contradicts our findings. Additionally, Hiltz and Laarman (2019) suggested that supplemental butyrate in the close-up diet of dairy cows had no effect on colostrum Ig levels. Factors such as genetics, age, and overall health status can play critical roles in colostrum production and quality (Banchero *et al.* 2015). This variability may have obscured any potential benefits from the treatments applied. Furthermore, physiological responses to SB and LPL may differ between species, which could account for the contrasting results observed in sheep compared to pigs and cattle. Additionally, the nutritional adequacy of the diet prior to treatment may also affect colostrum quality; if ewes were already receiving a nutritionally sufficient diet, supplementation with SB and LPL might not have provided additional benefits.

We hypothesized that SB and LPL would reduce the occurrence of fever and parturition-related disorders in ewes compared to the control group, potentially through the effect on the body's immune system. However, as noted, the body temperature of the ewes at 24, 48 and 72 hours post-parturition was not significantly affected by the experimental treatments. Additionally, we did not observed any reproductive disorders during or after the parturition (such as dystocia, abortion, retained placenta, metritis) in any of the treatment groups; thus, we did not report this data in the Tables. Tate *et al.* (2023) found that subcutaneous administration of LPL in Holstein heifer calves resulted in an increase in rectal temperature compared to the control group; however this increase was not statistically significant which aligns with our findings. The lack of significant treatment effects on ewes' health parameters and rectal temperature may be attributed to several factors, including: (1) the administered doses of SB and LPL, (2) the sources of these supplements, (3) the ewes' nutritional status, and (4) the duration of supplementation. Furthermore, the absence of positive outcomes from SB and LPL supplementation in close-up ewes may partly reflect the optimal nutritional and hygienic conditions maintained in the experimental sheep housing, which likely minimized potential health challenges that these supplements might otherwise address.

Our findings demonstrated a numerical increase in serum Glu (65.8, 65.3 and 66.5 *vs*. 58.5 mg/dL) concentration, relative to those in the control group. Herrick *et al.* (2017) reported that a single-dose infusion of SB increased BHBA concentration while decreased Glu concentration in lactating dairy cows. In agreement with our observation, Ulfina *et al.* (2015) found that supplementing the diet of transition dairy cows with butyric acid led to elevated plasma Glu and BHBA concentrations. Additionally, Liu *et al.* (2018) suggested that the Infusion of SB raised BHBA concentration in neonatal twin lambs, although serum Glu concentrations remained unchanged. Similarly, Abdi-benemar *et al.* (2020) indicated that the use of SB significantly increased blood BHBA concentration in suckling Holstein calves, with no significant effect on serum Glu concentration. The observed increase in blood BHBA concentration in our study might be attributed to enhanced ketogenesis due to elevated ruminal butyrate level (Rice *et al.* 2019). Conversely, it is possible that due to the coated and slow release form of SB utilized in this study, a portion of the butyrate bypassed the rumen and was absorbed post-ruminally, therefore leading to the observed increase in blood BHBA concentration. Due to the significant effect of time (sampling period) in this study, the non-significant increase in serum concentration of Glu and BHBA may be related to the timing of sampling, which occurred one week prior to and three weeks following parturition. It is likely that these non-significant results are influenced by temporal effects associated with parturition and the varying impacts of treatments over time.

The serum concentration of TG, Chol, HDL, LDL, and VLDL are important indicators of fat and carbohydrate metabolism and digestion. Our observation indicated that inclusion of LPL and SB, both alone and in combination, did not have significant effects on serum TG, Chol, LDL, VLDL, TP, Glob, ALt, and AST, relative to those of the control group. However, we observed a significant increase in serum Alb and HDL concentration in ewes supplemented with LPL and SB compared to the control group, respectively. In contrast to our findings, some studies reported an increase in serum TG concentration when beef steers diets were supplemented with lecithin. This discrepancy between results may be attributed to differences in the basal diet and the concentration of dietary fatty acids. The absence of significant changes in TG, VLDL, and LDL concentrations could be explained by the complex metabolic adaptations during the transition period. This physiological phase is marked by substantial hormonal fluctuations and metabolic stress as ewes mobilize energy reserves to meet the demands of impending lactation. Previous studies have shown that lipid metabolism is tightly regulated during the transition period, which may limit the impact of dietary

interventions on these specific lipid fractions (Bionaz *et al.* 2020). On the other hand, the observed increase in HDL levels with SB supplementation can be explained by its role in enhancing fatty acid oxidation and improving overall lipid metabolism. Sodium butyrate (SB) has been reported to influence gene expression related to lipid metabolism and promote the synthesis of Apo-lipoproteins associated with HDL (Sun *et al.* 2018). Additionally, HDL is known for its role in reverse cholesterol transport and anti-inflammatory properties (Kim *et al.* 2004), which could be beneficial for ewes undergoing physiological stress during the transition period. Future research should focus on elucidating the underlying mechanisms by which SB affects lipid profiles and exploring potential synergistic effects when combined with other dietary components.

Total protein (TP) and Alb are crucial markers for assessing protein metabolism. The observed increase in serum Alb concentration in freshly lambing ewes supplemented with LPL can be attributed to several key mechanisms that enhance protein synthesis and overall health. In contrast, the inclusion of coated SB did not demonstrate a significant effect on serum Alb levels, and its simultaneous use with LPL resulted in a reduction of serum Alb concentration. This finding warranted a closer examination of the underlying mechanisms involved. Lysophospholipids (LPL) are known to promote the synthesis of proteins in the liver, including Alb production. They may activate signaling pathways that enhance the expression of genes involved in protein synthesis (Koh *et al.* 2017). Additionally, LPL can enhance immune function, which may indirectly influence liver function and protein synthesis. Improved immune responses create a favorable environment for Alb production (Yamashita, 2010).

Moreover, LPL may possess anti-inflammatory properties that reduce the catabolic state often associated with inflammation. Lower levels of inflammation can contribute to increased Alb synthesis, as inflammation typically leads to a decrease in Alb production.

The simultaneous administration of LPL and SB may lead to interactions that diminish their individual effects on serum proteins, potentially explained the observed reduction in serum Alb concentration when both supplements are used together (Kreuzer, 2019). In a study on lambs, dietary supplementation with LPL had no significant effect on serum biochemical parameters (Huo *et al.* 2019), which contrast with the findings of current study. He *et al.* (2020) reported that LPL supplementation increased plasma Glob, TP and ALP activity while decreased total Chol in mid-lactation dairy cows. In our study, Alb concentration was notably affected by LPL at 14 days postpartum.

Albumin serves as an indicator for evaluating nitrogen utilization and excretion efficiency in animal. The increase in Alb due to LPL supplementation in this study suggests an improvement in protein status (Kohn *et al.* 2005).

Oxidative stress, resulting from an imbalance of reactive oxygen species (ROS), can lead to tissue damage and impair normal cell functions. In agreement with findings of the present study, Liu *et al.* (2021) reported that the SB administration did not affect serum SOD activities in pre-weaning dairy calves. However, they observed an increase in GPX and decrease in MDA concentration. Conversely, Ma *et al.* (2018) found that SB supplementation enhanced SOD enzyme activity and TAC while decreasing MDA concentration in dairy goats. Evidence suggested that SB improves antioxidant mechanism by influencing the expression of antioxidant genes (Memon *et al.* 2019). In our study, LPL supplementation led to significant increases in SOD activity and MDA concentration during transition period compared to the control group. The observed increases in SOD activity may reflect a compensatory response to heightened oxidative stress, highlighting the dynamic nature of antioxidant responses during these critical physiological transitions (Zhang *et al.* 2011). This observation aligns with previous research indicating that LPL can modulate inflammatory responses and enhance antioxidant defenses.

In contrast, SB did not demonstrate a significant effect on SOD activity, potentially due to the different mechanisms through which SB operates. Interestingly, when SB and LPL were administered together, no significant difference in SOD activity was observed. This findings raises questions about potential interactions between these two compounds; for instance, SB may modulate the effects of LPL, leading to a saturation of the antioxidant response. Moreover, the unexpected increase in serum MDA levels following LPL supplementation is particularly noteworthy. Malondialdehyde (MDA) is a well-established marker of lipid peroxidation and oxidative stress, and its elevated levels suggest an increase in oxidative damage despite the rise in SOD activity. This paradox may indicate that while SOD activity is enhanced, other pathways involved in oxidative stress response may be compromised or overwhelmed. For instance, an increase in lipid peroxidation could be due to an imbalance between ROS production and the capacity of antioxidant defenses to neutralize them (Halliwell and Gutteridge, 2015).

The observed discrepancy between increased SOD activity and elevated MDA levels may represent a compensatory antioxidant response to heightened oxidative stress (Halliwell and Gutteridge, 2015).

LPL supplementation could potentially modify membrane dynamics or cellular signaling pathways, thereby promoting ROS generation. Consequently, despite the upregulation of SOD activity in response to oxidative stress, the cellular environment may remain favorable for lipid peroxidation, ultimately leading to increased MDA concentrations.

The liver is the primary site of metabolism in the body and plays a crucial role in the storage and regulation of glucose. Any dysfunction n the liver can lead to change in the concentration of liver enzymes (AST, ALT, and ALP) and metabolites such as Alb (Tessari *et al.* 2010). The results of our study revealed significant fluctuations in enzyme levels across different time points, indicating complex physiological responses to dietary interventions. The significant increase in serum ALP levels in ewes supplemented with SB during the transition period can be attributed to the heightened metabolic demands associated with numerical increase in serum BHBA during transition period. ALP is often elevated in response to increased osteoblastic activity and hepatic function, particularly during the periods with high metabolic stress such as transition period (Nakamura *et al.* 2020; Titaux *et al.* 2023). The concurrent administration of SB and LPL leading to a significant decrease in ALP levels compared to the SB group, suggesting a potential synergistic effect that may enhance liver function and reduce hepatic stress. The contrasting effects of SB and LPL on liver enzyme levels throughout different stages of gestation and early lactation highlight the complexity of metabolic regulation in pregnant ewes.

CONCLUSION

This study demonstrates that the combined supplementation of sodium SB and LPL synergistically enhances dry matter intake (DMI) and fiber digestibility (NDF) in transition ewes, likely through improved rumen microbial activity and gut barrier function. While metabolic markers (e.g., glucose, BHBA) and inflammatory responses remained stable, SB+LPL modulated lipid metabolism (reduced cholesterol) and liver enzyme profiles, suggesting targeted effects on energy partitioning during this critical physiological phase. Notably, the lack of significant impacts on ewe performance, colostrum quality, and oxidative stress may reflect the study's short-term duration, optimal baseline nutrition, or dose-dependent responses. These findings underscore the potential of SB + LPL as a nutritional strategy to support transition-period adaptation, though further research is needed to optimize dosing regimens and evaluate long-term effects on productivity and offspring development.

ACKNOWLEDGEMENT

Authors would like to thank University of Kurdistan for funding this project.

REFERENCES

Abdi-benemar H., Seifdavati J., Seifzadeh S. and Ramezani M. (2020). Effects of microencapsulated sodium butyrate on performance, blood metabolites and nutrient digestibility of suckling Holstein calves. *J. Anim. Sci. Res.* **30(2),** 73-83.

AOAC. (2000). Official Methods of Analysis. 17th Ed. Association of Official Analytical Chemists, Arlington, Washington, DC., USA.

Appeddu L., Ely D.G., Aaron D.K., Deweese W.P. and Fink E. (2004). Effects of supplementing with calcium salts of palm oil fatty acids or hydrogenated tallow on ewe milk production and twin lamb growth. *J. Anim. Sci.* **82(9),** 2780-2789.

Babaei M.K., Mirzaei-Alamouti H. and Nikkhah A. (2019). Cereals level and source effects on rumen fermentation, colostrum and milk properties, and blood metabolites in periparturient ewes. *Animals*. **13(6),** 1165-1172.

Banchero G.E., Milton J.T.B., Lindsay D.R., Martin G.B. and Quintans G. (2015). Colostrum production in ewes: a review of regulation mechanisms and of energy supply. *Animals*. **9(5),** 831-837.

Baraz H., Jahani-Azizabadi H. and Azizi O. (2024). Supplementation of lysophospholipids in calf starter: Effects on growth performance, blood metabolites, health, and ruminal ammonia nitrogen concentration. *Anim. Feed Sci. Technol.* **318,** 116149-116158.

Bedford A. and Gong J. (2018). Implications of butyrate and its derivatives for gut health and animal production. *Anim. Nutr.* **4(2),** 151-159.

Bedford A., Yu H., Squires E.J., Leeson S. and Gong J. (2017). Effects of supplementation level and feeding schedule of butyrate glycerides on the growth performance and carcass composition of broiler chickens. *Poult. Sci.* **96(9),** 3221-3228.

Bionaz M., Vargas-Bello-Pérez E. and Busato S. (2020). Advances in fatty acids nutrition in dairy cows: from gut to cells and effects on performance. *J. Anim. Sci. Biotechnol*. **11,** 110-121.

Boontiam M., Jung B. and Kim Y.Y. (2017). Effects of lysophospholipid supplementation to lower nutrient diets on growth performance, intestinal morphology, and blood metabolites in broiler chickens. *Poult. Sci.* **96,** 593-601.

Carvalho M.R., Peñagaricano F., Santos J.E.P., DeVries T.J., McBride B.W. and Ribeiro E.S. (2019). Long-term effects of postpartum clinical disease on milk production, reproduction, and culling of dairy cows, *J. Dairy Sci*. **102(12),** 11701-11717.

Eiras S., Camiña J.P., Diaz-Rodriguez E., Gualillo O. and Casanueva F.F. (2004). Leptin inhibits lysophosphatidic acid-induced intracellular calcium rise by a protein kinase C-dependent mechanism. *J. Cell Physiol.* **201(2),** 214-226.

Farahmandpour M., Chashnidel Y., Teymouri Yansari A. and Kazemifard M. (2023). Effect of different levels of lysophospholipid on performance, degradability, ruminal parameters, microbial population, and carcass fatty acids in fattening lambs. *Anim. Prod. Res.* **12(1),** 13-24.

Guilloteau P., Savary G., Jaguelin-Peyrault Y., Rome V., LeNormand L. and Zabielski R. (2010). Dietary sodium butyrate supplementation increases digestibility and pancreatic secretion in young milk-fed calves. *J. Dairy Sci.* **93(12),** 5842-5850.

Guilloteau P., Zabielski R., David J.C., Blum J.W., Morisset J.A., Biernat M., Wolińsk J., Laubitz D. and Hamon Y. (2009). Sodium-butyrate as a growth promoter in milkreplacer formula for young calves. *J. Dairy Sci.* **92,** 1038-1049.

Halliwell B. and Gutteridge J.M.C. (2015). Free Radicals in Biology and Medicine. Pp. 126-133 in Antioxidants from the Diet. Oxford Univ., Press, England, UK.

Havekes C.D., Duffield T.F., Carpenter A.G. and DeVries T.J. (2020). Effects of molasses-based liquid feed supplementation to a high-straw dry cow diet on feed intake, health, and performance of dairy cows across the transition period. *J. Dairy Sci.* **103(6),** 5070-5089.

He B., Wang M., Guo H., Jia Y., Yang X. and Zhao R. (2016). Effects of sodium butyrate supplementation on reproductive performance and colostrum composition in gilts. *Animals.* **10(10),** 1722-1727.

He Y., Zhong R., Cheng L., You P., Yiyong Li Y. and Sun X. (2020). Effects of the supplementation of lysophospholipids through pelleted total mixed rations on blood biochemical parameters and milk production and composition of mid-Lactation dairy cows. *Animals.* **10,** 215-227.

Herrick K.J., Hippen A.R., Kalscheur K.F., Schingoethe D.J., Casper D.P., Moreland S.C. and van Eys J.E. (2017). Single-dose infusion of sodium butyrate, but not lactose, increases plasma hydroxyl-butyrate and insulin in lactating dairy cows. *J. Dairy Sci.* **100,** 757-768.

Hiltz R.L. and Laarman A.H. (2019). Effect of butyrate on passive transfer of immunity in dairy calves. *J. Dairy Sci.* **102(5),** 4190-4197.

Huo Q., Li B., Cheng L., Wu T., You P., Shen S., Li Y., He Y., Tian W., Li R., Li C., Li J., Song B., Wang C. and Sun X. (2019). Dietary supplementation of lysophospholipids affects feed digestion in lambs. *Animals*. **9,** 805-820.

Iranian Council of Animal Care. (1995). Guide to the Care and Use of Experimental Animals, vol. 1. Isfahan University of Technology, Isfahan, Iran.

Jianping Y. (2013). Butyric acid in ghee heals the mind and body. Indi. *J. Anim. Res.* **51(5),** 896-900.

Joshi A., Paratkar S.G. and Thorat B.N. (2006). Modification of lecithin by physical, chemical and enzymatic methods. *European J. Lipid Sci. Technol.* **108(4),** 363-373.

Kim M.S., Memon R., Shigenaga J.K., Moser A.H., Feingold K.R. and Grunfeld C. (2004). Thematic review series: The pathogenesis of atherosclerosis. Effects of infection and inflammation on lipid and lipoprotein metabolism mechanisms and consequences to the host. *J. Lipid Res.* **45(7),** 1169-1196.

Koh H.S. (2017). Lysophospholipid and its roles in intestinal health. *J. Nutr. Sci*. **6,** 35-45.

Kohn R.A., Dinneen M.M. and Russek-Cohen E. (2005). Using blood urea nitrogen to predict nitrogen excretion and efficiency of nitrogen utilization in cattle, sheep, goats, horses, pigs, and rats. *J. Anim. Sci.* **83 (4),** 879-889.

Kovács L., Pajor F., Bakony M., Fébel H. and Edwards J.E. (2023). Prepartum magnesium butyrate supplementation of dairy cows improves colostrum yield, calving ease, fertility, early lactation performance and neonatal vitality. *Animals.* **13,** 1319-1330.

Kreuzer M. (2019). Interactions between dietary components and gut microbiota: Implications for animal health. *Anim. Feed Sci. Technol*. **250,** 1-10.

Liu L., Sun D., Mao S., Zhu W. and Liu J. (2018). Infusion of sodium butyrate promotes rumen papillae growth and enhances expression of genes related to rumen epithelial VFA uptake and metabolism in neonatal twin lambs. *J. Anim. Sci.* **97(2),** 909-921.

Liu W., Zhu La A.L.T., Evans A., Gao S., Yu Z., Bu D. and Ma L. (2021). Supplementation with sodium butyrate improves growth and antioxidant function in dairy calves before weaning. *J. Anim. Sci. Biotechnol.* **12,** 2-14.

Liu L., Sun D., Mao S., Zhu W. and Liu J. (2019). Infusion of sodium butyrate promotes rumen papillae growth and enhances expression of genes related to rumen epithelial VFA uptake and metabolism in neonatal twin lambs. *J. Anim. Sci*. **97(2),** 909-921.

Ma N., Abaker J.A., Bilal M.S., Dai H. and Shen X. (2018). Sodium butyrate improves antioxidant stability in sub-acute ruminal acidosis in dairy goats. *BMC Vet. Res.* **14,** 275-285.

Maingret F., Patel A.J., Lesage F., Lazdunski M. and Honoré E. (2000). Lysophospholipids open the two-pore domain mechano-gated K (+) channels TREK-1 and TRAAK. *J. Biol. Chem.* **275(14),** 10128-10133.

Mazareei S., Mirzaei Aghjehgheshlagh F., Fathi- Achachlouei B., Mahdavi A. and Narenji sani R. (2024). Effects of extruded flaxseed and conjugated linoleic acid (CLA) on productive and reproductive performance of lactating qezel ewes. *Small Rumin. Res.* **231(2024),** 107180-107189.

Memon M.A., Dai H., Wang Y., Xu T., Aabdin Z., Bilal M.S., Chandra R.A. and Shen X. (2019). Efficacy of sodium butyrate in alleviating mammary oxidative stress induced by sub- acute ruminal acidosis in lactating goats, *Microb. Pathog.* **137,** 103781-103790.

Nakamura T., Nakamura-Takahashi A., Kasahara M., Yamaguchi A. and Azuma T. (2020). Tissue-nonspecific alkaline phosphatase promotes the osteogenic differentiation of osteoprogenitor cells. *Biochem. Biophys. Res. Commun.* **524,** 702-709.

Nicola M.S., Kalb A.L., Barbosa A.A., Velasquez B.E.S., Rincon J.A.A., Feijó J.O., Dellagostin E.N., Martins A.W.S., Blödorn E.B., Domingues W.B., Lopes F., Quinteiro-Filho W.M., Mondadori R.G., Campos V.F., Rabassa V.R., Komninou E.R., Delpino F.A.B. and Corrêa M.N. (2023). Butyrate supplementation in the liquid diet of dairy calves leads to a rapid recovery from diarrhea and reduces its occurrence and relapses in the preweaning period. *J. Dairy Sci.* **106,** 7908-7923.

NRC. (2007). Nutrient Requirements: Sheep, Goats, Cervids, and

New World Camelids. National Academy Press, Washington, DC, USA.

Porter N., Clark K., Rebelo L., Copelin J., Kwon I. and Lee C. (2024). Effects of saturated fatty acids with lysophospholipids on production and nutrient digestibility in lactating cows. *J. Dairy Sci*. **107(7),** 4524-4536.

Reis M.E., Toledo A.F., da Silva A.P., Poczynek M., Fioruci E.A., Cantor M.C., Greco L. and Bittar C.M.M. (2021). Supplementation of lysolecithin in milk replacer for Holstein dairy calves: Effects on growth performance, health, and metabolites. *J. Dairy Sci.* **104(5),** 5457-5466.

Ren Q.C., Xuan J.J., Wang L.K., Zhan Q.W., Yin D.Z., Hu Z.Z., Yang H.J., Zhang W. and Jiang L.S. (2018). Effects of tributyrin supplementation on ruminal microbial protein yield, fermentation characteristics and nutrients degradability in adult Small Tail ewes. *J. Anim. Sci.* **89,** 1271-1279.

Rice E.M., Aragona K.M., Moreland S.C. and Erickson P.S. (2019). Supplementation of sodium butyrate to postweaned heifer diets: Effects on growth performance, nutrient digestibility, and health. *J. Dairy Sci.* **102,** 3121-3130.

Roche J.R., Kay J.K., Phyn C.V.C., Meier S., Lee J.M. and Burke C.R. (2010). Dietary structural to nonfiber carbohydrate concentration during the transition period in grazing dairy cows. *J. Dairy Sci.* **93(8),** 3671-3683.

Sanjadi M. and Nayeri H. (2019). Evaluation of serum malondialdehyde concentrations and enzymatic activity of paraoxonase and arile esterase in women with a recurrent spontaneous abortion. *J. Kashan Univ. Med. Sci.* **23(5),** 535-542.

SAS Institute. (2004). SAS®/STAT Software, Release 9.4. SAS Institute, Inc., Cary, NC. USA.

Snyman G. and Olivier J.J. (1999). Repeatability and heritability of objective and subjective fleece traits and body weight in south african angora goats. *Small Rumin. Res.* **34(2),** 103-109.

Sun B., Jia Y., Hong J., Sun Q., Gao S., Hu Y., Zhao N. and Zhao N. (2018). Sodium butyrate ameliorates high-fat-diet-induced non-alcoholic fatty liver disease through peroxisome proliferator-activated receptor α-mediated activation of β oxidation and suppression of inflammation. *J. Agric. Food Chem.* **66,** 29-38.

Sun M., Ji W., Ye H., Cai Y., Yun Y., Wei X., Wang C. and Mao H. (2024). Sodium butyrate administration improves intestinal development of suckling lambs. *J. Anim. Sci.* **3(102),** 28-35.

Tan J., McKenzie C., Potamitis M., Thorburn A.N., Mackay C.R. and Macia L. (2014). The role of short-chain fatty acids in health and disease. *Adv. Immunol.* **121,** 91-119.

Tate B.N., Deys M., Gutierrez-Oviedo F.A., Ferguson A.D., Zang Y., Bradford B.J., Deme P., Haughey N.J. and McFadden J.W. (2023). Subcutaneous lysophosphatidylcholine administration promotes a febrile and immune response in holstein heifer calves. *J. Dairy Sci.* **107(6),** 3973-3987.

Tessari E.N., Kobashigawa E., Cardoso A.L.S., Ledoux D.R., Rottinghaus G.E. and Oliveira C.A. (2010). Effects of aflatoxin B1 and fumonisin B1 on blood biochemical parameters in broilers. *Toxins.* **2(4),** 453-460.

Titaux C., Ternynck C., Pauchet M., Stichelbout M., Bizet G., Maboudou P., Onraed B., Clément G., Lenne X., Potier G., Subtil D. and Chudzinski A. (2023). Total alkaline phosphatase levels by gestational age in a large sample of pregnant women. *Placenta.* **132,** 32-37.

Ulfina G.G., Kimothi S.P., Oberoi P.S., Baithalu R.K., Kumaresan A., Mohanty T.K., Imtiwati P. and Dang A.K. (2015). Modulation of post-partum reproductive performance in dairy cows through supplementation of long- or short-chain fatty acids during transition period. *J. Anim. Physiol. Anim. Nutr.* **99(6),** 1056-1064.

Van Keulen J.V. (1977). Evaluation of acid-insoluble ash as a natural marker in ruminant digestibility studies. *J. Anim. Sci.* **44,** 282-287.

Van Soest P.J., Robertson J.B. and Lewis B.A. (1991). Methods for dietary fiber, neutral detergent fiber, and no starch polysaccharides in relation to animal nutrition. *J. Dairy Sci.* **74,** 3583-3597.

Walsh S.W., Williams E.J. and Evans A.C.O. (2011). A review of the causes of poor fertility in high milk producing dairy cows. *J. Anim. Rep. Sci.* **123(3),** 127-138.

Yamashita K. (2010). Lysophosphatidylcholine promotes immunoglobulin production by B cells. *J. Immunol.* **184(10),** 5424-5430.

Yan J.J., Jung J.S., Lee J.E., Lee J., Huh S.O., Kim H.S., Jung K.C., Cho J.Y., Nam J.S., Suh H.W., Kim Y.H. and Song D.K. (2004). Therapeutic effects of lysophosphatidylcholine in experimental sepsis. *Nat. Med.* **10,** 161-167.

Zhang D., Jian Y.P., Zhang Y.N., Li Y., Gu L.T., Sun H.H., Liu M.D., Zhou H.L., Wang Y.S. and Xu Z.X. (2023a). Short-chain fatty acids in diseases. *Cell Commun. Signal.* **21,** 212-220.

Zhang J., Lijun B.U., Yapeng L., Wenjie H., Chengqiang X., Caixia P. and Qiang L. (2023b). Dietary supplementation of sodium butyrate enhances lactation performance by promoting nutrient digestion and mammary gland development in dairy cows. *Anim. Nutr.* **15,** 137-148.

Zhang W.H., Jiang Y., Zhu Q.F., Gao F., Dai S.F. and Chen J. (2011). Sodium butyrate maintains growth performance by regulating the immune response in broiler chickens. *Poult. Sci.* **52(3),** 292-301.

Zhao F., He W., Wu T., Elmhadi M., Jiang N., Zhang A. and Guan P. (2019). Supplementation of coated sodium butyrate relieved weaning stress and reshaped microbial flora in weaned lambs. *Front. Vet. Sci.* **11,** 1-11.

Zhao P., Zhang Z., Lan R., Liu W. and Kim I. (2016). Effect of lysophospholipids in diets differing in fat contents on growth performance, nutrient digestibility, milk composition and litter performance of lactating sows. *Animals*. **11(6),** 984-990.