Small Ruminant Research 259 (2026) 107750

Contents lists available at ScienceDirect

Small Ruminant Research

journal homepage: www.elsevier.com/locate/smallrumres

Factors influencing small ruminant colostrum quality: A comprehensive review from 2020 to present

K. DiGiacomo[a], M. González-Cabrera[b], K. Capdevila Ospina[a], A. Argüello[b,*], F. Zamuner[a], N. Castro[b]

[a] School of Agriculture, Food and Ecosystem Sciences, Faculty of Science, The University of Melbourne, Parkville, Vic 3010, Australia
[b] IUSA-ONEHEALTH 4 Animal Production and Biotechnology Group, Institute of Animal Health and Food Safety, Universidad de Las Palmas de Gran Canaria, (Campus Montaña Cardones, s/n, 35413, Arucas), Spain

ARTICLE INFO

Key words:
Colostrum
Small ruminants
Nutrition
Heat stress
Physiology

ABSTRACT

Colostrum is the primary source of passive immunity and nutritional support for neonatal small ruminants. Its quality and quantity are influenced by multiple interrelated factors including breed, litter size, parity, environmental stressors, maternal nutrition, metabolic and health status and management practices. This review consolidates findings from 2020 to the present, highlighting the genetic, physiological, nutritional, and environmental determinants of colostrum formation and their implications for offspring viability. Heat stress, maternal health and undernutrition during late gestation can compromise colostrum synthesis, composition, or immunoglobulin transfer. Conversely, targeted dietary supplementation and melatonin implants have shown potential in enhancing colostrum immunological and nutritional quality. Given the challenges posed by climate change and intensifying production demands, optimizing colostrum quality through genetic, nutritional, and management interventions remains a priority for improving early-life health outcomes in small ruminant systems.

1. Introduction

Colostrum is the first postpartum secretion of the mammary gland and serves as a critical source of nutrients, immune protection, and bioactive compounds for neonatal ruminants (Table 1; Baumrucker et al., 2023). Unlike humans, these neonates are born agammaglobulinemic due to the epitheliochorial structure of the placenta, which prevents a prenatal immunoglobulin transfer. Therefore, immediate and adequate colostrum intake is vital for ensuring passive immunity and early survival (Agenbag et al., 2021).

Based on a progressive decline of blood immunoglobulin (Ig) G and progesterone concentrations in the dams, colostrum is thought to be synthesized around 2–4 weeks before parturition (Brandon et al., 1971). Previous studies established the importance of colostrum immunoglobulin G (IgG) concentration and volume as the primary determinants of a successful transfer of passive immunity (TPI; Argüello et al., 2004; Castro et al., 2005), typically defined as serum IgG ≥ 12–15 mg/mL (O'Brien and Sherman, 1993; Alves et al., 2015) or serum total protein ≥ 5.5 g/dL within 24–48 h of birth in lambs and goat kids (Gökçe, Atakişi, 2019 Kelly et al., 2025). However, subsequent work expanded this understanding to include additional bioactive compounds, such as cytokines, enzymes, hormones, minerals, vitamins, and growth factors, that contribute to not only protect neonates from environmental pathogens but also facilitate intestinal development and metabolic programming (Fig. 1; Bigler et al., 2023).

Colostrum quality in small ruminants is commonly estimated using IgG concentration measured directly by laboratory assays (radial immunodiffusion or ELISA) or indirectly using refractometry. Reported values from observational surveys suggest that sheep and goat colostrum frequently exceeds 20 mg/mL IgG and approximately 20° Brix (Argüello et al., 2005; Kessler et al., 2021). However, these studies were descriptive in nature and did not evaluate associations with neonatal health, survival, or transfer of passive immunity outcomes. Therefore, these values should be interpreted as reported population averages rather than validated biological thresholds, and caution is warranted when defining universal quality cut-offs, particularly given that higher thresholds are used in other ruminant species such as dairy cattle.

Over the past two decades, numerous factors influencing colostrum

* Corresponding author.
E-mail address: tacho@ulpgc.es (A. Argüello).

https://doi.org/10.1016/j.smallrumres.2026.107750
Received 4 May 2025; Received in revised form 25 February 2026; Accepted 3 March 2026
Available online 11 March 2026

Table 1
Colostrum gross chemical composition and immunoglobulin G concentration in sheep and goats.

Specie	Chemical Composition			
	Lactose (%)	Fat (%)	Protein (%)	IgG (mg/mL)
Sheep	2.4 – 3.8	7.4 – 13.2	8.2 – 22.5	22.9 – 44.2
Goats	2.0 – 4.4	4.0 – 8.0	10.6 – 17.1	26.6 – 41.1

References: Galán-Malo et al. (2014); Alves et al. (2015); Hernández-Castellano et al. (2016); Kessler et al. (2019, 2020); Zarrin et al. (2021). Abbreviation: IgG = Immunoglobulin G

synthesis and composition have been identified (Fig. 1). Species and breed differences have been demonstrated to influence colostrum composition, with dairy breeds typically producing greater yields and lower immunoglobulins concentrations and solids compared to meat or dual-purpose breeds (Kessler et al., 2019). Additionally, physiological factors such as body condition score (BCS) and maternal metabolic status influence the availability of nutrients and precursors for colostrogenesis (Chagas et al., 2023; Bentley et al., 2024) while exogenous interventions such as melatonin implants have been investigated for their capacity to enhance colostral immunoglobulin concentrations and antioxidant status (Bouroutzika et al., 2021; Canto et al., 2022). Maternal nutrition during late gestation has been consistently linked to colostrum yield and immunological quality, with undernutrition reducing both IgG concentration and volume (Banchero et al., 2015; Chadio et al., 2016). Supplementation with energy-dense diets, and trace minerals has been shown to enhance colostrum composition and neonatal vigor in sheep (Banchero et al. 2004; Sales et al., 2020). These factors often interact with environmental stressors, particularly heat stress, which has been shown to impair mammary gland immune function (Skibiel et al., 2022) and dam metabolism (Baumgard and Rhoads, 2013; Chauhan et al., 2021).

Despite this progress, key knowledge gaps persist. Much of the available information remains inconsistent across studies due to varying methodologies, and none have synthesized findings across genetic, nutritional, environmental, and physiological factors. Given the recent influx of research exploring small ruminant colostrum quality, nutritional strategies, and management practices during late gestation, an updated synthesis is warranted. This review aims to consolidate current knowledge on the main factors affecting colostrum yield and quality in small ruminants (i.e., sheep and goats) and to identify the priorities for future research in this field.

2. Search strategy and selection criteria

A comprehensive literature search was conducted to identify peer-reviewed studies addressing factors influencing colostrum quality, yield, and composition in small ruminants as well as those factors impacting transfer of passive immunity and neonatal performance. The search was performed across major databases such as Web of Science, Scopus and PubMed to ensure broad coverage of relevant disciplines, including animal science, veterinary medicine, and physiology. The search terms combined key concepts and species-specific descriptors as follows: *("colostrum quality" OR "colostrum composition" OR "colostrum*

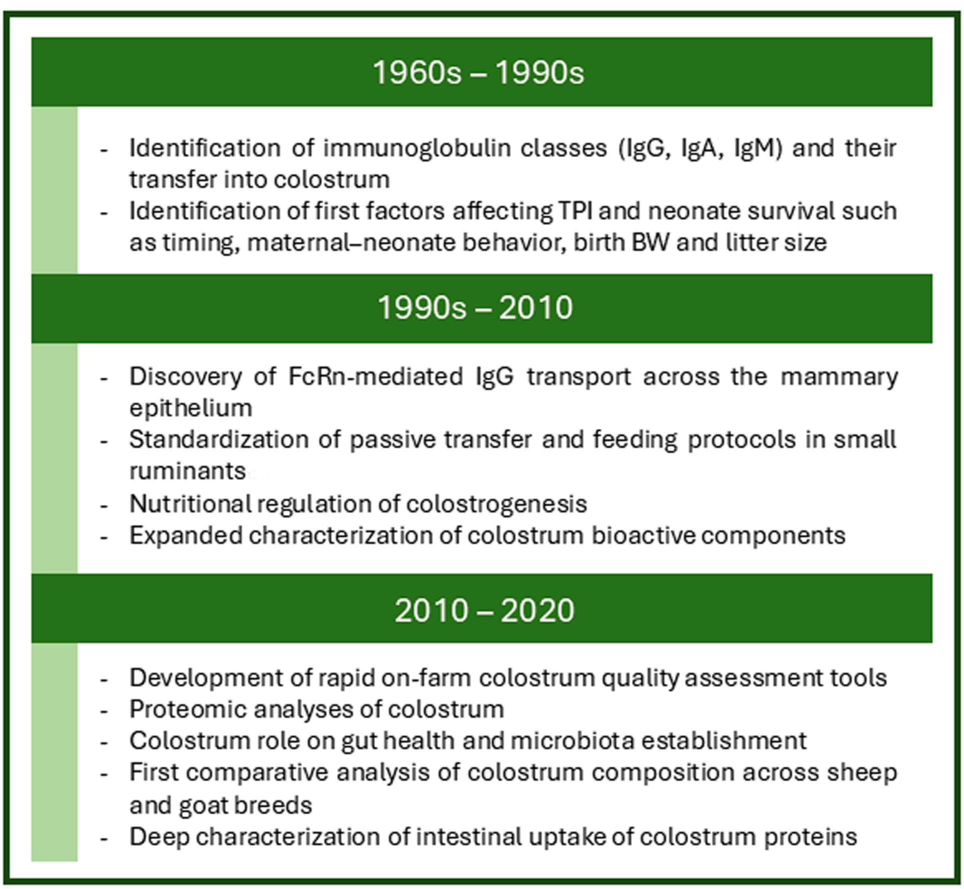

Fig. 1. Summary of key milestones in small ruminant colostrum research.References: Purser & Young (1964); Klaus et al. (1969); Brandon et al. (1971); Alexander (1974); Larson et al. (1980); Kacskovics et al. (2000); Kruzel et al. (2001); Arguello et al. (2004); Banchero et al. (2004); Castro et al. (2005); Banchero et al. (2006); Argüello et al. (2008); Hiss et al. (2008); Moretti et al. (2012); Nordi et al. (2012); Moretti et al. (2013); Ruiz et al. (2014); Hernández-Castellano et al. (2015); Lu et al. (2016); Hernández-Castellano et al. (2016); Abecia et al. (2017); Lopreiato et al. (2017); Castro et al. (2018); Kessler et al. (2019); Zobel et al. (2020); Zhu et al. (2021). Abbreviations: TPI = Transfer of passive immunity; BW = body weight; FcRn = Neonatal Fc receptor.

yield"), ("sheep/ewe" OR "goat") and ("metabolism" OR "nutrition" OR "heat stress"). The time frame considered was January 2020 to December 2024, focusing on recent advances in genetic, nutritional, environmental, and management factors affecting colostrum and neonatal performance. Articles were assessed based on their title and abstract, followed by full-text review. Studies were included if they reported original data on colostrum composition or immunological parameters, assessed the influence of physiological, nutritional, environmental, or management factors, and provided sufficient methodological detail. Studies without clear experimental designs were excluded. To minimize bias in data interpretation, each selected study was critically evaluated for experimental design quality (e.g., sample size, and replication) and rigor (e.g., validated quantification of IgG). Previous studies were included when necessary to provide context or support discussions. Only articles written in English were considered.

3. Genetic and physiological factors

Colostrum quality, typically determined by yield and immunoglobulin concentration especially IgG, can be associated with several dam factors such as genetics, litter size, parity (Buranakarl et al., 2021; Zhou et al., 2023b) and metabolic status (Banchero et al., 2004). Recent studies focussing on these factors have found that they can highly impact colostrum characteristics (Table 2). Therefore, this section summarizes peer-reviewed findings from 2020 to present, covering sheep and goats focusing on the influence of species and breed related factors, litter size and parity on colostrum yield and composition.

3.1. Genetics

Several studies highlight that breed, or genetic line significantly influences the composition and immunological value of colostrum in sheep and goats. Agradi et al. (2023) assessed colostrum in different goat breeds in Northern Italy finding notable differences in immunoglobulin content and nutritional composition. Despite colostrum yield was not reported, meat-oriented breeds (i.e., Frisa and Lariana) had significantly higher IgG concentrations and total solids compared to dairy breeds such as Camosciata delle Alpi, being likely associated with a high selection pressure towards greater milk yields (Kessler et al., 2019). In contrast, Buranakarl et al. (2021) compared Black Bengal, Saanen, and crossbred goats observing that Saanen and crossbreds had higher colostral IgG and vitamin A concentrations. These differences may be attributed to breed-specific traits such as the mammary gland development and metabolism and the immune system but also to the prepartum maternal nutrition (Hare et al., 2023). Although Kessler et al. (2019) and Agradi et al. (2023) studies suggest that milk yield selection appears to be negatively associated with colostrum quality, this should not be generalized for every local breed. Besides the genetic factors, nutrition and management practices have been shown to also contribute to these differences observed between breeds.

Similarly, genetic variations in sheep have also been reported to affect colostrum yield. Indeed, Higgins et al. (2023) observed that sheep selected for large litter sizes produced greater volumes of colostrum, likely as an adaptive response to nourish multiple lambs. Also, Richardson et al. (2023) explored how udder conformation relates to colostrum composition in Suffolk sheep, finding better colostrum quality estimated by total protein concentration and Brix values in well-formed udders, which was defined by traits such as udder floor, depth, teat placement and teat/mammary lesions. This suggests that selection for udder conformation could, indirectly, improve neonatal outcomes through better access to colostrum and efficient nursing.

In addition, Zhou et al. (2023a) took this further by identifying specific genetic mutations in Hu sheep linked to colostrum yield, indicating that colostrum quality traits may be heritable and subject to selection. For instance, missense variants in *SRC* and *HIF1A* genes are significantly associated with colostrum yield and elevated concentrations of IgG, IgA, and IgM concentrations (Zhou et al., 2023a). In dairy goats, polymorphisms in *POU1F1, PRLR*, and β-Lactoglobulin (*β-Lg*) have been associated with higher milk yield, lactation length, and average daily yield (Gündüz, Biçer, 2023), traits that likely influence mammary secretory capacity. Despite this, no studies have addressed such genes related to colostrum yield. Additionally, Ma et al. (2024) complemented Morammazi et al. (2016) findings, describing that *PRLR* expression in crossbreed goats modulates the proliferation and secretion of mammary epithelial cells, meaning that prolactin signaling may be involved in the mammary gland development during colostrogenesis. While these studies do not always address colostrum quality, their findings strengthen the importance of these genes in mammary development. Validation of these associations for colostrum traits (e.g., immunoglobulins and other bioactive compounds) is necessary as they may constitute robust candidates for breeding strategies targeting enhanced colostrum quality.

It should be noted that colostrum quality is not solely determined by IgG concentration but by the total mass of immunoglobulins available to the neonate, which depends on both concentration and volume. High-yielding animals may produce large volumes of colostrum with comparatively lower IgG concentrations, potentially resulting in similar total IgG mass as animals producing smaller volumes with higher concentrations. Unfortunately, most recent studies have not reported colostrum yield together with IgG concentration, likely due to experimental limitations often associated with extensive management systems, facilities or reliance on farmer-collected samples. Current knowledge on colostrum quality in goats and sheep is constrained, therefore future research would require adopting more standardized and controlled methodologies to improve the comprehensiveness and applicability of these findings.

3.2. Litter size

Litter size is a critical factor influencing colostrum yield and potentially its composition. According to Zhou et al. (2023b), large litter sizes may be associated with the dilution of some colostrum components in goats. In contrast, Buranakarl et al. (2021) reported that does bearing multiple kids did not show lower nutrients or IgG concentrations in their colostrum. However, the effect of litter size on colostrum yield was not determined as the kids were reared with the dams. In sheep, Higgins

Table 2
A schematic representation of how breed, parity, litter size, management and health factors affect colostrum yield and quality in sheep and goats.

Colostrum	Breed	Parity	Litter size	Management	Health
Yield	Dairy ↑	Multiparous ↑	≥ 2 fetuses ↑	Induced parturition ↓	—
Quality					
Gross composition	Meat ↑	Multiparous ↑	≥ 2 fetuses ↑	Melatonin implant ↑	Viral infections ↓
IgG concentration	Meat ↑	Multiparous ↑	—	Melatonin implant ↑	Viral infections↓ Mastitis ↑

Responses are relative to treatment compared to control, where arrows (↑/↓) indicate significant ($P < 0.05$) increase or decrease, and a dash line (—) indicates not reported. References: Bouroutzika et al. (2021); Buranakarl et al. (2021); Gavette (2021); Wallace et al. (2021); Canto et al. (2022); Agradi et al. (2023); Alcindo et al. (2023); Chagas et al. (2023); Higgins et al. (2023); Tekin and Akkus (2023); Zhou et al. (2023a; 2023b); Aphrodite and Athanasios (2024); González-Cabrera et al. (2024a).

et al. (2023) reported similar findings. Prolific ewes produced more colostrum, although lambs from large litters (i.e., twins or triplets) showed lower birth body weights (BW) and slightly delayed suckling behaviors. Similarly, Abdul-Rahman and Aguli (2024) observed that West African Dwarf singleton kids exhibited earlier suckling and higher vigor than twins. Therefore, despite the greater colostrum yield, multiple litters can increase the risk of a failure in the TPI, especially when colostrum intake is insufficient or delayed as macromolecules absorption during the first hours after birth might be compromised (Moretti et al. 2012; Weström et al. 2020). Regarding this fact, practical challenges remain to be solved as colostrum must be of good quality and shared between multiple neonates, potentially lowering per-animal intake unless colostrum feeding is monitored and managed properly.

Additionally, it has been demonstrated that large litter sizes increase maternal energy demands, compromising colostrum synthesis among other physiological process. Chagas et al. (2023) reported that multiparous ewes bearing triplets had the poorest colostrum quality, determined by low Brix values, and triplet lambs exhibited the lowest serum immunoglobulin concentration and BW. Thus, it seems that a marked negative energy balance, frequently linked to a physical limitation for feed intake in multiple bearing animals as well as an inadequate diet formulation, may reduce the availability of required nutrients for colostrogenesis. Therefore, maintaining optimal BCS and adequate nutritional management practices during late gestation are essential to guarantee a successful colostrum synthesis.

3.3. Parity

Parity, the number of times a female has given birth, has been shown to influence colostrum yield and quality. Multiple studies have reported that multiparous animals produce colostrum with higher immunoglobulin content and better overall composition compared to primiparous dams. In agreement with previous literature, Buranakarl et al. (2021) found that colostrum IgG concentrations were significantly higher in multiparous than in primiparous goats. These differences may be attributed to greater and diverse antigen exposure and an increased mammary gland development in older dams. However, studies have also shown that parity does not affect colostrum composition (Kessler et al. 2019), and that the observed differences between primiparous and multiparous may be more attributable to management factors such as maternal nutrition and immunization protocols rather than inherent physiological limitations in first-time pregnant animals. These contrasting findings highlight the need for future large-scale studies to clarify the true impact of parity on colostrum quality.

4. Nutritional factors

Maternal nutrition is a major contributing factor to colostrum quality and quantity (Table 3; Agenbag et al., 2021; Hare et al., 2023). Colostrum is rich in immunoglobulins, macronutrients (e.g., fats, proteins, carbohydrates), micronutrients (e.g., vitamins, minerals), and bioactive compounds (e.g., growth factors, lactoferrin, cytokines), all of which are essential for neonatal nourishment and passive immunity (Hare et al., 2023). Proper maternal nutrition not only ensures adequate nutrient supply for colostrum synthesis but also aids in hormonal regulation of colostrogenesis, promotes mammary gland development, and supports the accumulation of body reserves essential for sustaining lactation (Tucker, 2000; Banchero et al., 2015; Bigler et al., 2023). Dietary interventions influence colostrum yield and composition primarily by modulating metabolic and hormonal pathways.

In ruminants, colostrogenesis, defined as the transfer of immunoglobulins (primarily IgG) from the maternal circulation into mammary secretions, is regulated by a complex interplay of various hormones, primarily influenced by the decline of progesterone and the rise of prolactin and estradiol (Tucker, 2000; Bigler et al., 2023). Adequate feed intake enhances blood flow and hepatic clearance of progesterone, allowing for more timely and efficient hormonal transitions needed for lactogenesis (Banchero et al., 2015; Hare et al., 2023). Additionally, dietary energy and protein intake modulate growth hormone and insulin-like growth factor 1 (IGF-1) levels, improving nutrient partitioning towards mammary tissue and supporting colostrum production and mammary cell function (Tucker, 2000; Banchero et al., 2015; Hare et al., 2023). However, meeting metabolic requirements during the last 4–5 weeks of gestation can be quite challenging, as this period coincides with intense mammary gland development and rapid fetal growth, which significantly increases metabolic demands. At the same time, the expanding gravid uterus compresses the rumen, reducing voluntary feed intake and further limiting the dam's ability to meet its nutrient requirements (Tucker, 2000; Hare et al., 2023). This challenge is particularly pronounced in dams carrying multiple fetuses, a common occurrence in small ruminants.

4.1. Carbohydrates

To mitigate these challenges, several studies have explored the use of energy-dense supplementary feeding, like cereal grains or concentrates, during the final month of gestation, which can provide high energy and/or protein in a small volume of feed. This low-cost and practical intervention has been shown to not only increase colostrum yield but also its composition. For instance, supplementing Corriedale ewes with 0.5 kg/day of an energy-protein lick (24% CP, 14.6 MJ ME/kg; -2 weeks to lambing; Olivera-Muzante et al., 2022) and crossbred goats with 0.6 kg/day of flaked corn (8.7% CP, 12.8 MJ ME/kg; -2 weeks to kidding; Ramírez-Vera et al., 2012) boosted colostrum yield by 2.1- and 3.5-fold, respectively (Table 3). In contrast, Villar et al. (2023) found only a marginal, non-significant 25% improvement in colostrum yield in single-bearing Merino ewes under extensive grazing supplemented with a daily mix of 250 g corn and 250 g oat grain (10.4% CP, 10.6 MJ ME/kg; −2 weeks to lambing; Table 3). The authors attributed the limited response to lower amount of starch in oat grain available for post-ruminal digestion (2% compared to 14% for corn), which may have reduced glucose availability for colostrum synthesis. Indeed, higher colostrum yields resulting from starch supplementation are often associated with increasing lactose content (Ramírez-Vera et al., 2012; Olivera-Muzante et al., 2022) and declines in fat and protein concentrations (Ramírez-Vera et al., 2012; Zarrin et al., 2021), likely due to a dilution effect. Nevertheless, Babaei et al. (2019) compared the effects of feeding high and low levels of corn (starch:NDF; 0.59 and 0.39) or high and low levels of a mixture of wheat and barley (starch:NDF; 0.64, and 0.41) in Afshari Merino-cross ewes (-24 d to lambing; Table 3). Despite higher plasma glucose in ewes fed diets with high starch:NDF ratios, no discernible link was found between these diets and colostrum yield or composition. Although both single- and twin-bearing ewes were included in the study, the effects of litter size, if any, were not reported. This is unfortunate, as previous studies suggest that litter size may indirectly influence the digestibility of different feeds by affecting digesta passage rate (Hare et al., 2023).

4.2. Protein

On the other hand, colostrum yield and quality appear to be less responsive to protein-rich feeds. Kopp et al. (2020) reported that, when supplementing twin-bearing Merino ewes (-21 d to lambing) with barley (0.6 kg/d), the addition of canola meal (120 g/d) to the diet did not affect colostrum yield or composition, despite the greater ME and CP intake in the barley plus canola meal group, compared to barley alone (13 vs. 11 MJ/d and 69 vs. 38 g/d, respectively; Table 3). In contrast, in single-bearing Merino ewes grazing natural grassland (-60 d to lambing), supplementation with lupin grain (230 g/d; 29% CP, 14 MJ ME/kg) reduced colostrum protein percentage by 20%, while oat supplementation (270 g/d; 12% CP, 12 MJ ME/kg) increased colostral protein by 32% and IgG by 22% (Castellaro et al., 2022; Table 3).

Table 3
Summary of colostrum yield and composition responses to maternal nutrition in sheep and goats.

Species	Study	Dietary strategy	Period (until parturition)	Responses[a]				
				Yield	IgG	Fat	CP	Lactose
Sheep	Olivera-Muzante et al., 2022	Protein-lick (500 g/d)	-2 wks	↑ (2.1 ×)	—	↓	↓	↑
	Villar et al., 2023	Corn (250 g/d) + Oat (250 g/d)	-2 wks	ns	—	—	—	—
	Kopp et al., 2020	Canola (120 g/d)	-21 d	ns	ns	ns	ns	—
	Castellaro et al., 2022	Lupin (230 g/d)	-60 d	—	ns	↑ (50%)	↓ (20%)	—
		Oat (270 g/d)		—	↑ (22%)	ns	↑ (32%)	—
	Ababakri et al., 2021	Flaxseed (10% DM)	-3 wks	ns	—	ns	ns	—
		RUP (40 vs. 20% DM)		ns	—	ns	ns	—
	Nurlatifah et al., 2022	Lemuru Oil (6% DM)	-2 wks	—	—	ns	ns	ns
		Palm Oil (6% DM)		—	—	ns	ns	ns
		Lemuru + Palm Oil (3 + 3% DM)		—	—	ns	ns	ns
	Coleman et al., 2018	EPA (3.2 g/d) + DHA (2.2 g/d)	-50 d	—	—	↑ (CLA, PUFA)	—	—
	Babaei et al., 2019	High starch:NDF ratio	-24 d	ns	—	ns	ns	—
	Moradi et al., 2021	Extra ME (10% DM) from corn	-5 wks	↑ (13%)	—	ns	↑ (8%)	↑ (18%)
		Extra ME (10% DM) from flaxseed		↑ (32%)	—	↑ (15%)	↑ (11%)	ns
		Extra MP (10% DM) from bypass Lys+Met		↑ (54%)	—	ns	↑ (17%)	ns
	McGovern et al., 2015	ME 20% below requirements	-5 wks	↓ (6%)	—	—	ns	—
		ME 20% above requirements		↑ (17%)	—	—	ns	—
	Barcelos et al., 2023	Se (3.2 mg/Kg DM)	-38 d	ns	—	ns	ns	ns
	Voigt et al., 2022	Se (81.8 µg/kg of BW)	—	↑	—	—	—	—
	Khorrami et al., 2024	Se (0.2 mg/d) + Zn (20 mg/d)	-45 d	—	—	—	—	—
	Asadi et al., 2024	Organic Mn (40 mg/kg of DM)	-50 d	—	↑ (28%)	—	—	—
		Organic Mn (80 mg/kg of DM)		—	↑ (33%)	—	—	—
	Ataollahi et al., 2020	Ca (0.72% DM)	-30 d	—	ns	—	—	—
		Mg (0.72% DM)		—	ns	—	—	—
		Ca (0.66% DM) + Mg (0.47% DM)		—	ns	—	—	—
	Bompadre et al., 2020	CrPic (0.15 mg/d)	-7 months	—	ns	—	ns	—
		CrPic (0.30 mg/d)		—	ns	—	ns	—
		CrPic (0.45 mg/d)		—	ns	—	ns	—
	de Ávila Sphor et al. 2021	NaCl (13%) added to the concentrate ad libitum feeding	-30 d	ns	—	ns	ns	ns
		NaCl (17%) added to the concentrate ad libitum feeding		ns	—	ns	ns	ns
	Kopp et al., 2021	Niacin (5 g/d)	-14 d	ns	ns	ns	↑ (6%)	ns
	Navarrete et al., 2021	Liquid yeast (60 g DM/d)	-45 d	—	ns	ns	ns	—
	Duniere et al., 2022	*Saccharomyces cerevisiae* (8×10^9 CFU/d)	-30 d	—	↑ (50%)	ns	ns	ns
	Fallah et al., 2021	Lycopene (100 mg/d)	-10 d	ns	↑ (8%)	ns	ns	ns
		Lycopene (100 mg/d) + corn (300 g/d)		↑ (65%)	↑ (40%)	↑ (18%)	↑ (7%)	↑ (1.1 ×)
	Mirzaei-Alamouti et al., 2021	Broadleaf plantain and peppermint extract (2 g/d) + monensin (30 mg/d)	-21 d	↑ (31%)	—	—	—	—
		Broadleaf plantain and peppermint extract (2 g/d)		↑ (25%)	—	—	—	—
		Monensin (30 mg/d)		↑ (29%)	—	—	—	—
	Murdock et al., 2021	Caffeine (10 mg/Kg BW)	-30 d	—	ns	—	—	—
		Caffeine (20 mg/Kg BW)		—	ns	—	—	—
		Caffeine (20 mg/Kg BW)	-1 wk	—	ns	—	—	—
Goat	Ramírez-Vera et al., 2012	Corn (600 g/d)	-2 wks	↑ (3.5 ×)	—	↓	↓	↑
	Rahmani et al., 2017	Extra ME (+10% DM)	↑ (SFA)	ns	—	—	—	—
		Extra CP (+10% DM)		ns	—	—	—	—
		Extra ME + CP (10 + 10% DM)		ns	—	—	—	—
	Shabrandi et al., 2019	Extra ME (+10% DM)	-50 d	ns	—	ns	—	—
		Extra CP (+10% DM)		ns	—	ns	—	—
		Extra ME + CP (10 + 10% DM)		↑ (40%)	—	↑ (13%)		
	Mehmood et al., 2023	Se (2.2 mg/kg + Vit E (2.5 mg/kg)	-30 d	—	—	—	↑ (32%) TSP	—
	Hashem et al., 2021	*Boswellia sacra* resin (2 g/d)	-2 wks	—	ns	ns	↑ (8%)	↑ (44%)
		Boswellia sacra resin (4 g/d)		—	ns	↑ (37%)	↑ (9%)	↑ (34%)
	Viola et al., 2022	Hazelnut skin (116 g/Kg DM)	-45 d	—	↑ (55%)	—	—	—
	Ghavipanje et al., 2022	Dietary berberine (1 g/d)	-21 d	ns	—	ns	ns	ns
		Dietary berberine (2 g/d)		↑ (1 ×)	—	↓ (FAA, MUFA) ↑ (SFA)	ns	ns
		Dietary berberine (4 g/d)		ns	—	↓ (FAA) ↑ (SFA)	ns	ns
	Afzal et al., 2021	*Moringa oleifera* leaf powder (5 g/d)	-60 d	—	—	ns	ns	ns
		Moringa oleifera leaf powder (8.75 g/d)		—	—	ns	↑ (33%)	ns

Abbreviations: DM = dry matter; RUP = rumen undegradable protein; EPA = eicosapentaenoic acid; DHA = docosahexaenoic acid; NDF = neutral detergent fibre; ME = metabolizable energy; MP = metabolizable protein; CP = crude protein; ns = non-significant; BW = body weight; FFA = free fatty acids; SFA = saturated fatty acids; MUFA = mono-unsaturated fatty acids; PUFA = polyunsaturated fatty acids; TSP = total solid protein; Se = selenium; Zn = zinc; Mn = manganese Ca = calcium: Mg = magnesium; CrPic = chromium picolinate; NaCl = sodium chloride; CFU = colony forming unit.

[a] Responses are relative to treatment compared to control (or first listed vs. second), where arrows (↑/↓) indicate significant ($P < 0.05$) increase or decrease, 'ns' means not significant, and a dash line (—) indicates not reported.

However, the authors did not report colostrum yield in this study. Differences between studies may lie in the duration of supplementation, as well as in the nutrient profiles and digestibility of the feed used. While the addition of canola meal failed to improve colostrum yield and quality, lupin supplementation was found to be detrimental to colostral protein levels. These findings underscore the importance of balancing digestible energy and protein levels to optimize colostrum production. Excessive protein intake, particularly at high rumen-degradable protein to rumen-undegradable protein (RDP:RUP) ratio, has been linked to elevated urea levels when not matched with an adequate energy supply, which can impair glucose utilization and colostrum synthesis (Banchero et al., 2015; Hare et al., 2023).

4.3. Fats

Dietary fat, as a concentrated energy source, can help meet the increased energy demands in late gestation and may also improve ration palatability and reduce the heat increment of feeding, but inclusion should remain below 6–7% DM to avoid disrupting ruminal fermentation (Hare et al., 2023; Table 3). Recent studies suggest that while dietary fat inclusion during late gestation may have minimal effects on colostrum yield and composition, it can significantly alter the fatty acid (FA) profile, enhancing its nutritional quality and balance. For example, Ababakri et al. (2021) found that the inclusion of flaxseed [rich in polyunsaturated FA (PUFA)] at 10 vs. 0% DM (resulting in 6 vs. 3% crude fat, respectively) in the diet of Baluchi ewes (-3 weeks to lambing) had no evident effect on colostrum yield or percentages of fat and protein. Similarly, Nurlatifah et al. (2022) reported that supplementing Garut ewes (-2 weeks to lambing) with 6% lemuru oil (rich in PUFA), 6% palm oil (rich in saturated FA), or a combination of 3% of each, did not significantly affect colostrum composition or density (Table 3). In contrast, Coleman et al. (2018) found that increasing dietary PUFA in Suffolk ewes (-50 d to lambing) through eicosapentaenoic acid (3.2 g/d) and docosahexaenoic acid (2.2 g/d) improved colostrum quality, increasing total PUFA content (+2.3%), conjugated linoleic acid (+18%), and reducing the n-6/n-3 ratio (from 5.4 to 5.1; Table 3). However, while Ababakri et al. (2021) and Nurlatifah et al. (2022) reported on colostrum yield and composition without analyzing the fatty acid profile, Coleman et al. (2018) focused on fatty acid profile but did not report on yield or composition, and none of them assessed the effects of fat supplementation on colostral IgG, making it difficult to fully assess the nutritional and immunological benefits of dietary fat during late gestation. In beef cows, supplementation with 200 g/d of rumen-protected unsaturated FA (-90d to calving) markedly improved colostrum FA profile by increasing short-medium chain FA by 25%, PUFA by 150%, and monounsaturated FA by 27%, while also increasing colostral IgG by 62%, which led to an approximate 50% increase in plasma IgG concentrations in calves born to supplemented cows (Ricks et al., 2020). These results raise the possibility that improved FA profiles and IgG concentrations could be achieved in small ruminants with rumen-protected FA, a hypothesis that warrants further investigation.

4.4. Energy and protein supplementation

Beyond the type of feed, studies have investigated the effects of supplementing energy, protein, or their combination, as well as the starch:NDF and RDP:RUP ratio, shedding light on their roles in colostrum yield and composition. Wang et al. (2022) analyzed the effects of CP levels (9, 12, and 15% CP) during late gestation (-60d to lambing) in Hu sheep and revealed that a 15% CP resulted in a positive change in the proteomic profile of the colostral fat globule membrane (Table 3). This included increased abundance of proteins involved in immune defence, protein metabolism, and transport, suggesting a potential functional benefit for neonatal immune protection and adaptation. In goats, Rahmani et al. (2017) reported no significant changes in colostrum yield when increasing ME, MP, or their combination (+10% ME, +10% MP, or +10% ME and +10% MP) in single-bearing Sistani goats. However, Shabrandi et al. (2019), using a similar experimental design, found that only the group receiving the combined supplementation (+10% ME and +10% MP) showed increased colostrum yield (+40%) and fat content (+13%). The contrasting results may reflect differences in litter size and associated metabolic demand, as Rahmani et al. (2017) included only single-bearing goats, while Shabrandi et al. (2019) may have included multiple-bearing animals. The presence of multiple fetuses could have increased metabolic demands and mammary stimulation, amplifying the response to the combined ME and MP supplementation.

In sheep, Moradi et al. (2021) found that feeding Zell ewes (-6 weeks to lambing) with an extra 10% ME (using corn), or extra 10% MP (using a rumen-protected lysin and methionine supplement) led to gains in colostrum yield by 13 and 54% and in total solids by 9 and 11%, for ME and MP, respectively (Table 3), compared with a control diet formulated to meet 100% of the nutrient requirements for maintenance and pregnancy. These gains were even more pronounced for fat, protein, and lactose yields, which increased by 73%, 80%, and 50% with extra 10% MP and by 19%, 22%, and 33% with extra 10% ME (Table 3). In contrast, Ababakri et al. (2021), using an isoenergetic and isonitrogenous diet (12% CP, 9.2 MJ ME/kg), found no discernible link between varying RUP levels (20% vs. 40%) in Baluchi ewes (-3 weeks to lambing) and colostrum yield or composition, despite increased plasma glucose and urea concentrations in the higher RUP group. Variation in colostrum yield across studies may stem from inter-species variability between sheep and goats (e.g., metabolic demands, nutrient partitioning) and intra-species factors (e.g., litter size, breed). Additionally, variations in the timing and duration of supplementation, as well as the nutrient profiles and digestibility of the feed used (e.g., starch:NDF and RDP:RUP ratios), likely contribute to the inconsistent results, highlighting the complexity of optimizing colostrum production.

4.5. Minerals

In addition to macronutrient supplementation, several studies have evaluated the effects of micronutrients and bioactive compounds on colostrum quality. While mineral interactions can significantly influence nutrient bioavailability and metabolism, their complex nature falls beyond the scope of this review and will not be addressed herein. Among these, mineral supplementation during pregnancy has received growing attention, with selenium (Se), zinc (Zn), and manganese being commonly studied for their potential to enhance colostrum traits. In particular, the administration of Se during pregnancy has shown an influence on sheep's milk composition and yield. For instance, the inclusion of organic Se in the diets of Saanen goats (3.2 mg/kg DM; -38 to kidding), lowered the milk solids (13 vs. 11%), with no apparent impact on colostrum composition or somatic cell count (Barcelos et al., 2023; Table 3). Moreover, Voigt et al. (2022) explored the inclusion of adequate and high levels of Se (9.5 vs. 81.8 μg/kg of BW) in the diets of pregnant Rambouillet ewes, and reported that at high Se supplementation, more abundance of the FcRn receptor (responsible for the transcellular IgG transport from maternal circulation into mammary secretions) was found in the mammary gland, along with higher colostral IgG concentration. Furthermore, the injection of a combination of Se and vitamin E (2.2 and 2.5 mg/kg of BW, respectively) in Beetal goats (-30 d to kidding) improved antioxidant indices [(e.g. total antioxidant capacity (+3%), superoxide (+147%) and peroxidases activity (+13%) and the total soluble protein concentration of their colostrum (+32%)] (Mehmood et al., 2023; Table 3). In addition, Khorrami et al. (2024), compared the administration of Se and Zn in ewes, by feeding in the diet (0.2 and 20 mg/d (both inorganic forms), respectively; -45 d of lambing) or using a ruminal slow-release bolus (Table 3). Their results showed higher total antioxidant capacity (+17%) and levels of Se (+55%) and Zn (+55%) in the colostrum of supplemented ewes, regardless of the administration route. However, global variations in permissible dietary selenium levels may limit the practical application of research-proven effective supplementation rates. Results from Asadi et al. (2024) evaluating the effect of organic manganese supplementation (40 and 80 mg/kg of DM; -50 d to lambing) in the diets of Afshari sheep, found increased levels of IgG (+28 and 33%) in the colostrum (Table 3). This finding was also correlated with the increased level of IgG (+9%) in the plasma of 2-day-old lambs.

In contrast, the supplementation of dietary treatments with high levels of calcium (Ca), magnesium (Mg) or the combination of both (0.72% DM Ca, 0.48% DM Mg, and 0.66% DM Ca + 0.47% DM Mg; -30 d to lambing) in Merino ewes, showed no effect on the colostral IgG levels (Ataollahi et al., 2020; Table 3). Nevertheless, in the same study, the high total antioxidant capacity of plasma was higher in lambs born from supplemented ewes with Mg (+33%) and the Mg + Ca combination (+20%). The antioxidant quality of colostrum was also influenced with the supplementation of chromium picolinate (0.45 mg/d), during the breeding and pregnancy in Santa Ines ewes, which had no apparent effect on colostral IgG, but decreased peroxidase activity (- 48%; Bompadre et al., 2020). Finally, the colostrum of sheep seems to be less responsive to supplementation with NaCl, neither colostrum yield nor composition differ in Corriedale ewes that consumed concentrate with added salt (13 and 17% of NaCl added to the concentrate at ad libitum feeding; -30 d to lambing; de Ávila Sphor et al. 2021). Collectively, further research should focus on determining the maximum inclusion levels without deleterious effects on the colostrum quality.

4.6. Vitamins

Vitamin supplementation has shown influence on the antioxidant indices and protein levels of colostrum in sheep and goats. For instance, Kopp et al. (2021) supplemented Merino ewes with niacin (5 g/d of vitamin B3; -14 d to lambing), and reported higher levels of colostrum protein concentration (12 vs.13%; Table 3). However, colostrum yield, IgG concentration and gross chemical composition were not significantly affected. Similarly, Sales et al. (2020) found no clear effect on the udder volume at birth of Corriedale ewes supplemented with vitamin C and vitamin E (650 mg vitamin C and 450 UI of vitamin E / -100 d to lambing; Table 3). On the other hand, in Beetal goats, the administration of vitamin E associated with Se (2.2 mg Se and 2.5 mg/kg vitamin E /kg of BW; -30 d to lambing) improved the total antioxidant capacity (+3%) and total protein content (+32%) of the colostrum (Mehmood et al., 2023; Table 3).

4.7. Probiotics

Studies evaluating yeast supplementation in sheep have reported no significant changes in colostrum fat, protein, or lactose content, while findings on IgG concentration have differed among trials. For instance, Navarrete et al. (2021) reported no significant effect of liquid yeast inclusion (32 g or 60 g DM/animal/day; -45 d to lambing) in Suffolk x Dorset ewes on the IgG concentration, fat or protein content, nor did it improve lambs' serum IgG levels (Table 3). Similarly, Duniere et al. (2022) showed that supplementation with *Saccharomyces cerevisiae* (8 × 109 CFU/d; -30 d to lambing) in Romene ewes resulted in higher colostral IgG concentration (52 vs.79 mg/mL), with no significant difference in the fat, protein or lactose level (Table 3). Moreover, the same study reported a 65% increase in serum IgG in 2-day-old lambs from supplemented ewes, even though both groups were fed colostrum exclusively during the first 12 h postpartum. As pointed out by Duniere et al. (2022), the inclusion of *S. cerevisiae* increased the level of N-glycoylneuraminic oligosaccharides in the colostrum, which are molecules associated with the host defences by pathogen-binding, and for promoting the initial microbial colonisation in neonates. Further studies are needed to determine the optimal doses and duration of supplementation that can influence the colostrum quality, regarding IgG concentration and other bioactive molecules such as oligosaccharides, lactoferrin, lactoperoxidase and the proportion of fatty acids. The inclusion of other probiotics should also be explored.

4.8. Bioactive additives

The inclusion of plant-derived bioactive compounds in small ruminant diets has been associated with increased colostral IgG and IgM concentrations, improved colostrum composition, and enhanced antioxidant capacity. For instance, Hashem et al. (2021) evaluated the oral administration of two levels of Boswellia sacra resin (2 g or 4 g/d; -2 week to kidding) in Egyptian Nubians goats, and reported that the inclusion of 2 g of the resin increased the colostrum solids and content of IgM (+1%) but not of IgG (Table 3). In addition, resin supplementation increased colostrum fat (+37%), protein (+8%), lactose (+34%), solids not fat (+24%) and total solids (+25%). Similarly, Viola et al. (2022) reported higher colostral IgG concentrations (60 vs. 94 g/L) in Biellese ewes fed a diet supplemented with hazelnut skin (116 g/kg of DM; -45 d to lambing), along with increased serum IgG levels in their lambs (12 vs. 31 g/L; Table 3). However, the previous study did not report effects (if any) on colostrum yield.

Interestingly, the supplementation of lycopene (100 mg/d; -10 d to lambing), a carotenoid pigment found in many fruits and vegetables, combined with corn in Lori-Bakhtiari ewes (300 g/d; -21 d to lambing) resulted in higher concentration of IgG (+40%), protein (+7%) and the total volume of colostrum (+65%; Fallah et al., 2021; Table 3). Similarly, an increase in colostrum yield (+31%) was reported in Ashari sheep with the inclusion of plant extract of Broadleaf plantain and peppermint (2 g/d of the plants extract) and monensin (30 mg/d) in the feed ration (-21 d to lambing; Mirzaei-Alamouti et al., 2021; Table 3). In contrast, supplementing Merino ewes with caffeine (10 or 20 mg/kg BW; -20 days to lambing) was not associated with significant differences in colostral IgG, but lambs had three times greater serum IgG concentration in the 20 mg inclusion group, which can be explained by higher consumption and suckling behaviour (Murdock et al., 2021; Table 3).

Also, dietary supplementation with phytobiotics has been associated with improved antioxidant status in the colostrum of goats. For instance, the colostrum of Saanen goat supplemented with dietary berberine (2, or 4 g/d; -21 d to kidding) reported higher activity of superoxide dismutase (+16%), glutathione peroxidase (+30%) and catalase (+40%) and lower malondialdehyde (-24%), with no impact on colostrum composition (Ghavipanje et al., 2022; Table 3). In another study, Afzal et al. (2021) reported higher levels of vitamin C (+6%) and carotenoids (+22%) in the colostrum of Beetal goats fed with Moringa oleifera leaf powder (8.75 g/d; -60 d to lambing), which may improve antioxidant capacity in kids consuming this colostrum. Further research is necessary to determine the dosage, duration and method of supplementation of phytobiotics to reduce farm management efforts in terms of both time and cost.

4.9. Feed restriction

Deviations from nutrient requirements through under- or overfeeding during late gestation have been shown to influence colostrum yield and quality, with effects depending on the extent, timing, and duration of the feeding regime. Notably, the outcomes of underfeeding are often confounded by the mobilization of body reserves, which can partially sustain colostrum production despite nutrient deficits. For instance, McGovern et al. (2015) observed that under- and overfeeding (80 vs. 120% of ME requirements) in mixed-breed twin-bearing ewes (-1 month to lambing) had disproportionate effects on colostrum yield, with increases of 17% and decreases of 6%, respectively, compared to ewes fed 100% ME. Interestingly, despite the lower BCS observed at lambing, no significant differences were found in plasma free fatty acids and beta-hydroxybutyrate, or urea concentrations. This lack of significant differences in common indicators of body reserve mobilization may reflect the relatively modest level of restriction. Zarrin et al. (2021) applied a stepwise restriction over the last four weeks of gestation in single-bearing fat-tailed dairy sheep (i.e., Lori-Bakhtiari and Turkey-Qashqa), reducing nutrient supply to 50%, 65%, 80%, and 100% of requirements during weeks -4, -3, -2, and -1 from lambing, respectively, with each level applied for one week only. The authors reported a 30% reduction in colostrum yield, accompanied by significant increases in plasma free fatty acids, beta-hydroxybutyrate, and growth hormone concentrations. Unlike the expected greater colostrum yield with larger litter sizes (Zhou et al., 2023b), in Corriedale sheep, Turín et al. (2023) found that prepartum undernourishment had a greater negative impact on twin- than single-bearing ewes, with the former showing reduced colostrum yield, and IgG, protein, and lactose. In that study, the restricted group received only pasture from day 120 of gestation until lambing, whereas the control group received pasture plus concentrate supplementation (6.6 MJ ME/d and 232 g/d of CP). This might reflect nutrient partitioning favoring fetal development over colostrum synthesis during periods of nutrient deficit. Together, these findings suggest that both short-term severe restrictions and prolonged mild underfeeding can disrupt the metabolic and hormonal balance essential for optimal colostrum synthesis. Ensuring an adequate nutrition, particularly during late gestation, can mitigate these negative effects.

4.10. Maternal nutrition and neonatal performance

This review highlights prepartum dietary interventions as means to optimize colostrum yield and quality, thereby enhancing neonatal passive immunity and nutrient supply. However, the link between colostrum quality and offspring outcomes is not always straightforward. Castellaro et al. (2022) reported that oat supplementation (270 g/d) increased both colostrum IgG (97 vs. 119 g/L) and lamb serum IgG (58 vs. 72 g/L), while others found no apparent effects of MP supplementation (Kopp et al., 2020), or under- and overnutrition on IgG concentrations in colostrum or offspring serum (Gallo et al., 2020; Nouri et al., 2023). Another point for consideration is that increases in colostrum yield with prepartum supplementation often come at the cost of reduced fat and protein concentrations (Ramírez-Vera et al., 2012; Zarrin et al., 2021), resulting in a less nutrient-dense colostrum. Although this reduction can be offset by the increase in colostrum volume, thereby increasing nutrient yield, adequate nutrient intake ultimately depends on the offspring consuming sufficient amounts. Fortunately, maternal supplementation has also been linked to reduced colostrum viscosity (Olivera-Muzante et al., 2022; Villar et al., 2023), a factor believed to facilitate intake and improve consumption efficiency by newborns (Agenbag et al., 2021).

A common concern with supplementation is the potential for excessive birth BW, which could increase dystocia risk. Although mild increases in birth BW have been reported with energy (Moradi et al., 2021; Villar et al., 2023) and protein supplementation (Moradi et al., 2021; Wang et al., 2022), others found no clear link between increased colostrum yield from energy supplementation and changes in neonatal birth BW in sheep (Babaei et al., 2019; Gallo et al., 2020; Olivera-Muzante et al., 2022) and goats (Ramírez-Vera et al., 2012; Syeed Momen et al., 2021). Similarly, protein supplementation showed no effect on birth BW in sheep (Kopp et al., 2020) and goats (Rahmani et al., 2017). However, the magnitude of this indirect effect on birth difficulty is highly dependent on the breed and experimental conditions, such as the level of inclusion of each nutrient and length of supplementation.

Additionally, colostral hormones like growth hormone and IGF-1 stimulate intestinal growth, enhance nutrient absorption, and support gut maturation in neonates (Agenbag et al., 2021). While maternal supplementation has been shown to increase plasma insulin (Zarrin et al., 2021) and IGF-1 (Shabrandi et al., 2019), and reduce growth hormone (Zarrin et al., 2021) these studies did not report colostral levels. Additional studies should aim to explore how colostral hormone profiles influence neonatal development, including short-term benefits like gut maturation and long-term effects on growth and health. Another promising area for further research is the long-term effects of maternal nutrition on offspring performance. A series of companion papers explored the effects of under and overfeeding twin-bearing Dorset ewes (60, 100, or 140% of nutrient requirements; -4 months to lambing) and first- and second-generation offsprings. Although no discernible effects of prepartum nutrition were found on colostrum IgG levels in maternal or first-generation ewes (Bosco et al., 2023), underfeeding reduced birth BW by 30%, leading to a sustained 10% weight deficit at 252 days in first-generation lambs (Tillquist et al., 2023), and second-generation lambs from fed-restricted granddams were smaller from birth to maturity (Tillquist et al., 2024). These findings underscore the need for further research on how maternal nutrition influences not only colostrum but also the long-term health and performance of future generations.

5. Environmental factors

5.1. Thermal stress

It is well established that heat stress will negatively impact livestock animal performance and production. These responses in ruminants have been extensively reviewed (Marai et al., 2007; Belhadj Slimen et al., 2016) and therefore will not be described in detail here. Small ruminants are not exempt to such negative consequences of heat exposure, especially when experiencing increased metabolic heat loads during productive periods such as gestation or lactation. For example, Mehaba et al. (2021) showed that despite heat stress reducing DM intake and increasing heat loss mechanisms (i.e., respiration rate), milk yield and quality did not decrease during the second half of lactation in dairy sheep. A variety of heat loss mechanisms are employed by animals attempting to maintain core temperatures when exposed to high environmental heat loads, all of which can reduce productive performance. For example, heat stress results in redistribution of blood flow towards the limbs as part of a coordinated physiological response cascade to increase heat loss mechanisms, in this case by increasing blood flow to the skin where heat loss via convection can occur. This redistribution of blood results in a reduction in blood flow to tissues and organs, including reproductive and mammary tissues. It is well established that high heat loads will reduce milk yields in ruminants via a combination of reduced feed intake and altered metabolism (Fig. 2; Baumgard and Rhoads, 2013). Metabolically, heat stress also alters the circulation of key hormones and metabolites such as insulin and glucose. In sheep (and other ruminants), heat stress leads to a state of insulin resistance (Fig. 2; Hung et al., 2021; Salama et al., 2021; DiGiacomo et al., 2023) which alters numerous pathways including those involved in nutrient partitioning. Further, these responses to heat can impact other key mechanisms including immunity and gene expression. As summarised by Chauhan et al. (2021), heat stress increases the expression of genes related to immunity such as toll like receptors and interleukins.

In pregnant Saanen goats, while there was no impact of heat stress on gestation length or parturition, heat stressed goats showed greater number of cotyledons, worse placental efficiency and kids were born

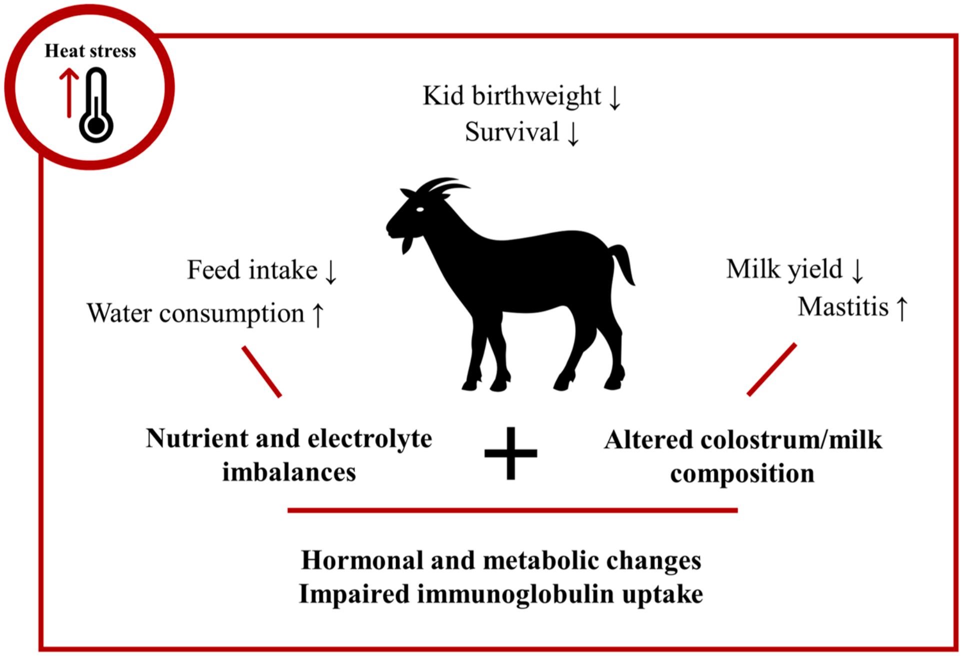

Fig. 2. Summary of impacts of heat stress on small ruminant milk and colostrum production. Responses are relative to treatment compared to control, where arrows (↑/↓) indicate significant ($P < 0.05$) increase or decrease, and a dash line (—) indicates not reported. References: Baumgard and Rhoads (2013); Vitali et al. (2020); Ahmed et al. (2021); Davidson et al. (2021); Hung et al. (2021); Salama et al. (2021); Silva et al. (2021); DiGiacomo et al. (2023).

5–7% lighter with a 10% reduction in survival rates at day 60 (Fig. 2; Silva et al., 2021). In pregnant dairy sheep, the timing of shearing, particularly prior to or during summer months, has been explored to address potential impacts on offspring, colostrum and milk production. In dairy breeds, recent evidence showed that sheep shorn during gestation, (around day 100), had 37% lower respiration rates while no impacts were observed on lamb size, colostrum composition (including IgG) or milk production (González-Luna et al., 2023). In contrast, sheep shorn during gestation had better BCS (i.e., ideal or over conditioned) which can be translated into higher glycaemia and fat mobilization after lambing without risk of developing ketosis (González-Luna et al., 2023). These authors suggest that these differences are due to the increased thermal comfort in the shorn sheep reducing the energy utilized to offload heat and thus increasing energy availability for fetal and mammary development. Despite this evidence in sheep, there is limited data on the impact of heat stress on productive performance in dairy goats, particularly in relation to colostrum yield and quality.

5.2. Influence of heat stress on colostrum yield and composition

In ewes, gestational heat stress reduced placental weight and 21-day milk yields but had no impact on colostrum yield (Fuentevilla et al., 2024). In this study colostrum quality was not reported. Although in sheep such negative impacts on colostrum and milk yield seem to be less severe, limited information exists in goats. Colostrum IgG concentration and Brix degrees did not differ between summer and winter months in lactating dairy ewes, although summer colostrum had greater saturated fatty acid concentrations while winter colostrum was richer in polyunsaturated fatty acids (Todaro et al., 2023). Further, the mineral concentration (i.e., copper, manganese and magnesium) was greater in summer compared to winter colostrum, due to differences in diet and supplementation of the dams (Todaro et al., 2023).

The impact on colostrum quality and volume are not the only considerations. In dairy calves, evidence shows that the uptake of immunoglobulins is compromised by in utero heat stress (Monteiro et al., 2014; Davidson et al., 2021) and accompanied by a reduction in immune organ weights (i.e., spleen and thymus) leading to compromised immediate and adaptative immunity (Ahmed et al., 2021). Additionally, because heat stress can impair gut function, the main site for immunoglobulin absorption from colostrum in young ruminants, it is likely to reduce their capacity for immunoglobulin absorption during periods of heat stress. Indeed, it has been reported in cattle that maternal heat stress resulted in a faster gut closure and increased intestinal cell apoptosis in neonate calves and in turn, this might have impacted the ability to absorb colostral immunoglobulins as well as other macromolecules (Fig. 2; Ahmed et al., 2021). Despite this, colostrum yield and quality modifications in response to heat stress are not well-established in small ruminants. Interestingly, compounds in goat milk, and potentially those found in colostrum, could serve to improve intestinal integrity as it has been observed that rats consuming goat milk exhibit reduced gastrointestinal permeability when exposed to heat stress (Prosser et al., 2004). This suggests that colostrum might promote gastrointestinal health when gut barrier function is compromised (Ghaffari et al. 2021)

5.3. Heat stress mitigation strategies

Besides housing and engineering modifications (i.e. cooling systems like sprinklers and fans), modifying nutrition and/or providing nutritional supplements is one of the most rapid methods to ameliorate the negative effects of heat stress in ruminants. However, limited published data has explored the impact of supplementation on colostrum production and quality in heat-stressed small ruminants. Supplementing goats with 0.9% or 1.2% yeast culture during summer significantly boosted serum total antioxidant capacity, as well as the activities of superoxide dismutase and glutathione peroxidase (Zhang et al. 2024). It also improved rumen fermentation by raising pH, increasing short-chain fatty acid concentrations, and enhancing fibrolytic enzyme activities such as xylanase. Additionally, growth performance was also promoted, with higher DM intake, average daily gain, and improved digestibility of DM, neutral and acid detergent fiber (Zhang et al., 2024). In fat-tailed dairy sheep, feed restriction did not affect colostrum IgG concentrations (Nouri et al., 2023), which is a positive finding given that ruminants commonly respond to heat stress by reducing feed intake.

However, in this study the lamb growth and performance was reduced which would negatively impact overall farm productivity and efficiency. Currently, multiple dietary supplements including antioxidants, electrolytes, energy and protein sources, vitamins and minerals are being explored in dairy cattle for their ability to increase colostrum production, yet similar research is still required in small ruminants.

As previously described, colostrum IgG concentrations can vary between breeds. For example, IgG concentrations were greater in goat and sheep meat breeds compared to dairy breeds (Kessler et al. 2019). It is likely that differences also exist between more thermally adapted animals such as native Indian breeds compared to European ones, although such comparisons have not been made. While farmers are conscious of climate change and its impacts, one study demonstrated that few are aware of breeding practices to improve thermal tolerance (Martin-Collado et al., 2024). In dairy cattle the impacts of heat stress on productivity and animal health are more pronounced, leading to a greater effort to select for thermal tolerance in this species. For example, in Australia the incorporation of a heat load index as a genomic breeding value has been implemented in recent years to allow farmers to select for heat tolerance amongst other traits (Pryce and Haile-Mariam, 2020). However, there is a common assumption that heat tolerant animals tend to produce less milk, but do have improved fertility (Nguyen et al., 2016). Despite this, the authors are unaware of any published data examining the selection of thermotolerant small ruminants to improve colostrum production. Ideally, a genetic selection process and breeding for thermal tolerance that does not negatively impact colostrum quality or yield in small ruminant species needs to be developed and implemented globally, particularly in large production systems. However, a large investment in research and development in this space currently precludes such developments.

This review highlights the dearth of information relating to the impact of heat exposure on colostrum production and quality in small ruminants. Given the increase in current and predicted global temperatures due to climate change, this lack of research may reduce potential productivity gains and efficiencies in these small ruminant systems. Despite comparatively more research in dairy cattle and other large ruminants, there remains a large knowledge gap in the physiology and genetics of colostrum production in ruminants, both large and small. Further research in this area should be undertaken as a matter of urgency, with a particular focus upon breeding, species-specific thermotolerance profiles and nutritional management practices.

6. Management and health factors

Beyond genetics and nutrition, a variety of management and health factors have been shown to influence both the quantity and quality of colostrum. Health disorders such as mastitis or peripartum diseases and hormonal modulation can compromise colostrogenesis and immunoglobulin transfer. Understanding how these interconnected factors function is critical for developing targeted interventions to improve colostrum quality, reduce perinatal losses, and enhance resilience in sheep and goat production systems.

6.1. Hormonal modulation

Melatonin, a pineal hormone used to manipulate seasonal breeding in small ruminants, has recently garnered interest for its effects on colostrum quality (Table 2). As a potent antioxidant and immunomodulator, melatonin administered during late gestation can impact maternal endocrine and immune function, influencing colostrogenesis (Bouroutzika et al., 2021; Tekin and Akkus, 2023). Several studies confirm that melatonin implants in late gestation improve colostrum IgG levels in ewes. Abecia et al. (2020) showed that a single 18 mg implant during the fourth month of gestation significantly increased colostral IgG concentration. Similarly, Canto et al. (2022) found that ewes implanted 40 days before lambing with two implants (36 mg total) exhibited significantly higher IgG levels. These benefits were accompanied by higher colostral protein and lactose content, suggesting improved nutritive quality (Canto et al., 2022). However, it is important to note that none of these studies reported colostrum yield. Therefore, the observed increases in colostral components should be interpreted with caution, as melatonin treatments could potentially affect colostrum production through reduced prolactin secretion (Molik et al., 2020; Yang et al., 2020).

Melatonin also exerts antioxidative and immunomodulatory effects. Bouroutzika et al. (2021) demonstrated that melatonin implantation in heat-stressed ewes enhanced total antioxidant capacity in colostrum and modulated immune markers in both dams and lambs. Specifically, colostrum showed elevated crude protein and fat content, alongside a post-lambing surge in IL-6 and IL-10 expression in ewes and offspring, respectively. Tekin and Akkus (2023) further confirmed these findings in Awassi sheep, reporting enhanced antioxidant defense and significantly increased colostral IgG levels in melatonin-treated ewes. They also observed a reduction in the normally lower IgG levels associated with female offspring.

While melatonin's effect on colostrum volume is inconsistent, several studies noted indirect benefits to neonatal health and performance. Canto and Abecia (2024b) found no significant changes in colostrum volume or Brix degrees, but melatonin-treated ewes showed improved milk yield and reduced somatic cell counts during lactation. Moreover, lambs born to melatonin-treated ewes demonstrated higher weaning weights and improved thermoregulation shortly after birth (Canto and Abecia, 2024a). However, not all trials yielded consistent results. In a separate study, Canto and Abecia (2024b) reported no significant difference in colostral IgG when melatonin was administered 30 days prepartum or at lambing. The authors suggested that sampling time and analytical methods might explain discrepancies among studies.

Research on goats is less extensive. In dairy Creole goats, melatonin administered 7 weeks before kidding increased subsequent milk yield by over 20%, although no significant impact on colostrum IgG or composition was observed (Avilés et al., 2019). These findings suggest melatonin may support udder health and early lactation, although direct effects on colostrum immunoglobulins in goats remain unknown. A study in Inner Mongolian cashmere goats found that melatonin administered mid-lactation reduced milk yield but increased fat content, likely due to photoperiod effects (Yang et al., 2020). Since these implants were used post-kidding, colostrum effects were not examined, highlighting a gap in caprine research. In addition to melatonin implants, a study in Guanzhong dairy goats investigated whether prepartum serotonin administration could improve calcium homeostasis reducing the risk of hypocalcaemia. The authors reported that daily serotonin injections during the 10 days prior to expected parturition increased serum calcium levels but did not alter the gross chemical composition of colostrum (Zhang et al., 2022).

6.2. Exercise and physical activity

Recent evidence suggests that maternal exercise during late gestation may positively influence colostrum quality in small ruminants, especially sheep. Gavette (2021) conducted a controlled study in ewes, demonstrating that those provided with moderate exercise during the third trimester produced colostrum with significantly higher IgG concentrations than sedentary controls, though differences on colostrum yield were not addressed. Despite moderated feed intake and gestational weight gain in the exercised group, lamb birth BW was unaffected. Furthermore, lambs born to exercised ewes exhibited elevated serum total protein post-ingestion, reflecting enhanced passive transfer (Gavette, 2021). These findings may suggest that maternal exercise can improve colostrum immunological quality without compromising volume or offspring growth. However, further research is needed to confirm the metabolic mechanisms behind these findings as no other studies have been conducted. In goats, no peer-reviewed studies from 2020 to present directly assess the relationship between maternal exercise and colostrum outcomes. Nonetheless, indirect evidence supports the relevance of physical activity. In goats, housing systems that promote movement, such as pasture access, have been associated with changes in milk microbial profile, though effects on IgG remain unquantified (Jing et al., 2021). Additionally, genetic and environmental influences on colostrum IgG in dairy goats have been documented (Wicki et al., 2024), suggesting a complex interaction of physiological and management factors.

6.3. Peripartum disorders

Despite the well-known impact of peripartum metabolic diseases (i.e., hypocalcaemia, pregnancy toxemia) on energy partitioning, endocrine regulation, and nutrient availability in sheep and goats (Mongini, Van Saun, 2023; Munn et al., 2024; Uztimür et al., 2024), their specific effects on colostrum quality remain poorly characterized. Conditions such as pregnancy toxemia and hypocalcemia can alter maternal metabolism during late gestation, and are therefore likely to impair the synthesis, accumulation, or secretion of key colostrum components. However, while numerous studies have described the pathophysiology and production consequences of these disorders in small ruminants, direct evaluations of colostrum quality in affected animals are unavailable. As a result, current knowledge regarding the impact of these diseases on colostrum quality in sheep and goats are mostly extrapolated from other ruminant species (Immler et al., 2021; Rossi et al., 2022; Siachios et al., 2024; Sohrabi et al., 2024). These recent studies have shown that metabolic parameters such as glucose, β-hydroxybutyrate or glutamate-dehydrogenase concentrations can be positively associated with colostrum yield and quality (determined by Brix refractometry) while others showed that colostrum quality (determined by Brix refractometry) is not affected by early postpartum serum calcium concentrations, although it can be associated with greater failure of TPI in calves. These findings indicate that colostrum yield and quality can remain relatively stable despite metabolic disturbances, suggesting the presence of compensatory mechanisms that prioritize colostrogenesis, possibly through nutrient mobilization or endocrine adaptations. However, the lack of studies, especially in small ruminants, represents a key knowledge gap, highlighting the need for research that links maternal metabolic status, including subclinical disorders, with colostrum composition and neonatal passive transfer.

In addition to the metabolic disorders, recent studies have shown that perinatal complications and drug administration can also impact colostrum composition and offspring immunity acquisition. Akkus et al. (2022) found that dystocia did not reduce colostrum IgG content in Damascus goats, but kids born after difficult births had significantly lower serum IgG concentrations. This was attributed to a delayed or impaired suckling and increased neonatal oxidative stress. In other circumstances, premature births or induced parturitions in sheep and goats may lead to an incomplete colostrogenesis and therefore, to poor colostrum quality (Castro et al., 2011; Wallace et al., 2021). Indeed, Narciso et al. (2022) observed that dexamethasone administration, used to stimulate fetal maturation and respiratory function in premature deliveries, can compromise colostrum intake and absorption. Further, Pollock et al. (2021) demonstrated that after parturition induction in dairy goats, colostrum collection and feeding needs to be performed in the first hours after birth to achieve low kid mortality rates. In sheep, Shiels et al. (2021) observed that farms with established protocols for assisted suckling and stored colostrum had lower lamb mortality. Similarly, Balasopoulou et al. (2022) associated neonatal kid mortality in German goat farms to inadequate colostrum access and peripartum care among other factors. These studies demonstrate that farm management practices, especially during the peripartum period and those related to colostrum feeding and manipulation, can highly influence neonatal outcomes across species.

Preventing and managing peripartum metabolic disorders is critical to support colostrum production and passive immunity in sheep and goats. Although direct species-specific evidence is limited, maintaining adequate late-gestation nutrition, mineral balance, and effective peripartum supervision, will likely ensure an adequate colostrum quality. Overall, integrated nutritional and management approaches are required to mitigate peripartum disorders, although direct evidence linking these interventions to improved colostrum quality in small ruminants remains a major research gap.

6.4. Mammary gland health and response to infections

Infections in late gestation can influence colostrum quality directly or indirectly. Chronic viral infections, such as caprine arthritis encephalitis virus (CAEV) has been shown to impair the mammary gland function. Buranakarl et al. (2022) found that CAEV-positive Saanen goats have significantly lower IgG and protein levels in their colostrum. Despite no apparent detrimental effects on kids growing patterns, such immunological deficits in colostrum could increase susceptibility to diseases when adequate colostrum feeding practices are not implemented. Although no recent studies have reported the effects of viral infections on sheep colostrum, Aphrodite and Athanasios (2024) found that lentiviruses infections in dairy sheep can lead to a 20% reduction in milk protein and a 12% in fat yield compared to uninfected animals. Similar findings were reported by Juste et al. (2020) in Laxta sheep seropositive flocks to Visna-Maedi virus. Despite it seems infectious diseases may influence colostrum synthesis, no additional studies have addressed the effect of these pathogens on colostrogenesis in small ruminants, remaining unexplored how these agents can alter the mammary gland physiology during late gestation.

The immune response of the mammary gland to pathogens is another critical factor. Alcindo et al. (2023) reported greater somatic cell counts (SCC), IgG and lactoferrin concentration in colostrum whey at 48 h postpartum in goats with a natural mastitis. In experimental conditions, González-Cabrera et al. (2024a) showed that the udder inflammation induced by an intramammary lipopolysaccharide (LPS) challenge at parturition can increase IgG and IgM concentrations in goat colostrum without reducing yield. Although, this study did not assess the prepartum effect of LPS on colostrogenesis, it suggests that intramammary infections can modify the alveoli epithelial integrity, increasing the passage of components from blood to colostrum. However, in their follow-up study, González-Cabrera et al. (2024b) found no effects on the TPI in goat kids, suggesting that regardless the colostrum immunoglobulin concentration, early intestinal absorption of immune components may be conditioned by multiple factors, such as endocytosis mechanisms, timing or interaction with pathogens within the gut lumen.

Besides viral and bacterial infections, parasitism seems to also modulate colostrum quality. Recently, Bentley et al. (2024) demonstrated that ewes with lower fecal egg count (FEC) estimated breeding values, an indicative parameter of parasite resistance, produced colostrum with significantly higher IgG concentrations than high-FEC ewes. This study suggests a valuable association between genetic resistance with colostrum quality management.

To mitigate the potential negative effects of infections on colostrum quality, an adequate farm health management is essential. Routine screening for viral pathogens combined with biosecurity measures and vaccination, can help limit infection prevalence, while selecting animals with better adaptation or resistance to infections can improve the herd immunity. Monitoring udder health through somatic cell counts and routine microbiological analysis can also contribute to preserve colostrum composition, and careful management practices such as hygienic colostrum collection, storage and assisted feeding of neonates will contribute to successful TPI.

7. Future research directions

Although notable advances have been made in understanding the physiological, nutritional, and environmental determinants of colostrum quality in small ruminants, significant remaining gaps limit the translation of current knowledge into practical improvements in neonatal health. Future research should prioritize a multidisciplinary approach, integrating genomics, nutrition, immunology, and environmental physiology to better elucidate the mechanisms behind colostrogenesis. In particular, the identification of genetic markers and candidate genes associated with colostrum yield, immunoglobulin transport, and bioactive compound synthesis would enable the development of breeding strategies targeting enhanced TPI. Similarly, omics-based approaches (e.g., transcriptomics, metabolomics, proteomics) should be employed to clarify the molecular pathways linking maternal nutrition, metabolic status, and immune function with colostrum composition and neonatal outcomes. The use of modern computing technology, such as artificial intelligence and machine learning, should also be utilized to assist in the analysis and interpretation of large and collaborative data sets where possible.

Given the accelerating impacts of climate change, studies are urgently needed to evaluate how thermal stress affects colostrum synthesis, immunoglobulin transfer, and offspring immunity in heat-prone regions. These investigations should include both physiological responses and potential mitigation strategies, such as dietary antioxidants, adaptive feeding systems, and genetic selection for thermotolerance without compromising milk or colostrum quality.

Further, more research is warranted on maternal interventions such as melatonin supplementation, mastitis and other diseases control, welfare practices, with special attention to their long-term effects on maternal and neonatal performance, immunity, and productivity. Finally, future studies should adopt a systems-level perspective, linking maternal management practices during late gestation to lifetime performance and health of the offspring, thereby providing a foundation for evidence-based guidelines that enhance animal welfare and sustainability in small ruminant production systems.

8. Conclusion

This review highlights the multifactorial nature of colostrum synthesis in small ruminants. Maternal genetics, metabolic and immune status, nutritional management during late gestation, and environmental stressors, particularly heat, collectively determine colostrum yield and immunological value. Strategic nutritional interventions, including energy-dense and rumen-protected supplements, have demonstrated potential to improve colostrum composition, while hormonal modulation through melatonin may enhance immunoglobulin concentration. Moderate maternal exercise and adequate body condition also contribute positively to passive immune transfer without compromising neonatal growth. Despite these advances, substantial knowledge gaps persist regarding the molecular and endocrine regulation of colostrogenesis, the integration of nutritional and environmental factors, and the long-term consequences of prenatal interventions on offspring health and productivity. Future research should focus on standardizing colostrum quality indicators, exploring colostrum bioactive profiles, and evaluating management strategies under diverse production and climatic conditions. Addressing these gaps will be critical for enhancing neonatal survival, resilience, and productivity in small ruminant systems.

CRediT authorship contribution statement

N Castro: Writing – review & editing, Writing – original draft, Supervision. **Ospina Capdevila:** Writing – review & editing, Writing – original draft. **M González-Cabrera:** Writing – review & editing, Writing – original draft. **F Zamuner:** Writing – review & editing, Writing – original draft. **Argüello Anastasio:** Writing – review & editing, Writing – original draft, Supervision, Conceptualization. **K DiGiacomo:** Writing – review & editing, Writing – original draft, Supervision.

Declaration of Generative AI and AI-assisted technologies in the writing process

During the preparation of this work the authors used ChatGPT in order to improve the readability and the English grammar. After using this tool/service, the authors reviewed and edited the content as needed and take full responsibility for the content of the published article.

Consent for publication

Not applicable.

Funding

González-Cabrera, M acknowledges financial support from the Formación de Profesorado Universitario programme (FPU, Ministerio de Universidades, Gobierno de España, Spain; FPU21/00956).

Declaration of Competing Interest

All authors declare no competing financial or non-financial interests in relation to this work.

Data availability

Not applicable.

References

Ababakri, R., Dayani, O., Khezri, A., Naserian, A.A., 2021. Influence of flaxseed with rumen undegradable protein level on milk yield, milk fatty acids and blood metabolites in transition ewes. J. Anim. Sci. Technol. 63, 475–490. https://doi.org/10.5187/jast.2021.e50.

Abdul-Rahman, I.I., Aguli, Z., 2024. Maternal and neonatal factors affecting neonatal behaviour in West African Dwarf goats. Trop. Anim. Health Prod. 56, 3. https://doi.org/10.1007/s11250-023-03845-4.

Abecia, J.A., Garrido, C., Gave, M., Garcia, A.I., Lopez, D., Luis, S., Valares, J.A., Mata, L., 2020. Exogenous melatonin and male foetuses improve the quality of sheep colostrum. J. Anim. Physiol. Anim. Nutr. 104, 1305–1309. https://doi.org/10.1111/jpn.13362.

Abecia, L., Jiménez, E., Martínez-Fernandez, G., Martín-García, A.I., Ramos-Morales, E., Pinloche, E., Denman, S.E., Newbold, C.J., Yáñez-Ruiz, D.R., 2017. Natural and artificial feeding management before weaning promote different rumen microbial colonization but not differences in gene expression levels at the rumen epithelium of newborn goats. PLoS ONE 12, e0182235. https://doi.org/10.1371/journal.pone.0182235.

Afzal, A., Hussain, T., Hameed, A., Shahzad, M., Mazhar, M.U., Yang, G., 2021. Dietary *Moringa oleifera* alters periparturient plasma and milk biochemical indicators and promotes productive performance in goats. Front. Vet. Sci. 8, 787719. https://doi.org/10.3389/fvets.2021.787719.

Agenbag, B., Swinbourne, A.M., Petrovski, K., van Wettere, W.H.E.J., 2021. Lambs need colostrum: a review. Livest. Sci. 251, 104624. https://doi.org/10.1016/j.livsci.2021.104624.

Agradi, S., González-Cabrera, M., Argüello, A., Hernández-Castellano, L.E., Castro, N., Menchetti, L., Brecchia, G., Vigo, D., Tuccia, E., Curone, G., 2023. Colostrum quality in different goat breeds reared in Northern Italy. Animals 13, 3146. https://doi.org/10.3390/ani13193146.

Ahmed, B.M.S., Younas, U., Asar, T.O., Monteiro, A.P.A., Hayen, M.J., Tao, S., Dahl, G.E., 2021. Maternal heat stress reduces body and organ growth in calves: relationship to immune status. JDS Commun. 2, 295–299. https://doi.org/10.3168/jdsc.2021-0098.

Akkus, T., Korkmaz, O., Emre, B., Zonturlu, A.B., Dinçer, P.F.P., Yaprakci, O., 2022. The effect of dystocia on oxidative stress, colostral antibody/passive immune status and blood gases in Damascus goats and their kids. Turk. J. Vet. Anim. Sci. 46, 18–27. https://doi.org/10.3906/vet-2106-102.

Alcindo, J.F., Vieira, D.S., Braga, G.I., Marinho, M., Mendes, L.C.N., Peiró, J.R., Poló, T.S., Feitosa, F.L.F., 2023. Can intramammary infections change immunoglobulins and acute phase proteins of colostrum and transition milk in dairy goats? Arq. Bras. Med. Vet. Zootec. 74, 1039–1048. https://doi.org/10.1590/1678-4162-12469.

Alexander, G., 1974. Birth weight of lambs: influences and consequences. In: Elliott, K.E., Knight, J. (Eds.), Size at Birth (Ciba Found. Symp. No. 27). Elsevier, Amsterdam, The Netherlands, pp. 215–245. https://doi.org/10.1002/9780470720097.ch11.

Alves, A.C., Alves, N.G., Ascari, I.J., Junqueira, F.B., Coutinho, A.S., Lima, R.R., Pérez, J.R.O., De Paula, S.O., Furusho-Garcia, I.F., Abreu, L.R., 2015. Colostrum composition of Santa Inês sheep and passive transfer of immunity to lambs. J. Dairy Sci. 98, 3706–3716. https://doi.org/10.3168/jds.2014-7992.

Aphrodite, I.K., Athanasios, I.G., 2024. The impact of small ruminant lentiviruses infections on milk yield and milk quality traits in intensively reared dairy sheep. Small Rumin. Res. 243, 107424. https://doi.org/10.1016/j.smallrumres.2024.107424.

Argüello, A., Castro, N., Batista, M., Moreno-Indias, I., Morales-delaNuez, A., Sanchez-Macias, D., Quesada, E., Capote, J., 2008. Chitotriosidase activity in goat blood and colostrum. J. Dairy Sci. 91, 2067–2070. https://doi.org/10.3168/jds.2007-0826.

Argüello, A., Castro, N., Capote, J., Tyler, J.W., Holloway, N.M., 2004. Effect of colostrum administration practices on serum IgG in goat kids. Livest. Prod. Sci. 90, 235–239. https://doi.org/10.1016/j.livprodsci.2004.06.006.

Argüello, A., Castro, N., Capote, J., 2005. Short communication: Evaluation of a color method for testing immunoglobulin G concentration in goat colostrum. J. Dairy Sci. 88, 1752–1754. https://doi.org/10.3168/JDS.S0022-0302(05)72849-6.

Asadi, M., Toghdory, A., Ghoorchi, T., Hatami, M., 2024. The effect of maternal organic manganese supplementation on performance, immunological status, blood biochemical and antioxidant status of Afshari ewes and their newborn lambs in transition period. J. Anim. Physiol. Anim. Nutr. 108, 493–499. https://doi.org/10.1111/jpn.13909.

Ataollahi, F., Friend, M., McGrath, S., Dutton, G., Peters, A., Bhanugopan, M., 2020. Maternal supplementation of twin bearing ewes with calcium and magnesium alters immune status and weight gain of their lambs. Vet. Anim. Sci. 9, 100097. https://doi.org/10.1016/j.vas.2020.100097.

Avilés, R., Delgadillo, J.A., Flores, J.A., Duarte, G., Vielma, J., Flores, M.J., Petrovski, K., Zarazaga, L.A., Hernández, H., 2019. Melatonin administration during the dry period stimulates subsequent milk yield and weight gain of offspring in subtropical does kidding in summer. J. Dairy Sci. 102, 11536–11543. https://doi.org/10.3168/jds.2019-16836.

Babaei, M.K., Mirzaei-Alamouti, H., Nikkhah, A., 2019. Cereals level and source effects on rumen fermentation, colostrum and milk properties, and blood metabolites in periparturient ewes. Anim 13, 1165–1172. https://doi.org/10.1017/S1751731118002720.

Balasopoulou, V., Kalić, M., Zablotski, Y., Zerbe, H., Voigt, K., 2022. Goat kid mortality on Southern German dairy farms. Berl. Münch. Tierarztl. Woche 135, 1–10. https://doi.org/10.2376/1439-0299-2022-14.

Banchero, G.E., Milton, J.T.B., Lindsay, D.R., Martin, G.B., Quintans, G., 2015. Colostrum production in ewes: a review of regulation mechanisms and of energy supply. Anim 9, 831–837. https://doi.org/10.1017/S1751731114003243.

Banchero, G.E., Quintans, G., Martin, G.B., Lindsay, D.R., Milton, J.T.B., 2004. Nutrition and colostrum production in sheep. 1. Metabolic and hormonal responses to a high-energy supplement in the final stages of pregnancy. Reprod. Fertil. Dev. 16, 633–643. https://doi.org/10.1071/RD03091.

Banchero, G.E., Milton, J.T.B., Lindsay, D.R., Martin, G.B., Quintans, G., 2006. Endocrine and metabolic factors involved in the effect of nutrition on the production of colostrum in female sheep. Reprod. Nutr. Dev. 46, 447–460. https://doi.org/10.1051/rnd:2006024.

Barcelos, B., Gomes, V., Vidal, A.M.C., de Freitas, J.E., de Araújo, M.L.G.M., Alba, H.D.R., Netto, A.S., 2023. Milk yield, composition and immune status of dairy goats and respective goat kids fed diets with selenium and vitamin E supplementation. Small Rumin. Res. 225, 106999. https://doi.org/10.1016/j.smallrumres.2023.106999.

Baumgard, L.H., Rhoads, R.P., 2013. Effects of heat stress on postabsorptive metabolism and energetics. Annu. Rev. Anim. Biosci. 1, 311–337. https://doi.org/10.1146/annurev-animal-031412-103644.

Baumrucker, C.R., Gross, J.J., Bruckmaier, R.M., 2023. The importance of colostrum in maternal care and its formation in mammalian species. Anim. Front 13, 37–43. https://doi.org/10.1093/af/vfad012.

Belhadj Slimen, I., Najar, T., Ghram, A., Abdrrabba, M., 2016. Heat stress effects on livestock: molecular, cellular and metabolic aspects, a review. J. Anim. Physiol. Anim. Nutr. 100, 401–412. https://doi.org/10.1111/jpn.12379.

Bentley, K.L., Wright, D.L., Greiner, S.P., Bowdridge, S., 2024. Differences in colostrum components of Katahdin ewes varies with post-weaning FEC EBV. Small Rumin. Res. 233, 107249. https://doi.org/10.1016/j.smallrumres.2024.107249.

Bigler, N.A., Gross, J.J., Baumrucker, C.R., Bruckmaier, R.M., 2023. Endocrine changes during the peripartal period related to colostrogenesis in mammalian species. J. Anim. Sci. 101, skad146. https://doi.org/10.1093/jas/skad146.

Bompadre, T.F.V., Moretti, D.B., Sakita, G.Z., Ieda, E.H., Martinez, M.I.V., Fernandes, E. A.N., Machado-Neto, R., Abdalla, A.L., Louvandini, H., 2020. Long-term chromium picolinate supplementation improves colostrum profile of Santa Ines ewe. Biol. Trace Elem. Res. 193, 414–421. https://doi.org/10.1007/s12011-019-01741-3.

Bosco, J., Tillquist, N.M., Kawaida, M.Y., Reiter, A.S., Bettencourt, A., Gifford, R.J., Engle, T.E., Reed, S.A., Zinn, S.A., Govoni, K.E., 2023. Effects of poor maternal nutrition during gestation on F0 and F1 ewe colostrum and milk composition and colostrum IgG. J. Anim. Sci. 101, 420–421. https://doi.org/10.1093/jas/skad281.497.

Bouroutzika, E., Ciliberti, M.G., Caroprese, M., Theodosiadou, E., Papadopoulos, S., Makri, S., Skaperda, Z.V., Kotsadam, G., Michailidis, M.L., Valiakos, G., Chadio, S., Kouretas, D., Valasi, I., 2021. Association of melatonin administration in pregnant ewes with growth, redox status and immunity of their offspring. Animals 11, 3161. https://doi.org/10.3390/ani11113161.

Brandon, M.R., Watson, D.L., Lascelles, A.K., 1971. The mechanism of transfer of immunoglobulin into mammary secretion of cows. Aust. J. Exp. Biol. Med. Sci. 49, 613–623. https://doi.org/10.1038/icb.1971.67.

Buranakarl, C., Thammacharoen, S., Katoh, K., 2022. Low colostrum immunoglobulin G concentration in Saanen dams seropositive to caprine arthritis encephalitis virus infection without affecting kid growth rate. Thai J. Vet. Med. 52, 193–197.

Buranakarl, C., Thammacharoen, S., Semsirmboon, S., Sutayatram, S., Nuntapaitoon, M., Dissayabutra, T., Katoh, K., 2021. Effects of litter size and parity number on mammary secretions including insulin-like growth factor-1, immunoglobulin G and vitamin A of Black Bengal, Saanen and their crossbred goats in Thailand. Vet. Sci. 8, 95. https://doi.org/10.3390/vetsci8060095.

Canto, F., Abecia, J.A., 2024a. Effects of melatonin implants in late gestation and at lambing on colostrum and milk quality of ewes, birth temperature and growth performance of their lambs. Small Rumin. Res. 232, 107210. https://doi.org/10.1016/j.smallrumres.2024.107210.

Canto, F., Abecia, J.A., 2024b. Exogenous melatonin: effects on lactation and colostrogenesis in small ruminant livestock. Large Anim. Rev. 30, 273–280.

Canto, F., Gonzalez, E., Abecia, J.A., 2022. Effects of implanting exogenous melatonin 40 days before lambing on milk and colostrum quality. Animals 12, 1257. https://doi.org/10.3390/ani12101257.

Castellaro, G., Ochoa, I., Borie, C., Parraguez, V.H., 2022. Effects of strategic supplementation with *Lupinus angustifolius* and *Avena sativa* grains on colostrum quality and passive immunological transfer to newborn lambs. Animals 12, 3159. https://doi.org/10.3390/ani12223159.

Castro, N., Argüello, A., Gomez-Gonzalez, L., 2018. Use of clinic refractometer at farm as a tool to estimate the IgG content in goat colostrum. J. Anim. Sci. 96, 455. https://doi.org/10.1093/jas/sky404.993.

Castro, N., Capote, J., Alvarez, S., Argüello, A., 2005. Effects of lyophilized colostrum and different colostrum feeding regimens on passive transfer of immunoglobulin G in Majorera goat kids. J. Dairy Sci. 88, 3650–3654. https://doi.org/10.3168/jds.S0022-0302(05)73050-2.

Castro, N., Capote, J., Batista, M., Bruckmaier, R.M., Argüello, A., 2011. Effects of induced parturition in goats on immunoglobulin G and chitotriosidase activity in colostrum and plasma and on plasma concentrations of prolactin. Domest. Anim. Endocrinol. 40, 192–196. https://doi.org/10.1016/j.domaniend.2010.12.001.

Chadio, S., Katsafadou, A., Kotsampasi, B., Michailidis, G., Mountzouris, K.C., Kalogiannis, D., Christodoulou, V., 2016. Effects of maternal undernutrition during late gestation and/or lactation on colostrum synthesis and immunological parameters in the offspring. Reprod. Fertil. Dev. 28, 384–393. https://doi.org/10.1071/RD14147.

Chagas, D.W., de Oliveira Feijó, J., Corrêa, M.N., Furtado, M., Gueretz, J.S., Peripolli, V., Bianchi, I., Moreira, F., Schwegler, E., 2023. Metabolic profile of transition period in ewes and its influence on passive immunity transference in lambs. Trop. Anim. Health Prod. 55, 112. https://doi.org/10.1007/s11250-023-03531-5.

Chauhan, S.S., Rashamol, V.P., Bagath, M., Sejian, V., Dunshea, F.R., 2021. Impacts of heat stress on immune responses and oxidative stress in farm animals and nutritional strategies for amelioration. Int. J. Biometeorol. 65, 1231–1244. https://doi.org/10.1007/s00484-021-02083-3.

Coleman, D.N., Murphy, K.D., Relling, A.E., 2018. Prepartum fatty acid supplementation in sheep. II. Supplementation of eicosapentaenoic acid and docosahexaenoic acid during late gestation alters the fatty acid profile of plasma, colostrum, milk and adipose tissue, and increases lipogenic gene expression. J. Anim. Sci. 96, 1181–1204. https://doi.org/10.1093/jas/skx013.

Davidson, B.D., Dado-Senn, B., Ouellet, V., Dahl, G.E., 2021. Effect of late-gestation heat stress in nulliparous heifers on postnatal growth, passive transfer of immunoglobulin G, and thermoregulation of their calves. JDS Commun. 2, 165–169. https://doi.org/10.3168/jdsc.2020-0069.

de Ávila Sphor, L., Lira Fernández, R.J., Zlatar, F.S., Jardim Barcellos, J.O., Terra-Braga, M., Tontini, J.F., Villalba, J.J., Poli, C.H.E.C., 2021. Voluntary intake, milk and colostrum production and lamb growth when ewes are fed high-NaCl diets during pre- and post-lambing. Small Rumin. Res. 205, 106537. https://doi.org/10.1016/j.smallrumres.2021.106537.

DiGiacomo, K., Simpson, S., Leury, B.J., Dunshea, F.R., 2023. Dietary betaine impacts metabolic responses to moderate heat exposure in sheep. Animals 13, 1691. https://doi.org/10.3390/ani13101691.

Duniere, L., Renaud, J.B., Steele, M.A., Achard, C.S., Forano, E., Chaucheyras-Durand, F., 2022. A live yeast supplementation to gestating ewes improves bioactive molecule composition in colostrum with no impact on its bacterial composition and beneficially affects immune status of the offspring. J. Nutr. Sci. 11, e5. https://doi.org/10.1017/jns.2022.3.

Fallah, R., Kiani, A., Khaldari, M., 2021. Supplementing lycopene combined with corn improves circulating IgG concentration in pregnant ewes and their lambs. Trop. Anim. Health Prod. 53, 360. https://doi.org/10.1007/s11250-021-02802-3.

Fuentevilla, E., Rios, A., Limesand, S., Diaz, D.E., 2024. Gestational heat stress and its impact on placental weight, colostrum production, and milk production on Columbia-Rambouillet ewes. J. Anim. Sci. 102, 548. https://doi.org/10.1093/jas/skae234.615.

Galán-Malo, P., Valares, J.-A., Langa, V., Razquin, P., Mata, L., 2014. Determination of IgG levels in bulk ewe's milk. Small Rumin. Res. 119 (1–3), 156–160. https://doi.org/10.1016/j.smallrumres.2014.02.014.

Gallo, S.B., Moretti, D.B., Oliveira, M.C., dos Santos, F.F., Brochine, L., Micai, G., da, Silva, M.M., Tedeschi, L.O., 2020. The colostrum composition of sheep fed with high-energy diets supplemented with chromium. Small Rumin. Res. 191, 106177. https://doi.org/10.1016/j.smallrumres.2020.106177.

Gavette, J.S., 2021. The Effects of Late Gestational Exercise on Colostrum Quality and Neonatal Immunoglobulin Absorption, Master's Thesis. North Dakota State University, Fargo, ND, USA. 〈https://hdl.handle.net/10365/32635〉.

Ghaffari, M.H., Sadri, H., Steinhoff-Wagner, J., Hammon, H.M., Sauerwein, H., 2021. Effects of colostrum feeding on the mRNA abundance of genes related to toll-like receptors, key antimicrobial defense molecules, and tight junctions in the small intestine of neonatal dairy calves. J. Dairy Sci. 104, 10363–10373. https://doi.org/10.3168/jds.2021-20386.

Ghavipanje, N., Fathi Nasri, M.H., Farhangfar, S.H., Ghiasi, S.E., Vargas-Bello-Perez, E., 2022. The impact of dietary berberine supplementation during the transition period

on blood parameters, antioxidant indicators and fatty acids profile in colostrum and milk of dairy goats. Vet. Sci. 9, 76. https://doi.org/10.3390/vetsci9020076.
González-Cabrera, M., Álvarez, S., Salomone-Caballero, M., Castro, N., Argüello, A., Hernández-Castellano, L.E., 2024b. Intramammary administration of lipopolysaccharides at parturition does not affect the transfer of passive immunity in goat kids. J. Dairy Sci. 107, 9888–9896. https://doi.org/10.3168/jds.2024-25073.
González-Cabrera, M., Torres, A., Salomone-Caballero, M., Castro, N., Argüello, A., Hernández-Castellano, L.E., 2024a. Intramammary administration of lipopolysaccharides at parturition enhances immunoglobulin concentration in goat colostrum. Anim 18, 101082. https://doi.org/10.1016/j.animal.2024.101082.
González-Luna, S., Cordón, L., Salama, A.A.K., Such, X., Albanell, E., Contreras-Jodar, A., de Lucas-Tron, J., Caja, G., 2023. When to shear dairy ewes: before breeding, during pregnancy or let them unshorn? Anim 17, 100698. https://doi.org/10.1016/j.animal.2022.100698.
Gökçe, E., Atakişi, O., 2019. Interrelationships of serum and colostral IgG (passive immunity) with total protein concentrations and health status in lambs. Kafkas Univ. Vet. Fak. Derg. 25 (3), 387–396. https://doi.org/10.9775/kvfd.2018.21035.
Gündüz, Z., Biçer, O., 2023. Milk-y Way: the impact of single-nucleotide polymorphisms on milk production traits in Kilis dairy goats. Arch. Anim. Breed. 66, 369–378. https://doi.org/10.5194/aab-66-369-2023.
Hare, K.S., Fischer-Tlustos, A.J., Wood, K.M., Cant, J.P., Steele, M.A., 2023. Prepartum nutrient intake and colostrum yield and composition in ruminants. Anim. Front 13, 24–36. https://doi.org/10.1093/af/vfad031.
Hashem, N.M., Morsy, A.S., Soltan, Y.A., Sallam, S.M., 2021. Potential benefits of resin on immunity, metabolic status, udder and uterus health, and milk production in transitioning goats. Agriculture 11, 900. https://doi.org/10.3390/agriculture11090900.
Hernández-Castellano, L.E., Almeida, A.M., Renaut, J., Argüello, A., Castro, N., 2016. A proteomics study of colostrum and milk from the two major small ruminant dairy breeds from the Canary Islands: a bovine milk comparison perspective. J. Dairy Res. 83, 366–374. https://doi.org/10.1017/S0022029916000273.
Hernández-Castellano, L.E., Argüello, A., Almeida, A.M., Castro, N., Bendixen, E., 2015. Colostrum protein uptake in neonatal lambs examined by descriptive and quantitative liquid chromatography–tandem mass spectrometry. J. Dairy Sci. 98, 135–147. https://doi.org/10.3168/jds.2014-8143.
Higgins, J.T., Lott, S., Markiewicz-Keszycka, M., Lynch, M.B., McEvoy, M., McGovern, F., Boland, T.M., 2023. Effect of prolific breed type and silage type on ewe performance during late pregnancy. Small Rumin. Res. 223, 106981. https://doi.org/10.1016/j.smallrumres.2023.106981.
Hiss, S., Meyer, T., Sauerwein, H., 2008. Lactoferrin concentrations in goat milk throughout lactation. Small Rumin. Res. 80, 87–90. https://doi.org/10.1016/j.smallrumres.2008.07.027.
Hung, A.T., Leury, B.J., Sabin, M.A., Fahri, F., DiGiacomo, K., Lien, T.-F., Dunshea, F.R., 2021. Dietary nano chromium picolinate can ameliorate some of the impacts of heat stress in cross-bred sheep. Anim. Nutr. 7, 198–205. https://doi.org/10.1016/j.aninu.2020.07.004.
Immler, M., Failing, K., Gärtner, T., Wehrend, A., Donat, K., 2021. Associations between the metabolic status of the cow and colostrum quality as determined by Brix refractometry. J. Dairy Sci. 104, 10131–10142. https://doi.org/10.3168/jds.2020-19812.
Jing, T., Yao, X., Ji, T., Dong, J., Chen, X., Chen, F., Feng, H., Wang, T., Zhao, H., Chen, D., Ma, W., 2021. Effect of pasture versus indoor feeding on milk microbiota of goats. Kafkas Univ. Vet. Fak. Derg. 27, 641–648. https://doi.org/10.9775/kvfd.2021.26134.
Juste, R.A., Villoria, M., Leginagoikoa, I., Ugarte, E., Minguijon, E., 2020. Milk production losses in Latxa dairy sheep associated with small ruminant lentivirus infection. Prev. Vet. Med. 176, 104886. https://doi.org/10.1016/j.prevetmed.2020.104886.
Kacskovics, I., Wu, Z., Simister, N.E., Frenyó, L.V., Hammarström, L., 2000. Cloning and characterization of the bovine MHC class I-like Fc receptor. J. Immunol. 164, 1889–1897. https://doi.org/10.4049/jimmunol.164.4.1889.
Kelly, R.F., Jennings, A., Burrough, E., Russell, G., Adam, K., Gascoigne, E., Davies, P.L., Duncan, J., Hopker, A., Hyde, R.M., Lovatt, F.M., Bruce, A., Corbishley, A., 2025. Use of serum total protein as a proxy for passive transfer status in lambs. Vet. Rec. 197, e5435. https://doi.org/10.1002/vetr.5435.
Kessler, E.C., Bruckmaier, R.M., Gross, J.J., 2019. Immunoglobulin G content and colostrum composition of different goat and sheep breeds in Switzerland and Germany. J. Dairy Sci. 102, 5542–5549. https://doi.org/10.3168/jds.2018-16235.
Kessler, E.C., Bruckmaier, R.M., Gross, J.J., 2021. Short communication: comparative estimation of colostrum quality by Brix refractometry in bovine, caprine, and ovine colostrum. J. Dairy Sci. 104, 2438–2444. https://doi.org/10.3168/JDS.2020-19020.
Khorrami, Z., Aliarabi, H., Farahavar, A., Fadayifar, A., 2024. Effect of pre and postpartum maternal supplementation of zinc and selenium via slow-release glass bolus or the element salts on feed intake and some blood parameters in ewes and their lambs. Anim. Feed Sci. Technol. 311, 115949. https://doi.org/10.1016/j.anifeedsci.2024.115949.
Klaus, G.G., Bennett, A., Jones, E.W., 1969. A quantitative study of the transfer of colostral immunoglobulins to the newborn calf. Immunology 16, 293–299.
Kopp, K.J., Robertson, S.M., Abuelo, A., Xie, G., Friend, M.A., 2021. The production and composition of colostrum from ewes supplemented with niacin (vitamin B). Anim. Prod. Sci. 61, 117–122. https://doi.org/10.1071/An20142.
Kopp, K., Robertson, S., Abuelo, A., Gunn, A., Xie, G., Friend, M., 2020. Supplementing protein and starch combined to ewes in good body condition may not improve colostrum in ewes. Anim. Prod. Sci. 61, 108–116. https://doi.org/10.1071/AN19607.
Kruzel, M.L., Janusz, M., Lisowski, J., Fischleigh, R.V., Georgiades, J.A., 2001. Towards an understanding of biological role of colostrinin peptides. J. Mol. Neurosci. 17, 379–389. https://doi.org/10.1385/JMN:17:3:379.
Larson, B.L., Heary Jr., H.L., Devery, J.E., 1980. Immunoglobulin production and transport by the mammary gland. J. Dairy Sci. 63, 665–671. https://doi.org/10.3168/jds.S0022-0302(80)82988-2.
Lu, J., Liu, L., Pang, X., Zhang, S., Jia, Z., Ma, C., Zhao, L., Lv, J., 2016. Comparative proteomics of milk fat globule membrane in goat colostrum and mature milk. Food Chem. 209, 10–16. https://doi.org/10.1016/j.foodchem.2016.04.020.
Lopreiato, V., Ceniti, C., Trimboli, F., Fratto, E., Marotta, M., Britti, D., Morittu, V.M., 2017. Evaluation of the capillary electrophoresis method for measurement of immunoglobulin concentration in ewe colostrum. J. Dairy Sci. 100, 6465–6469. https://doi.org/10.3168/jds.2016-12284.
Ma, X., Liu, H., Li, W., Chen, J., Cui, Z., Wang, Z., Hu, C., Ding, Y., Zhu, H., 2024. Prolactin modulates the proliferation and secretion of goat mammary epithelial cells via regulating sodium-coupled neutral amino acid transporter 1 and 2. Cells 13, 1461. https://doi.org/10.3390/cells13171461.
Marai, I.F.M., El-Darawany, A.A., Fadiel, A., Abdel-Hafez, M.A.M., 2007. Physiological traits as affected by heat stress in sheep: a review. Small Rumin. Res. 71, 1–12. https://doi.org/10.1016/j.smallrumres.2006.10.003.
Martin-Collado, D., Diaz, C., Ramón, M., Iglesias, A., Milán, M.J., Sánchez-Rodríguez, M., Carabaño, M.J., 2024. Are farmers motivated to select for heat tolerance? Linking attitudinal factors, perceived climate change impacts, and social trust to farmers' breeding desires. J. Dairy Sci. 107, 2156–2174. https://doi.org/10.3168/jds.2023-23722.
McGovern, F., Campion, F., Lott, S., Boland, T., 2015. Altering ewe nutrition in late gestation: I. the impact on pre- and postpartum ewe performance. J. Anim. Sci. 93, 4860–4872. https://doi.org/10.2527/jas.2015-9019.
Mehaba, N., Coloma-Garcia, W., Such, X., Caja, G., Salama, A.A.K., 2021. Heat stress affects some physiological and productive variables and alters metabolism in dairy ewes. J. Dairy Sci. 104, 1099–1110. https://doi.org/10.3168/jds.2020-18943.
Mehmood, N., Hussain, T., Hameed, A., Yaseen, A., Ahmed, A., Hussain, M., Al Jbawi, E., 2023. Prospective effect of vitamin E and selenium supplementation on colostrum quality in Beetal goats. Cogent Food Agric. 9, 2197711. https://doi.org/10.1080/23311932.2023.2197711.
Mirzaei-Alamouti, H., Namdarpour, H., Abdollahi, A., Amanlou, H., Patra, A.K., Shahir, M.H., Aliyari, D., Vazirigohar, M., 2021. Nutrient digestibility, blood metabolites, and production performance of peripartal ewes fed dietary plant extract and monensin. Small Rumin. Res. 202, 106453. https://doi.org/10.1016/j.smallrumres.2021.106453.
Molik, E., Błasiak, M., Pustkowiak, H., 2020. Impact of photoperiod length and treatment with exogenous melatonin during pregnancy on chemical composition of sheep's milk. Animals 10, 1721. https://doi.org/10.3390/ani10101721.
Mongini, A., Van Saun, R.J., 2023. Pregnancy toxemia in sheep and goats. Vet. Clin. N. Am. Food Anim. Pr. 39, 275–291. https://doi.org/10.1016/j.cvfa.2023.02.010.
Monteiro, A.P.A., Tao, S., Thompson, I.M., Dahl, G.E., 2014. Effect of heat stress during late gestation on immune function and growth performance of calves: isolation of altered colostral and calf factors. J. Dairy Sci. 97, 6426–6439. https://doi.org/10.3168/jds.2013-7891.
Moradi, M., Chashnidel, Y., Teimouri Yansari, A., Khazari, B., Mansouryar, M., 2021. Moderate overfeeding of different sources of metabolizable energy and protein. II: Effects on inflammatory status of sheep in late pregnancy and growth trajectory of the offspring. Theriogenology 176, 115–121. https://doi.org/10.1016/j.theriogenology.2021.09.021.
Moretti, D.B., Nordi, W.M., Lima, A.L., Pauletti, P., Machado-Neto, R., 2013. Enterocyte IgG uptake in the small intestine of goat kids during the period of passive immunity acquisition. Small Rumin. Res. 114, 182–187. https://doi.org/10.1016/j.smallrumres.2013.05.012.
Moretti, D.B., Nordi, W.M., Lima, A.L., Pauletti, P., Susin, I., Machado-Neto, R., 2012. Goat kids' intestinal absorptive mucosa in period of passive immunity acquisition. Livest. Sci. 144, 1–10. https://doi.org/10.1016/j.livsci.2011.10.007.
Morammazi, S., Masoudi, A.A., Vaez Torshizi, R., Pakdel, A., 2016. Changes in the expression of the prolactin receptor (PRLR) gene in different physiological stages in the mammary gland of the Iranian Adani goat. Reprod. Domest. Anim. 51, 585–590. https://doi.org/10.1111/rda.12723.
Munn, A.L., Swinbourne, A.M.F., Brougham, B.J., van Wettere, W.H.E.J., Weaver, A.C., 2024. The effects of maternal calcium status during late gestation on lamb growth and survival in twin-bearing Merino ewes grazing pasture. Aust. Vet. J. 102, 249–255. https://doi.org/10.1111/avj.13321.
Murdock, N.J., Weaver, A.C., Kelly, J.M., Kleemann, D.O., van Wettere, W., Swinbourne, A.M., 2021. Supplementing pregnant Merino ewes with caffeine to improve neonatal lamb thermoregulation and viability. Anim. Reprod. Sci. 226, 106715. https://doi.org/10.1016/j.anireprosci.2021.106715.
Narciso, L.G., Alcindo, J.F., Bovino, F., Trevizan, J.T., da Silva Vieira, D., Martins de Almeida, B.F., Formiga-Feitosa, F.L., 2022. Impact of dexamethasone treatment protocols in goats for preterm outcomes. Small Rumin. Res. 216, 106818. https://doi.org/10.1016/j.smallrumres.2022.106818.
Navarrete, J., Earing, J., Holder, M., Rickard, J.W., Lugar, D.W., 2021. The effect of the inclusion of liquid brewers yeast during gestation on colostrum quality and passive transfer of immunity in lambs. J. Anim. Sci. 99, 283–284. https://doi.org/10.1093/jas/skab235.520.
Nguyen, T.T.T., Bowman, P.J., Haile-Mariam, M., Pryce, J.E., Hayes, B.J., 2016. Genomic selection for tolerance to heat stress in Australian dairy cattle. J. Dairy Sci. 99, 2849–2862. https://doi.org/10.3168/jds.2015-9685.

Nordi, W.M., Moretti, D.B., Lima, A.L., Pauletti, P., Susin, I., Machado-Neto, R., 2012. Intestinal IgG uptake by small intestine of goat kid fed goat or lyophilized bovine colostrum. Livest. Sci. 144, 205–210. https://doi.org/10.1016/j.livsci.2011.11.017.
Nouri, M., Zarrin, M., Ahmadpour, A., Castro, N., González-Cabrera, M., Hernández-Castellano, L.E., 2023. Feed restriction around parturition does not affect colostrum immunoglobulin G concentration in dairy fat-tailed sheep but does affect performance and blood metabolites in newborn lambs. J. Dairy Sci. 106, 2980–2988. https://doi.org/10.3168/jds.2022-22505.
Nurlatifah, A., Khotijah, L., Arifiantini, R.I., Maidin, M.S., Astuti, D.A., 2022. Colostrum quality of ewe fed flushing diet containing EPA and DHA associated with lamb performance. Trop. Anim. Sci. 45, 348–355. https://doi.org/10.5398/tasj.2022.45.3.348.
O'Brien, J.P., Sherman, D.M., 1993. Serum immunoglobulin concentrations of newborn goat kids and subsequent kid survival through weaning. Small Rumin. Res. 11, 71–77. https://doi.org/10.1016/0921-4488(93)90119-3.
Olivera-Muzante, J., Fierro, S., Durán, J.M., Antognazza, J., Sánchez, S., Dutra, F., Baldi, F., Banchero, G., 2022. Birth, colostrum, and vigour traits of lambs born from Corriedale ewes grazing native pastures supplemented during the peripartum period. Small Rumin. Res. 216, 106795. https://doi.org/10.1016/j.smallrumres.2022.106795.
Pollock, J.M., Miner, K., Buzzell, N., Schofield, M., Hawkins, N., Blash, S., Barton, B., Gavin, W.G., 2021. Induction of parturition in a large number of pregnant dairy goats and its benefits as a management tool in a commercial scale goat operation. Theriogenology 172, 1–7. https://doi.org/10.1016/j.theriogenology.2021.05.024.
Purser, A.F., Young, G.B., 1964. Mortality among twin and single lambs. Anim. Sci. 6, 321–329. https://doi.org/10.1017/S000335610002211X.
Prosser, C., Stelwagen, K., Cummins, R., Guerin, P., Gill, N., Milne, C., 2004. Reduction in heat-induced gastrointestinal hyperpermeability in rats by bovine colostrum and goat milk powders. J. Appl. Physiol. 96, 650–654. https://doi.org/10.1152/japplphysiol.00295.2003.
Pryce, J.E., Haile-Mariam, M., 2020. Symposium review: genomic selection for reducing environmental impact and adapting to climate change. J. Dairy Sci. 103, 5366–5375. https://doi.org/10.3168/jds.2019-17732.
Rahmani, R.F., Teimouri, A.Y., Dirandeh, E., 2017. Effects of energy and protein levels of maternal diets at late gestation on growth, health and performance of goat kids. Iran. J. Appl. Anim. Sci. 7, 611–620.
Ramírez-Vera, S., Terrazas, A., Delgadillo, J.A., Serafín, N., Flores, J.A., Elizundia, J.M., Hernández, H., 2012. Feeding corn during the last 12 days of gestation improved colostrum production and neonatal activity in goats grazing subtropical semi-arid rangeland. J. Anim. Sci. 90, 2362–2370. https://doi.org/10.2527/jas.2011-4306.
Richardson, H., Ahmadzadeh, A., Konetchy, D., 2023. Use of a visual scoring system to assess external udder conformation and its relationship to colostrum quality and lamb growth rates. Animals 13, 2900. https://doi.org/10.3390/ani13182900.
Ricks, R.E., Cook, E.K., Long, N.M., 2020. Effects of supplementing ruminal-bypass unsaturated fatty acids during late gestation on beef cow and calf serum and colostrum fatty acids, transfer of passive immunity, and cow and calf performance. Appl. Anim. Sci. 36, 271–284. https://doi.org/10.15232/aas.2019-01900.
Rossi, R.M., Cullens, F.M., Bacigalupo, P., Sordillo, L.M., Abuelo, A., 2022. Changes in biomarkers of metabolic stress during late gestation of dairy cows associated with colostrum volume and immunoglobulin content. J. Dairy Sci. 106, 718–732. https://doi.org/10.3168/jds.2022-22240.
Ruiz, P., Seseña, S., Palop, M.L., 2014. Characterization of bacterial populations from Murciano-Granadina goat colostrum. Dairy Sci. Technol. 94, 549–560. https://doi.org/10.1007/s13594-014-0179-0.
Salama, A.A.K., Hamzaoui, S., Albanell, E., Such, X., Caja, G., 2021. Metabolic and behavior responses of lactating goats under heat stress. Small Rumin. Res. 203, 106496. https://doi.org/10.1016/j.smallrumres.2021.106496.
Sales, F., Parraguez, V.H., Freitas-de-Melo, A., Ungerfeld, R., 2020. Maternal nutrition and antioxidant supplementation: effects on mother–young behaviors in a Patagonian sheep extensive grazing system. Appl. Anim. Behav. Sci. 228, 105010. https://doi.org/10.1016/j.applanim.2020.105010.
Shabrandi, F., Dirandeh, E., Ansari-Pirsaraei, Z., Teimouri-Yansari, A., 2019. Increasing metabolizable energy and protein supplementation to stimulate the subsequent milk production during late gestation by increasing proliferation and reducing apoptosis in goat mammary gland prepartum. Anim. Prod. Sci. 59, 1820. https://doi.org/10.1071/AN17876.
Shiels, D., Loughrey, J., Dwyer, C.M., Hanrahan, K., Mee, J.F., Keady, T.W.J., 2021. A survey of farm management practices relating to the risk factors, prevalence, and causes of lamb mortality in Ireland. Animals 12, 30. https://doi.org/10.3390/ani12010030.
Silva, P.S., Hooper, H.B., Manica, E., Merighe, G.K.F., Oliveira, S.A., Traldi, A.S., Negrão, J.A., 2021. Heat stress affects the expression of key genes in the placenta, placental characteristics, and efficiency of Saanen goats and the survival and growth of their kids. J. Dairy Sci. 104, 4970–4979. https://doi.org/10.3168/jds.2020-18301.
Skibiel, A.L., Koh, J., Zhu, N., Zhu, F., Yoo, M.J., Laporta, J., 2022. Carry-over effects of dry period heat stress on the mammary gland proteome and phosphoproteome in the subsequent lactation of dairy cows. Sci. Rep. 12, 6637. https://doi.org/10.1038/s41598-022-10461-z.
Sohrabi, H.R., Farahani, T.A., Karimi-Dehkordi, S., Farsuni, N.E., 2024. Association of different classifications of hypocalcemia with quantity and quality of colostrum, milk production, and health of Holstein dams and their calves. Vet. J. 307, 106205. https://doi.org/10.1016/j.tvjl.2024.106205.
Syeed Momen, S., Sharifi Hosseini, M., Tahmasbi, R., Dayani, O., Asadi, M., 2021. Effect of energy and protein levels in supplemental diets on performance of Rayeni cashmere does and goat kids under natural grazing conditions. J. Anim. Feed Sci. 30, 303–311. https://doi.org/10.22358/jafs/144847/2021.
Tekin, T.B., Akkus, T., 2023. The effect of melatonin administration on colostrum IgG levels and oxidative stress in advanced pregnant Awassi sheep. Isr. J. Vet. Med. 78, 9–17.
Tillquist, N.M., Reed, S.A., Kawaida, M.Y., Reiter, A.S., Smith, B.I., Jang, H., Lee, J.-Y., Lee, E.C., Zinn, S.A., Govoni, K.E., 2023. Restricted- and over-feeding during gestation decreases growth of offspring throughout maturity. Transl. Anim. Sci. 7, txad061. https://doi.org/10.1093/tas/txad061.
Tillquist, N.M., Reed, S.A., Reiter, A.S., Kawaida, M.Y., Lee, E.C., Zinn, S.A., Govoni, K.E., 2024. Effects of poor maternal diet during gestation are detected in F2 offspring. Transl. Anim. Sci. 8, txae055. https://doi.org/10.1093/tas/txae055.
Todaro, M., Scatassa, M.L., Gannuscio, R., Vazzana, I., Mancuso, I., Maniaci, G., Laudicina, A., 2023. Effect of lambing season on ewe's colostrum composition. Ital. J. Anim. Sci. 22, 14–23. https://doi.org/10.1080/1828051X.2022.2155587.
Tucker, H.A., 2000. Hormones, mammary growth, and lactation: a 41-year perspective. J. Dairy Sci. 83, 874–884. https://doi.org/10.3168/jds.S0022-0302(00)74951-4.
Turín, J., Sales, F., Peralta, O.A., De los Reyes, M., Borie, C., Carrasco, A., González-Bulnes, A., Parraguez, V.H., 2023. Colostrum traits and newborn body weight and growth: comparison between single and twin underfed sheep pregnancies. Front. Vet. Sci. 10, 1256989. https://doi.org/10.3389/fvets.2023.1256989.
Uztimür, M., Gazioğlu, A., Yilmaz, Ö., 2024. Changes in free amino acid profile in goats with pregnancy toxemia. Vet. Res. Commun. 48, 839–847. https://doi.org/10.1007/s11259-023-10255-2.
Villar, M.L., Giraudo, C.G., Cueto, M.I., 2023. Short-term energy supplementation before lambing improves maternal behaviour, udder volume, colostrum viscosity and lamb birthweight in ewes under extensive grazing. Small Rumin. Res. 219, 106893. https://doi.org/10.1016/j.smallrumres.2022.106893.
Viola, I., Tizzani, P., Perona, G., Lussiana, C., Mimosi, A., Ponzio, P., Cornale, P., 2022. Hazelnut skin in ewes' diet: effects on colostrum immunoglobulin G and passive transfer of immunity to the lambs. Animals 12, 3220. https://doi.org/10.3390/ani12223220.
Vitali, A., Felici, A., Lees, A.M., Giacinti, G., Maresca, C., Bernabucci, U., Lacetera, N., 2020. Heat load increases the risk of clinical mastitis in dairy cattle. J. Dairy Sci. 103, 8378–8387. https://doi.org/10.3168/jds.2019-17748.
Voigt, R.A., Hammer, C.J., Guenther, M.C., Borowicz, P.P., Neville, T.L., Swanson, T.J., Vonnahme, K.A., Redmer, D.A., Reynolds, L.P., Caton, J.S., 2022. Evaluation of maternal plane of nutrition and selenium supplementation on the neonatal fragment crystallizable receptor (FcRn) in ewe mammary tissue. J. Anim. Sci. 100, 264. https://doi.org/10.1093/jas/skac247.479.
Wallace, J.M., Shepherd, P.O., Milne, J.S., Aitken, R.P., 2021. Perinatal complications and maximising lamb survival in an adolescent paradigm characterised by premature delivery and low birthweight. PLoS One 16, e0259890. https://doi.org/10.1371/journal.pone.0259890.
Wang, Z., Zhang, N., Li, F., Yue, X., 2022. Effects of pre-partum dietary crude protein level on colostrum fat globule membrane proteins and the performance of Hu ewes and their offspring. Front. Vet. Sci. 9, 1046214. https://doi.org/10.3389/fvets.2022.1046214.
Weström, B., Arévalo Sureda, E., Pierzynowska, K., Pierzynowski, S.G., Pérez-Cano, F.J., 2020. The immature gut barrier and its importance in establishing immunity in newborn mammals. Front. Immunol. 11, 1153. https://doi.org/10.3389/fimmu.2020.01153.
Wicki, M., Fassier, T., Huau, C., Corbière, F., Rupp, R., 2024. Genetic and environmental determinants of immunoglobulin G in kid serum and adult colostrum of dairy goats. J. Dairy Sci. 108, 623–634. https://doi.org/10.3168/jds.2024-25113.
Yang, C.H., Wu, Z.Y., Li, Y., Zhang, W., 2020. Effect of melatonin administration to lactating cashmere goats on milk production of dams and on hair follicle development in their offspring. Animal 14, 1241–1248. https://doi.org/10.1017/S1751731119002726.
Zarrin, M., Sanginabadi, M., Nouri, M., Ahmadpour, A., Hernández-Castellano, L.E., 2021. Prepartum and postpartum feed restrictions affect blood metabolites and hormones reducing colostrum and milk yields in fat-tailed dairy sheep. Animals 11, 1258. https://doi.org/10.3390/ani11051258.
Zhang, Z., Du, W., Liu, W., Wong, B.T., Zheng, H., 2022. Increasing serotonin concentrations alter calcium metabolism in periparturient dairy goats. J. Anim. Sci. 100 (3), skac065. https://doi.org/10.1093/jas/skac065.
Zhang, S., Geng, Y., Ling, Y., Wang, D., Hu, G., 2024. Yeast culture is beneficial for improving the rumen fermentation and promoting the growth performance of goats in summer. Fermentation 10, 307. https://doi.org/10.3390/fermentation10060307.
Zhou, A., Chong, Y., Liu, G., Jiang, X., Huang, Y., Bo, D., Guo, Q., Hu, R., Chi, S., Wang, M., Yan, Y., Sun, L., Mao, X., 2023a. Changes in colostrum ingredients of Hu sheep, as well as the missense mutation genes associated with colostrum yield. Anim. Biotechnol. 34, 1492–1504. https://doi.org/10.1080/10495398.2022.2034641.
Zhou, A., Zhang, X., Zhou, Y., Xiao, L., Li, T., 2023b. Effects of lactation number and litter size on the chemical composition and immune components of goat colostrum. Anim. Biotechnol. 34, 1662–1672. https://doi.org/10.1080/10495398.2021.2013856.
Zhu, H.L., Zhao, X.W., Han, R.W., Du, Q.J., Qi, Y.X., Jiang, H.N., Huang, D.W., Yang, Y.X., 2021. Changes in bacterial community and expression of genes involved in intestinal innate immunity in the jejunum of newborn lambs during the first 24 h of life. J. Dairy Sci. 104, 9263–9275. https://doi.org/10.3168/jds.2020-19888.
Zobel, G., Rodriguez-Sanchez, R., Hea, S.Y., Weatherall, A., Sargent, R., 2020. Validation of Brix refractometers and a hydrometer for measuring the quality of caprine colostrum. J. Dairy Sci. 103, 9277–9289. https://doi.org/10.3168/jds.2020-18165.

Glossary

BCS: Body condition score
BW: Body weight
Ca: Calcium
CAEV: Caprine arthritis encephalitis virus
CLA: Linoleic acid
CP: Crude protein
DM: Dry matter
FA: Fatty acid
FEC: Faecal egg count
FFA: Free fatty acids
Ig: Immunoglobulin
IGF-1: Insulin-like growth factor 1
IL: Interleukin
ME: Metabolizable energy
Mg: Magnesium
Mn: Manganese
MP: Metabolizable protein
NDF: Neutral detergent fibre
PUFA: Polyunsaturated fatty acids
RDP: Rumen degradable protein
RUP: Rumen undegradable protein
SCC: Somatic cell counts
Se: Selenium
TPI: Transfer of passive immunity
Zn: Zinc