VETERINARIA ITALIANA
RIVISTA DI SANITÀ PUBBLICA VETERINARIA

Paper

Immunological and bacteriological quality of bovine colostrum, passive transfer of immunity, and associated maternal, colostral and management-related risk factors in dairy calves in northern Algeria

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Veterinaria Italiana, Vol. 62 No. 4 (2026) DOI: 10.12834/VetIt.4079.42963.2

Abstract

Adequate colostrum management is critical for ensuring successful transfer of passive immunity (TPI) and reducing neonatal morbidity and mortality in dairy calves. However, comprehensive data on colostrum quality and its impact on calf health remain scarce in North African dairy production systems. Objectives: This prospective cohort study evaluated the immunological and bacteriological quality of first-milking colostrum and the prevalence of TPI, neonatal diarrhoea and mortality, and identified the independent risk factors associated with colostrum quality and failure of passive transfer (FPT) in commercial dairy herds in northern Algeria. A total of 188 cow–calf pairs (188 cows and 192 calves, with four twin pregnancies) from 16 commercial dairy farms in Tizi-Ouzou were enrolled between March 2025 and June 2026. Colostral immunological quality was assessed using the COL-IgG-Test® (BioX Diagnostics), while bacteriological quality was determined by standard culture and biochemical identification. Passive transfer was evaluated in calves aged 2–6 days using the Calf-IgG-Test®. Early-onset diarrhoea was recorded over the first 7 days of life, and mortality throughout the neonatal period. Associations were analysed using univariable and multivariable logistic regression, with model discrimination assessed by the area under the ROC curve (AUC). Overall, 58.0% (109/188) of colostrum samples were of good quality (IgG ≥ 50 g/L) and 28.7% (54/188) were bacterially contaminated, predominantly by *S. aureus* and *E. coli* (25.9% each). Successful passive transfer occurred in 60.4% (116/192) of calves, while 37.0% (71/192) developed neonatal diarrhoea and 24.0% (46/192) died. In multivariable analysis, dystocia (aOR = 29.89; 95% CI: 5.95–150.33) and positive/neutral energy balance (aOR = 0.015; 95% CI: 0.002–0.155) independently predicted poor colostrum quality. For FPT, the strongest predictors were poor colostrum quality (aOR = 11.48; 4.26–30.91), delayed first suckling > 2 h (aOR = 6.24; 2.32–16.79), colostrum intake < 4 L (aOR = 4.35; 1.72–11.02), positive bacterial culture (aOR = 3.63; 1.39–9.45), dystocia (aOR = 3.19; 1.18–8.61) and negative energy balance (aOR = 2.56; 1.01–6.46). The final model showed good discrimination (AUC = 0.82). Poor colostrum quality, bacterial contamination and inadequate management remain the main determinants of FPT and neonatal mortality in Algerian dairy herds. Routine Brix-based assessment, improved transition-cow nutrition, hygienic colostrum handling and administration of adequate colostrum volumes within 2 h after birth are recommended to improve calf health and productivity.

Keywords

bovine colostrum, passive transfer of immunity, bacteriological contamination, neonatal diarrhea, risk factors

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Introduction

The neonatal period represents one of the most critical phases in dairy production because calf health and survival during the first weeks of life have profound consequences for lifetime productivity, animal welfare and farm profitability. Neonatal diseases, particularly diarrhoea and septicaemia, remain among the leading causes of morbidity and mortality in pre-weaned calves worldwide despite substantial advances in herd management and veterinary medicine (Cho and Yoon, 2014; Godden et al., 2019; Lombard et al., 2020). Beyond their immediate impact on calf survival, early-life diseases have been associated with impaired growth, delayed age at first calving, reduced first-lactation milk yield and increased culling risk, generating considerable economic losses for dairy producers (Abuelo et al., 2021; Lopez and Heinrichs, 2022).

Because the bovine placenta is syndesmochorial (synepitheliochorial), the transplacental transfer of maternal immunoglobulins is virtually absent, leaving calves born essentially agammaglobulinaemic at birth. Consequently, successful transfer of passive immunity depends entirely on the ingestion of adequate amounts of high-quality colostrum within the first hours after birth (Godden et al., 2019; Lopez and Heinrichs, 2022). In addition to immunoglobulin G (IgG), colostrum contains numerous bioactive compounds—including leucocytes, cytokines, lactoferrin, growth factors, hormones and oligosaccharides—that contribute to intestinal maturation, immune development and resistance to infectious diseases (Lopez and Heinrichs, 2022; Westhoff et al., 2024; Flynn et al., 2025). Accordingly, both the immunological and microbiological qualities of colostrum are now recognised as fundamental determinants of neonatal calf health.

Failure of passive transfer (FPT) remains one of the most important preventable risk factors affecting dairy calves. Numerous epidemiological studies have demonstrated that inadequate passive immunity markedly increases the risk of neonatal diarrhoea, respiratory disease, antimicrobial treatment, mortality and reduced productive performance (Godden et al., 2019; Lombard et al., 2020). The occurrence of FPT is, however, a multifactorial process influenced by maternal factors, transition-cow management, colostrum quality, bacterial contamination, timing of first feeding and the volume of colostrum ingested (Fischer et al., 2018; Lopez and Heinrichs, 2022; Westhoff et al., 2024). Although these determinants have been extensively investigated in North America and Europe, information from North African dairy production systems remains extremely limited.

This lack of evidence is particularly important in Algeria, where the dairy sector has expanded considerably over recent decades in response to increasing demand for milk and dairy products. Despite substantial governmental investment aimed at improving domestic milk production, the country continues to face important challenges related to herd productivity and calf health, while dairy production systems remain highly heterogeneous in terms of herd management and technical performance (Kaouche-Adjlane et al., 2015; Boukhechem et al., 2019). Under these conditions, routine evaluation of colostrum quality, passive transfer of immunity and bacteriological contamination is rarely incorporated into herd-health programmes, resulting in a lack of locally generated epidemiological evidence to support evidence-based recommendations for neonatal calf management adapted to Algerian dairy production systems (FAO, 2023; Hales, 2024).

To date, few studies conducted in Algeria have simultaneously investigated the relationships between colostrum quality, bacteriological contamination, passive immunity transfer and neonatal calf health. Most available studies have focused on isolated aspects of calf management or have relied on descriptive observations without evaluating the independent contribution of maternal, colostral and management-related risk factors. As a result, important knowledge gaps remain regarding the determinants of successful passive immunity under Algerian dairy farming conditions and their subsequent impact on neonatal diarrhoea and mortality.

The present prospective study was therefore designed to provide an integrated evaluation of colostrum management and neonatal calf health in commercial dairy herds in northern Algeria. Specifically, the objectives were to (i) assess the immunological and bacteriological quality of bovine colostrum, (ii) determine the prevalence of successful passive immunity transfer, neonatal diarrhoea and mortality, (iii) identify the bacterial species contaminating colostrum, and (iv) investigate the independent maternal and management-related risk factors associated with colostrum quality, passive immunity and neonatal health using multivariable logistic regression models. By addressing these objectives simultaneously, this study provides one of the first comprehensive epidemiological assessments of colostrum management in Algerian dairy herds and generates evidence that may support the development of locally adapted recommendations for improving calf health, welfare and dairy-farm productivity.

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Materials and methods

Study design, setting and period

A prospective observational cohort study was carried out from March 2025 to June 2026 on commercial dairy farms located in the wilaya (province) of Tizi-Ouzou, northern Algeria. The study area lies within a humid Mediterranean bioclimatic zone and represents one of the main dairy-producing regions in the country. The 16-month study period covered two successive calving seasons (spring 2025 and autumn 2025–spring 2026), allowing seasonal variation to be captured.

Three municipalities were purposively selected to reflect the diversity of dairy production systems in the area: Freha, Larbaa Nath Irathen and Tizi-Rached. These municipalities included intensive peri-urban farms, semi-intensive family-operated farms and smallholder units, covering the main husbandry patterns encountered in northern Algeria.

A cow–calf paired design was adopted, in which each enrolled cow and her corresponding calf were considered as a single observational unit. Data collection covered maternal characteristics, calving conditions, colostrum quality, passive transfer of immunity and neonatal health outcomes.

Study population and eligibility criteria

The study population consisted of dairy cows and their newborn calves raised under commercial farming conditions. A total of 188 cow–calf pairs were included.

Cows were eligible when they were clinically healthy at calving, had complete reproductive and management records and gave birth to a live calf. Calves were eligible when they were available for blood sampling between 2 and 6 days of age, the age window recommended for assessment of passive transfer (Lombard et al., 2020).

Animals were excluded when the dam presented with severe systemic disorders at calving (clinical milk fever, severe clinical mastitis, retained placenta or septicaemia), when first-milking colostrum was unavailable or insufficient for analysis, or when essential clinical information was missing.

The enrolled cows belonged mainly to the Holstein, Montbéliarde, Simmental, and Fleckvieh breeds, reflecting the genetic diversity of dairy herds in northern Algeria, and were managed under semi-intensive production systems combining confined housing with grazing during spring and summer.

Data collection and recorded variables

A standardised questionnaire was developed, pre-tested on 10 non-enrolled cow–calf pairs, and refined before the start of data collection to ensure clarity and consistency. For each enrolled cow–calf pair, information was collected through direct on-farm observations, structured interviews with farmers, and laboratory analyses. Herd-level data included the geographical location (municipality), production system (intensive, semi-intensive, or smallholder), overall farm hygiene (classified as good, acceptable, or poor), feeding practices, and calving season (spring or autumn–winter). Maternal variables comprised breed, age, parity, body condition score (BCS), dry period length, peripartum energy balance, dry cow antibiotic therapy, and udder health status. Udder health was assessed on the day of calving using the California Mastitis Test (CMT), and dry cow antibiotic therapy was recorded as a binary variable (yes/no).

BCS was evaluated by the same trained investigator using the five-point scale (1 = emaciated to 5 = obese) with 0.25-point increments, as described by Edmonson et al. (1989). BCS was recorded at drying-off and again within 24 h after calving. Prepartum energy balance dynamics were inferred from the change in BCS between these two time points. Cows that maintained or increased their BCS were classified as having a neutral/positive prepartum energy balance, whereas cows with a decrease in BCS were classified as having experienced a negative energy balance prior to calving. Calving-related variables included calving difficulty, classified as eutocia or dystocia (defined as any calving requiring obstetrical assistance), and type of birth (singleton or twin). Colostrum characteristics comprised immunoglobulin G (IgG) concentration, estimated using a glutaraldehyde coagulation test, specific gravity measured with a colostrometer, inflammatory status assessed by the California Mastitis Test (CMT), bacteriological contamination status, and estimated colostrum yield (L). Calf-level variables included sex, the interval between birth and first colostrum feeding (h), the volume of colostrum ingested at the first feeding (L), passive transfer of immunity

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status (successful or failed), the occurrence of neonatal diarrhoea during the first 7 days of life, and mortality during the follow-up period, both recorded as binary outcomes (yes/no).

Calf follow-up was conducted through weekly farm visits until weaning or until the calf died, whichever occurred first. Neonatal diarrhoea was defined as the presence of watery or semi-liquid faeces for at least 24 h, with or without systemic signs.

Colostrum sampling and handling

Approximately 500 mL of first-milking colostrum were collected from each cow within 2–6 h after calving. Prior to collection, teats were cleaned with water and disinfected with chlorhexidine-based antiseptic solution and the first streams of colostrum were discarded. Colostrum was harvested into sterile, single-use containers.

Samples were immediately refrigerated at 4 ± 2 °C and transported to the laboratory. When immediate analysis was not possible, aliquots were stored at −20 °C and subsequently thawed in a water bath at 37 °C before examination. Each sample underwent a single freeze–thaw cycle to limit IgG degradation.

Evaluation of colostrum immunological quality

The immunological quality of first-milking colostrum was assessed using the COL-IgG-Test® (BioX Diagnostics, Rochefort, Belgium), a rapid field test designed to estimate colostral immunoglobulin G (IgG) concentration through glutaraldehyde-induced coagulation. The test was performed according to the manufacturer's instructions. Briefly, 3 mL of thoroughly homogenised colostrum were mixed with the reagent provided in the kit, and the coagulation time was recorded. The coagulation time was then interpreted using the manufacturer's reference chart, which provides an estimate of colostral IgG concentration. Based on current international recommendations for colostrum management (Godden et al., 2019; Lopez and Heinrichs, 2022), colostrum was classified as good quality (estimated IgG ≥ 50 g/L) or poor quality (estimated IgG < 50 g/L).

Assessment of passive transfer of immunity

Blood samples (5 mL) were collected from the jugular vein of calves aged 2–6 days using sterile evacuated tubes without anticoagulant (BD Vacutainer®, USA). Samples were allowed to clot at room temperature for 30 min, then centrifuged at 1,500 × g for 10 min. Serum was harvested and either analysed immediately or stored at −20 °C until analysis.

Passive transfer of immunity was evaluated using the Calf-IgG-Test® (BioX Diagnostics, Rochefort, Belgium), a rapid field assay designed to estimate serum IgG concentration. The interpretation of passive transfer status was based on established thresholds for serum IgG concentration (Hogan et al., 2015).

Following the manufacturer's recommendations and the international consensus threshold (Lombard et al., 2020), passive transfer was classified as:

Successful passive transfer (SPT): coagulation time ≤ 1 min (serum IgG ≥ 10.1 g/L);

Failure of passive transfer (FPT): coagulation time ≥ 2 min (serum IgG < 10.1 g/L).

Bacteriological analysis of colostrum

Colostrum samples were transported to the laboratory under refrigerated conditions (4 ± 2 °C) and processed within 24 h of collection. Each sample was thoroughly homogenised before inoculation. With a calibrated sterile 10-µL inoculating loop, aliquots were streaked onto the following media (Oxoid, Basingstoke, UK):

5% sheep blood agar (for total aerobic count and haemolytic patterns);

MacConkey agar (for Gram-negative enteric bacteria);

Mannitol Salt Agar (for staphylococci).

Plates were incubated aerobically at 37 °C for 24–48 h and examined daily for bacterial growth. Plates with no growth after 48 h were recorded as negative.

Presumptive identification of bacterial isolates was based on colony morphology, haemolytic pattern on blood agar,

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Gram staining, catalase and coagulase tests. Definitive identification was performed using the appropriate API® biochemical galleries (API 20E for Enterobacteriaceae, API Staph for staphylococci, API Strep for streptococci; bioMérieux, Marcy-l'Étoile, France) according to the manufacturer's instructions. Biochemical profiles were interpreted using the APIweb™ identification system, and bacterial species were identified against the manufacturer's database. Final identification was confirmed by integrating API profiles with conventional microbiological characteristics and the taxonomic criteria described in Bergey's Manual of Systematic Bacteriology (Goodfellow et al., 2012).

The bacteriological quality of colostrum was assessed qualitatively according to the presence or absence of bacterial growth. Samples showing bacterial growth on at least one culture medium were classified as culture-positive, whereas samples with no bacterial growth after 48 h of incubation were classified as culture-negative.

Statistical analysis

All statistical analyses were performed using R software version 4.4.1 (R Foundation for Statistical Computing, Vienna, Austria). Descriptive statistics were expressed as means ± standard deviations (SD) for continuous variables and as frequencies and percentages for categorical variables. Associations between explanatory variables and study outcomes were initially explored using univariable logistic regression. Variables considered biologically relevant and those associated with the outcome at $P < 0.20$ were considered for inclusion in the multivariable logistic regression model. A backward elimination procedure was subsequently applied to derive the most parsimonious model while accounting for potential confounding. Adjusted odds ratios (aOR) and their corresponding 95% confidence intervals (95% CI) were reported. Multicollinearity among candidate predictors was assessed using the variance inflation factor (VIF), with values >5 indicating potential collinearity. Model performance was evaluated by assessing both discrimination and calibration. Discrimination was quantified using the area under the receiver operating characteristic curve (AUC), whereas calibration was assessed using the Hosmer–Lemeshow goodness-of-fit test. Model parsimony was evaluated using the Akaike Information Criterion (AIC). Spearman's rank correlation coefficient was used to assess associations between continuous or ordinal variables, while the Phi coefficient was applied to binary variables. Statistical significance was set at $P < 0.05$.

Results

Study population and maternal characteristics

A total of 188 dairy cows and their 192 newborn calves from commercial dairy farms located in three municipalities of the wilaya of Tizi-Ouzou (northern Algeria) were prospectively enrolled between March 2025 and June 2026. The difference between the number of cows and calves corresponded to the four twin calvings recorded during the study period. Most animals originated from the municipality of Freha (164/188; 87.2%), while Larbaa Nath Irathen and Tizi-Rached contributed 10 (5.3%) and 14 (7.4%) cows, respectively. Cow-level variables were analysed on the 188 enrolled cows, whereas calf-level outcomes (passive transfer, neonatal diarrhoea and mortality) were assessed in the 192 calves (Figure 1).

The study population consisted mainly of Montbéliarde cows (104/188; 55.3%), followed by Holstein (58/188; 30.9%), Fleckvieh (19/188; 10.1%) and Simmental (7/188; 3.7%). The mean age was 3.86 ± 0.92 years (range: 2–6 years), with 4-year-old cows representing the largest age group (124/188; 66.0%). Cows aged 2, 3, 5 and 6 years accounted for 13.9%, 4.6%, 12.3% and 3.1% of the study population, respectively.

At drying-off, the mean body condition score (BCS) was 2.47 ± 0.30, with 81.5% of cows presenting an intermediate BCS (2.5–2.75). At calving, the mean BCS increased to 2.73 ± 0.55, and 40.0% of cows had a BCS between 3.0 and 3.5. Based on the change in BCS between drying-off and calving, 134 of 188 cows (71.3%) maintained a positive or neutral energy balance, whereas 54 (28.7%) experienced a negative energy balance (Table 1).

Second-parity cows represented the largest parity group (72.3%). Eutocia occurred in 105 cows (55.8%), whereas 83 (44.2%) experienced dystocia. Singleton births accounted for 97.9% of calvings, with four twin calvings (2.1%). Among the 192 calves, 142 (73.9%) were males and 50 (26.1%) were females (Table 1).

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Mammary health

The California Mastitis Test (CMT) performed on the day of calving showed that 72 of 188 cows (38.3%) had evidence of subclinical mammary inflammation, whereas 116 (61.7%) were CMT-negative. Among CMT-positive cows, scores 1, 2 and 3 represented 40.3%, 31.9% and 27.8% of positive animals, respectively, indicating that nearly one-third of affected cows presented with severe mammary inflammation.

Variable	Category	n	% (95% CI)
Regions	Freha	164	**87.2 (81.6–91.2)**
	Larbaa Nath Irathen	10	**5.3 (2.9–9.5)**
	Tizi-Rached	14	**7.4 (4.5–12.0)**
Breed	Montbéliarde	104	**55.3 (48.2–62.2)**
	Holstein	58	**30.9 (24.8–37.7)**
	Fleckvieh	19	**10.1 (6.6–15.2)**
	Simmental	7	**3.7 (1.8–7.5)**
Age (years)	Mean ± SD	3.86 ± 0.92	—
	Range	2–6	—
Calving type	Eutocia	105	**55.8 (48.7–62.7)**
	Dystocia	83	**44.2 (37.3–51.3)**
Birth type	Singleton	184	**97.9**
	Twin	4	**2.12**
Sex of calves	Male	142	**73.9 (67.2–79.7)**
	Female	50	**26.1 (20.3–32.8)**
Energy balance	Positive/Neutral	134	**71.3 (65.0–77.6)**
	Negative	54	**28.7 (23.2–34.3)**
Immunological quality of colostrum	Good quality (IgG ≥50 g/L)	109	**58.0 (50.9–65.1)**
	Poor quality (IgG <50 g/L)	79	**42.0 (34.9–49.1)**

Table I. Descriptive characteristics of the study population and immunological quality of bovine colostrum (n = 188 cows).

Immunological quality of colostrum

The immunological quality of first-milking colostrum was assessed using the COL-IgG-Test®, considering an IgG concentration ≥ 50 g/L as the threshold for adequate quality. Overall, 109 of 188 colostrum samples (58.0%; 95% CI: 50.9–65.1) were classified as good quality, whereas 79 samples (42.0%; 95% CI: 34.9–49.1) were classified as poor quality (Table 1).

According to the four-grade classification, 19.2% of samples were classified as excellent, 38.8% as good, 21.3% as moderate and 20.7% as poor. Overall, 58.0% of colostrum samples were considered satisfactory (excellent or good), whereas 42.0% failed to reach the recommended IgG concentration.

Bacteriological quality of colostrum

Bacterial culture was positive in 54 of the 188 colostrum samples (28.7%; 95% CI: 22.3–35.2), whereas 134 samples (71.3%) showed no bacterial growth (Table 2). Staphylococcus aureus and Escherichia coli were the predominant isolates (14 isolates each; 25.9%), followed by Streptococcus agalactiae (16.7%), Pseudomonas aeruginosa (11.1%), β-haemolytic Streptococcus spp. (9.3%) and other bacterial species (11.1%). Gram-positive bacteria accounted for 51.9% of all isolates, Gram-negative bacteria for 37.0%, and other bacterial species for 11.1%.

Passive transfer of immunity

Passive transfer of immunity (PTI) was successfully achieved in 116 of the 192 calves (60.4%; 95% CI: 53.5–67.3), whereas 76 calves (39.6%; 95% CI: 32.7–46.5) experienced failure of passive transfer (FPT) (Table 3).

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Bacterial species	N isolates	% of culture-positive samples (95% CI)
Staphylococcus aureus	14	**25.9 (14.2–37.6)**
Escherichia coli	14	**25.9 (14.2–37.6)**
Streptococcus agalactiae	9	**16.7 (6.7–26.6)**
Pseudomonas aeruginosa	6	**11.1 (2.7–19.6)**
β-haemolytic *Streptococcus* spp.	5	**9.3 (1.5–17.0)**
Others	6	**11.1 (2.7–19.6)**
Total culture-positive samples	**54**	28.7 (22.3–35.2)

Table II. Distribution of bacterial isolates recovered from first-milking colostrum samples (n = 188).

Variable	n	% (95% CI)
Successful passive transfer	116	**60.4 (53.5–67.3)**
Failure of passive transfer	76	**39.6 (32.7–46.5)**
Neonatal diarrhoea	71	**37.0 (30.2–43.8)**
No diarrhoea	121	**63.0 (56.2–69.8)**
Mortality	46	**24.0 (18.0–30.0)**
Survival	146	**76.0 (70.0–82.0)**

Table III. Passive transfer of immunity and neonatal health (n=192).

Neonatal health outcomes

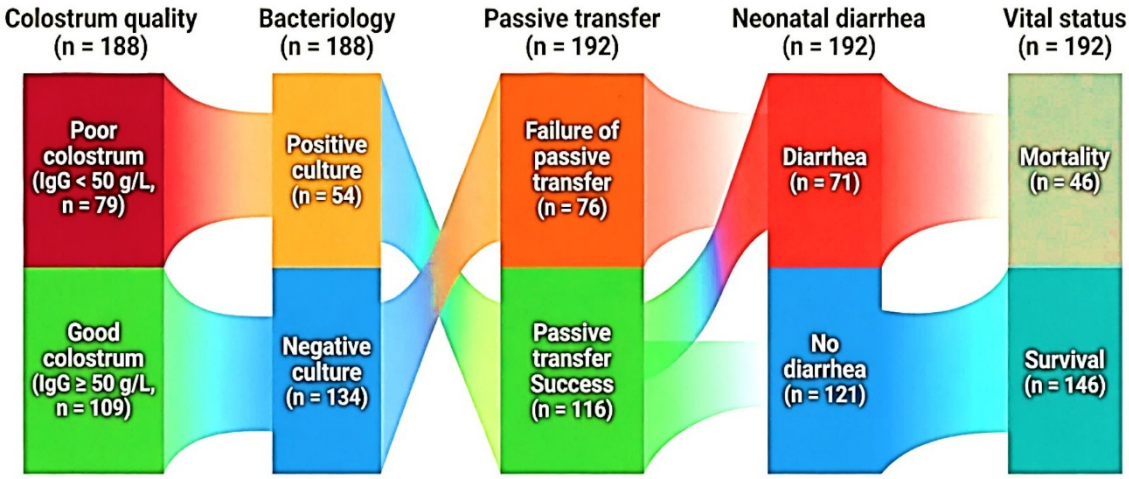


Figure 1. Sankey diagram illustrating the distribution of the study population across five successive outcomes.

During the neonatal follow-up period, 71 calves (37.0%; 95% CI: 30.2–43.8) developed neonatal diarrhoea, whereas 121 (63.0%) remained clinically healthy. Overall, 46 calves (24.0%; 95% CI: 18.0–30.0) died during the neonatal period, while 146 (76.0%) survived until the end of follow-up (Table 3). The overall cascade from colostrum quality to

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neonatal outcomes is illustrated in Figure 1.

Factors associated with poor-quality colostrum

Univariable analyses identified breed, calving type, dry cow antibiotic therapy, CMT score, bacteriological status of colostrum and maternal energy balance as factors significantly associated with immunological colostrum quality (all $P < 0.001$) (Table 4). Good-quality colostrum was more frequently observed in Montbéliarde cows than in Holstein and Fleckvieh cows. Likewise, 91.4% of cows undergoing eutocia produced good-quality colostrum compared with only 15.7% of cows experiencing dystocia. Cows receiving dry cow antibiotic therapy also showed a higher proportion of good-quality colostrum than untreated cows (77.6% vs. 41.7%).

Mammary health markedly influenced colostrum quality. None of the cows with a CMT score of 3 produced colostrum containing adequate IgG concentrations, whereas 86.2% and 87.0% of cows with CMT scores of 1 and 2, respectively, produced good-quality colostrum. Moreover, all bacteriologically positive colostrum samples were classified as poor quality. Maternal energy balance was also strongly associated with colostrum quality, as 98.1% of cows with a negative energy balance produced poor-quality colostrum compared with only 19.4% of cows with a positive or neutral energy balance (Table 4).

Variables with $P < 0.20$ in the univariable analysis were entered into the multivariable logistic regression model. Variables exhibiting complete separation (CMT score and bacteriological culture) were excluded because reliable parameter estimation was not possible. The final model included 188 observations and showed good explanatory performance (McFadden's pseudo-$R^2 = 0.637$; likelihood ratio test, $P < 0.001$).

After adjustment for potential confounders, dystocia remained independently associated with poor-quality colostrum (adjusted OR = 29.89; 95% CI: 5.95–150.33; $P < 0.001$), whereas a positive or neutral maternal energy balance was associated with markedly reduced odds of poor-quality colostrum (adjusted OR = 0.015; 95% CI: 0.002–0.155; $P < 0.001$). Breed and dry cow antibiotic therapy were no longer independently associated with colostrum quality after adjustment (Table 5, Figure 2).

The adjusted odds ratios (aOR) and 95% confidence intervals of the variables retained in the final model are displayed in Figure 2.

Variable	Category	n	Good-quality n (%)	Poor-quality n (%)	P value
Breed	Montbéliarde	104	78 (75)	26 (25)	<0.001
	Holstein	58	17 (29.3)	41 (70.7)	
	Fleckvieh	19	10 (52.6)	9 (47.4)	
	Simmental	7	4 (57.1)	3 (42.8)	
Calving type	Eutocia	105	96 (91.4)	9 (8.6)	<0.001
	Dystocia	83	13 (15.7)	70 (84.3)	
Dry cow antibiotic therapy	Yes	85	66 (77.6)	19 (22.3)	<0.001
	No	103	43 (41.7)	60 (58.3)	
CMT score	Negative	116	64 (55.2)	52 (44.8)	<0.001
	Score 1	29	25 (86.2)	4 (13.8)	
	Score 2	23	20 (87.0)	3 (13.0)	
	Score 3	20	0 (0.0)	20 (100.0)	
Bacteriology	Negative	134	109 (81.3)	25 (18.7)	<0.001
	Positive	54	0 (0.0)	54 (100.0)	
Energy balance	Positive	134	108 (80.6)	26 (19.4)	<0.001
	Negative	54	1 (1.8)	53 (98.1)	
Total		**188**	**109 (58)**	**79 (42)**	

Table IV. Univariable analysis of factors associated with poor-quality colostrum.

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Variable	β	Adjusted OR	95% CI	P value
Breed (Holstein vs Montbéliarde)	0.852	2.34	0.52–10.65	0.270
Breed (Fleckvieh vs Montbéliarde)	1.075	2.93	0.39–22.29	0.299
Dystocia	3.398	29.89	5.95–150.33	<0.001
Dry cow antibiotic therapy	-1.248	0.29	0.06–1.29	0.104
Positive/Neutral energy balance	-4.176	0.015	0.002–0.155	<0.001

Table V. Multivariable logistic regression for poor-quality colostrum.

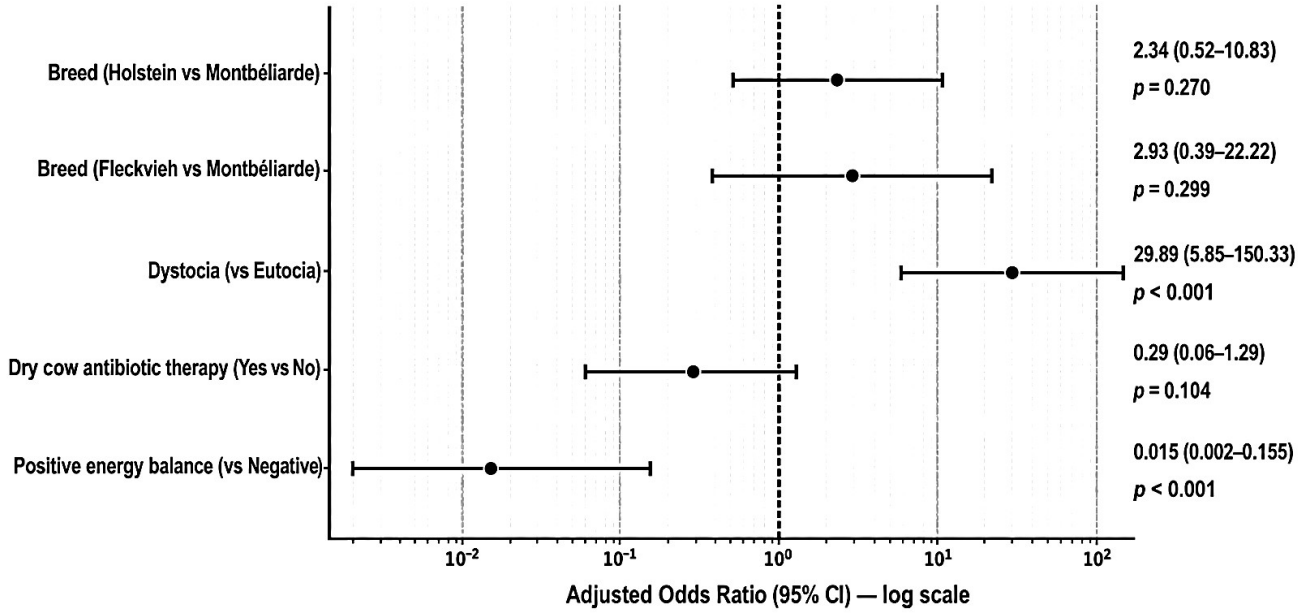


Figure 2. Adjusted odds ratios (aOR) and 95% confidence intervals from the final multivariable logistic regression model for poor-quality colostrum (IgG < 50 g/L).

Factors associated with failure of passive transfer

Univariable logistic regression identified dystocia, absence of dry cow antibiotic therapy, positive CMT, positive bacteriological culture, poor-quality colostrum, negative maternal energy balance, delayed first suckling (>2 h), low colostrum intake (<4 L), and neonatal diarrhoea as variables significantly associated with FPT (all P < 0.05), whereas breed was not significantly associated with FPT (Table 6).

Before model construction, candidate variables were screened using univariable logistic regression. Cow age, calving season, parity, dry period length, calf sex, and the continuous forms of colostrum volume and interval from calving to first suckling did not meet the predefined inclusion criterion ($P < 0.20$) or were removed during backward elimination. In contrast, their categorical forms, defined using clinically relevant thresholds (<4 L for colostrum intake and >2 h for first suckling), were retained in the final model because they showed significant associations with FPT.

After adjustment for potential confounders, poor-quality colostrum remained the strongest independent predictor of FPT (adjusted OR = 11.48; 95% CI: 4.26–30.91; P < 0.001). Delayed first suckling (>2 h) (adjusted OR = 6.24; 95% CI: 2.32–16.79; P < 0.001), low colostrum intake (<4 L) (adjusted OR = 4.35; 95% CI: 1.72–11.02; P = 0.002), positive bacteriological culture of colostrum (adjusted OR = 3.63; 95% CI: 1.39–9.45; P = 0.008), dystocia (adjusted OR =

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3.19; 95% CI: 1.18–8.61; P = 0.022), and negative maternal energy balance (adjusted OR = 2.56; 95% CI: 1.01–6.46; P = 0.047) also remained independently associated with FPT (Table 7, Figure 3).

Model diagnostics indicated satisfactory calibration (Hosmer–Lemeshow goodness-of-fit test, P > 0.05) and good discrimination (AUC = 0.82). Multicollinearity was negligible (all variance inflation factors [VIF] <2), and the final model achieved an Akaike Information Criterion (AIC) of 119.0.

Overall, the multivariable analyses identified dystocia and maternal energy balance as determinants of poor-quality colostrum, whereas poor-quality colostrum, delayed suckling, low colostrum intake, bacteriological contamination, dystocia and maternal energy balance independently predicted FPT (Figure 4).

Variable	Category	Crude OR	95% CI	P value
Breed	Holstein vs Montbéliarde	**1.62**	0.88–2.98	0.118
Breed	Fleckvieh vs Montbéliarde	**1.21**	0.54–2.73	0.641
Calving type	Dystocia vs Eutocia	**4.83**	2.42–9.65	<0.001
Dry cow antibiotic therapy	No vs Yes	**3.11**	1.61–6.01	<0.001
CMT	Positive vs Negative	**3.82**	2.01–7.28	<0.001
Bacterial culture	Positive vs Negative	**5.46**	2.72–10.96	<0.001
Colostrum quality	Poor vs Good	**8.94**	4.45–17.96	<0.001
Energy balance	Negative vs Positive	**6.58**	3.15–13.73	<0.001
Time to first suckling	>2 h vs ≤2 h	**7.25**	3.54–14.84	<0.001
Colostrum intake	<4 L vs ≥4 L	**5.81**	2.86–11.81	<0.001
Neonatal diarrhoea	Yes vs No	**6.14**	3.10–12.17	<0.001

Table VI. Univariable logistic regression analysis of factors associated with failure of passive transfer (FPT) in dairy calves (n = 192).

Variable	β	Adjusted OR	95% CI	P value
Poor-quality colostrum	2.44	**11.48**	4.26–30.91	<0.001
Delayed first suckling (>2 h)	1.83	**6.24**	2.32–16.79	<0.001
Low colostrum intake (<4 L)	1.47	**4.35**	1.72–11.02	0.002
Positive bacterial culture	1.29	**3.63**	1.39–9.45	0.008
Dystocia	1.16	**3.19**	1.18–8.61	0.022
Negative energy balance	0.94	**2.56**	1.01–6.46	0.047

Table VII. Multivariable logistic regression model for failure of passive transfer.

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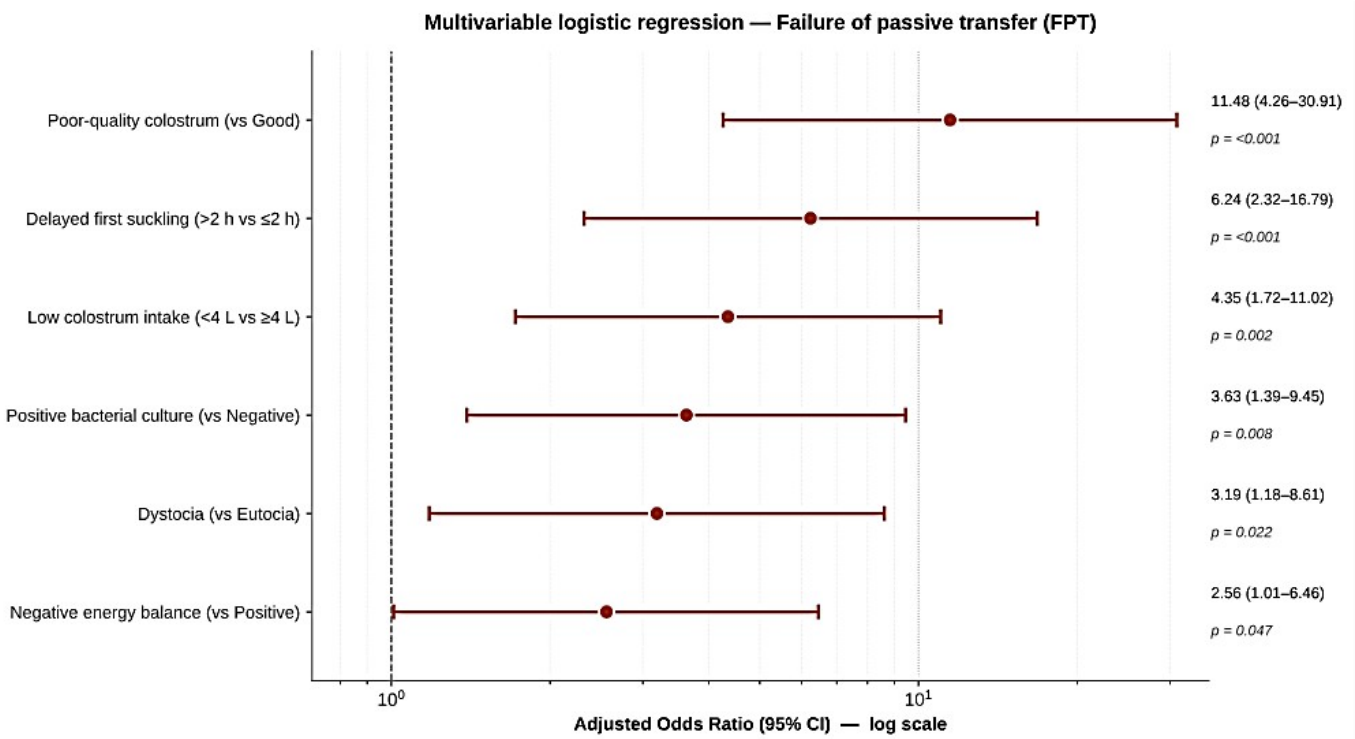


Figure 3. Adjusted odds ratios (aOR) and 95% confidence intervals from the final multivariable logistic regression model for failure of passive transfer (FPT).

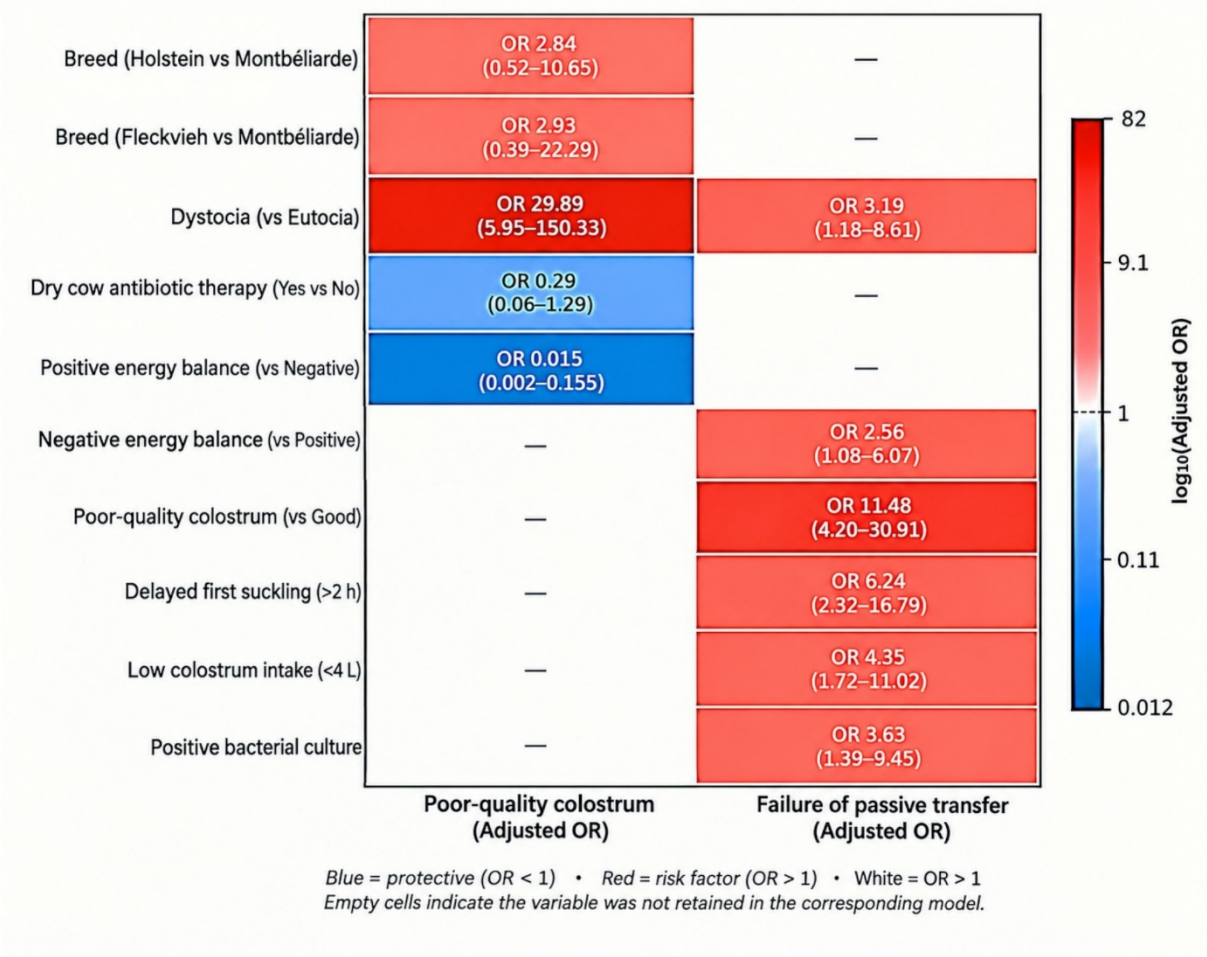


Figure 4. Heatmap of adjusted odds ratios (aOR) from the two final multivariable logistic regression models (poor-quality colostrum and failure of passive transfer). Red indicates risk factors (aOR > 1), blue protective factors (aOR < 1) and white aOR = 1 (log10 scale). Dashes indicate variables not retained in the corresponding model.

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Discussion

Colostrum quality is a cornerstone of neonatal calf health because, owing to the syndesmochorial (synepitheliochorial) placenta of cattle, virtually no maternal immunoglobulins are transferred during gestation. Consequently, newborn calves depend entirely on the timely ingestion of adequate quantities of high-quality colostrum to acquire passive immunity during the first hours of life (Lombard et al., 2020; Westhoff et al., 2024). Beyond immunoglobulin G (IgG), bovine colostrum contains a wide range of bioactive compounds—including leucocytes, cytokines, lactoferrin, growth factors, hormones and oligosaccharides—which promote intestinal maturation, immune system development, microbial colonisation and early metabolic adaptation in neonatal calves (Westhoff et al., 2024; Flynn et al., 2025).

In the present study, 58.0% of colostrum samples contained ≥ 50 g/L IgG, whereas 42.0% were classified as poor quality. Although comparable with values reported in several commercial dairy herds worldwide, this prevalence remains above the level expected under optimal colostrum management (Shivley et al., 2018; Godden et al., 2019; Westhoff et al., 2024).

The multivariable analysis demonstrated that dystocia and maternal energy balance were the only independent predictors of colostrum quality after adjustment for potential confounding factors. Cows experiencing dystocia had markedly greater odds of producing poor-quality colostrum, whereas cows maintaining a positive or neutral energy balance during the transition period were substantially less likely to do so. The association between maternal energy balance and colostrum quality is biologically plausible. During the late transition period, cows experiencing negative energy balance undergo extensive lipid mobilisation, oxidative stress and transient immunosuppression, which may impair mammary secretory activity and reduce the active transfer of IgG_1 from the maternal circulation into mammary secretions (Westhoff et al., 2024). Similarly, dystocia is associated with prolonged labour, increased inflammatory responses, endocrine alterations and greater metabolic stress, all of which may compromise mammary function and delay or impair colostrum secretion (Godden et al., 2019; Lopez and Heinrichs, 2022).

The complete separation observed for both the California Mastitis Test (CMT) score and bacteriological status in the multivariable analysis was noteworthy. Cows presenting with severe mammary inflammation or bacteriologically contaminated colostrum consistently produced poor-quality colostrum. Although these variables were excluded from the final logistic model, this observation strongly supports the close relationship between mammary health and colostrum immunological quality. Subclinical mastitis may reduce IgG concentration by disrupting mammary epithelial integrity, altering secretory function and increasing local inflammatory activity before calving (Westhoff et al., 2024).

From a herd-management perspective, routine assessment of colostrum quality before feeding, combined with improved transition-cow nutrition, effective mastitis control and appropriate calving management, could substantially reduce the proportion of calves exposed to poor-quality colostrum. Recent international recommendations advocate systematic on-farm assessment of colostrum quality using a digital Brix refractometer because of its simplicity, rapidity and good agreement with laboratory-based IgG determination (Lopez and Heinrichs, 2022; Westhoff et al., 2024).

Colostrum hygiene is now recognised as an essential component of successful colostrum management because microbiological quality directly influences both neonatal health and the efficiency of passive transfer. Besides serving as a potential source of pathogenic microorganisms, bacterially contaminated colostrum may impair intestinal immunoglobulin absorption through competition with IgG for epithelial transport mechanisms, binding of immunoglobulins within the intestinal lumen, and acceleration of gut closure (Fischer et al., 2018; Godden et al., 2019; Lopez and Heinrichs, 2022).

In the present study, bacterial growth was detected in 28.7% of colostrum samples. Several sources may account for bacterial contamination. Microorganisms may originate from intramammary infections, contaminated teat skin, bedding material, milking equipment, collection containers or inadequate storage after harvesting (Westhoff et al., 2024; Flynn et al., 2025).

Among culture-positive samples, *Staphylococcus aureus* and *Escherichia coli* were the predominant isolates, each representing 25.9% of all bacterial isolates, followed by *Streptococcus agalactiae* (16.7%), *Pseudomonas aeruginosa* (11.1%), β-haemolytic *Streptococcus* spp. (9.3%) and other bacterial species (11.1%). The predominance of *S. aureus* suggests that subclinical intramammary infections contributed substantially to colostrum contamination, whereas the frequent isolation of *E. coli* is more indicative of environmental or faecal contamination occurring during or shortly after colostrum collection (Constable et al., 2017; Ruegg, 2017). Detection of *S. agalactiae* further supports the contribution of contagious mastitis to poor colostrum hygiene, while the recovery of *P. aeruginosa* points toward deficiencies in water quality or equipment sanitation (Quigley et al., 2013; Constable et al., 2017).

The predominance of Gram-positive bacteria over Gram-negative organisms agrees with previous reports indicating

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that freshly harvested colostrum is frequently contaminated by mastitis-associated pathogens, whereas prolonged storage under inadequate hygienic conditions generally favours proliferation of environmental Gram-negative bacteria (Morrill et al., 2012; Cummins et al., 2016).

Importantly, our statistical analyses demonstrated that bacteriological contamination was independently associated with failure of passive transfer. This finding strengthens previous experimental evidence showing that bacterial contamination reduces the apparent efficiency of IgG absorption independently of colostrum IgG concentration (Fischer et al., 2018; Lopez and Heinrichs, 2022). Producing high-IgG colostrum alone is insufficient if hygienic quality is not simultaneously maintained.

From a herd-health perspective, appropriate dry-cow therapy, maintenance of good udder health, careful teat preparation before first milking, strict sanitation of collection and feeding equipment, rapid cooling of harvested colostrum and, where appropriate, heat treatment at 60 °C for 60 minutes represent evidence-based interventions capable of reducing bacterial contamination while preserving immunoglobulin integrity (Malik et al., 2022; Westhoff et al., 2024).

Neonatal diarrhoea remains the leading cause of morbidity and mortality in pre-weaned dairy calves worldwide and continues to impose substantial economic losses through increased treatment costs, reduced growth performance and higher replacement rates (Abebe et al., 2023; Alemu et al., 2025). Although neonatal diarrhoea is a multifactorial syndrome involving infectious agents, nutritional factors and environmental conditions, adequate passive immunity acquired through colostrum intake remains the primary determinant of resistance during the first weeks of life (Berge et al., 2024; Davies et al., 2025).

In the present study, 37.0% of calves developed neonatal diarrhoea and 24.0% died during the neonatal period. Although direct comparisons between studies should be made cautiously because of differences in follow-up duration, disease definitions and herd-management practices, both diarrhoea and mortality rates exceeded the performance targets generally reported for well-managed dairy herds (Mee, 2023; Umaña Sedó et al., 2023; Trzebiatowski et al., 2025). It is also important to note that these figures likely represent conservative estimates of the true burden of neonatal disease in unselected Algerian commercial herds. This underestimation is driven by two methodological features of our study design: first, the systematic exclusion of dams with severe peripartum pathologies, and second, the requirement for calves to survive until the 2–6 days sampling window for blood collection. Consequently, calves experiencing hyperacute mortality (e.g., within the first 24–48 hours of life due to severe septic shock or profound FPT, often associated with compromised dams) were inherently excluded from the epidemiological analysis, meaning the most dramatic cases of passive transfer failure and early neonatal death were not captured.

The relatively high frequency of neonatal diarrhoea observed in this study is likely the consequence of several interacting factors. Indeed, almost 40% of calves experienced FPT, 42% of cows produced poor-quality colostrum and 28.7% of colostrum samples were bacteriologically contaminated. Together, these deficiencies create favourable conditions for the establishment of enteric infections during the first weeks of life (Lichtmannsperger et al., 2023; Flynn et al., 2025; Male Here et al., 2026).

The close association between passive immunity and neonatal health is biologically well established. Besides providing immunoglobulins, bovine colostrum supplies leucocytes, lactoferrin, cytokines, antimicrobial peptides and growth factors that contribute to intestinal barrier maturation and modulation of the neonatal immune response (Lopez and Heinrichs, 2022; Westhoff et al., 2024; Flynn et al., 2025). Consequently, calves with successful passive immunity are better equipped to neutralise enteric pathogens.

Calves experiencing FPT remain highly susceptible to infections caused by enterotoxigenic Escherichia coli, Cryptosporidium parvum, bovine rotavirus, bovine coronavirus and *Salmonella* spp., all of which are recognised as major causes of neonatal diarrhoea worldwide (Jessop et al., 2024; Sedky et al., 2025; Torreggiani et al., 2025). Inadequate passive immunity also increases the risk of systemic dissemination of enteric pathogens, thereby contributing to septicaemia and increased mortality.

From a practical perspective, substantial improvements in calf health could likely be achieved through early administration of adequate volumes of hygienic, high-quality colostrum, systematic monitoring of passive transfer, improved calving hygiene and prompt identification of clinically affected calves (Carulla et al., 2023; Stancheva and Penev, 2025).

Successful transfer of passive immunity (TPI) is universally regarded as one of the most important determinants of calf survival, health and future productivity. Because calves are born virtually agammaglobulinaemic, adequate passive immunity depends entirely on the timely ingestion of sufficient quantities of high-quality colostrum before physiological

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gut closure occurs (Lombard et al., 2020; Lopez and Heinrichs, 2022). Failure of passive transfer (FPT) has consistently been associated with increased risks of neonatal diarrhoea, respiratory disease, antimicrobial treatments, mortality and impaired growth, making it a major indicator of calf-management efficiency (Cummins et al., 2016; Abuelo et al., 2021).

In the present study, 60.4% of calves achieved successful passive transfer, whereas 39.6% experienced FPT. According to the most recent international recommendations, this prevalence remains substantially higher than the desired target of fewer than 10–20% of calves should experiencing inadequate passive immunity (Cummins et al., 2016; Lombard et al., 2020).

Multivariable logistic regression identified poor-quality colostrum as the strongest independent predictor of FPT, increasing the odds of inadequate passive immunity more than any other investigated factor. Delayed first suckling (>2 h after birth) also remained independently associated with FPT. This finding agrees with the well-established physiology of intestinal IgG absorption, whereby specialised enterocytes rapidly lose their ability to internalise intact immunoglobulins after birth (Lopez-Bondarchuk et al., 2025; Stancheva and Penev, 2025; Yang et al., 2025). Similarly, calves receiving less than 4 L of colostrum at first feeding were significantly more likely to experience FPT (Flynn et al., 2025; Stancheva and Penev, 2025; Wicki et al., 2025).

An important finding was the independent association between bacteriological contamination of colostrum and FPT. Experimental studies have shown that excessive bacterial contamination reduces IgG absorption efficiency by binding immunoglobulins within the intestinal lumen and interfering with epithelial uptake mechanisms (Fischer et al., 2018; Lopez and Heinrichs, 2022). Maternal factors also influenced passive immunity. Dystocia and negative maternal energy balance remained independently associated with FPT after multivariable adjustment, probably reflecting indirect effects mediated through impaired colostrum quality, delayed maternal–calf interaction and reduced calf vigour immediately after birth (Hoffmann et al., 2024; Abdelfattah et al., 2025; Davies et al., 2025).

Unlike univariable analyses, multivariable modelling allows the independent contribution of each variable to be evaluated while accounting for potential confounding, thereby providing a more reliable understanding of the biological mechanisms underlying neonatal calf health (Olmos Antillón et al., 2024; Tug et al., 2025). For colostrum quality, the final model identified dystocia and maternal energy balance as the only independent predictors after adjustment for confounding variables. Although breed and dry-cow antibiotic therapy were associated with colostrum quality in the univariable analysis, these associations disappeared in the multivariable model, indicating that their apparent effects were largely mediated through stronger biological determinants. The association between dystocia and poor-quality colostrum is biologically plausible. Difficult calving is frequently accompanied by prolonged labour, endocrine disturbances, inflammation and increased metabolic stress, all of which may impair mammary secretory activity during the final stages of colostrogenesis (Godden et al., 2019; Lopez and Heinrichs, 2022). Maternal energy balance also emerged as an important determinant of colostrum quality. Transition cows experiencing negative energy balance undergo intense adipose tissue mobilisation, oxidative stress and transient immunosuppression, factors known to compromise mammary function and immune competence (Westhoff et al., 2024).

Interestingly, both dystocia and maternal energy balance remained independently associated with FPT even after adjustment for colostrum quality, suggesting that these maternal factors influence passive immunity through additional pathways beyond their effects on IgG concentration alone. Overall, the multivariable analyses support a coherent biological pathway linking maternal management to neonatal health. Maternal metabolic disturbances and dystocia impair colostrum quality; poor-quality or bacteriologically contaminated colostrum, together with delayed administration and inadequate intake, increases the risk of FPT; and inadequate passive immunity subsequently predisposes calves to neonatal diarrhoea and mortality. This integrated interpretation highlights that improvements in calf health require coordinated interventions throughout the transition period rather than isolated corrective measures after birth.

Strengths and limitations

To our knowledge, this is the first prospective study in Algeria to simultaneously evaluate colostrum quality, bacteriological contamination, passive transfer, and neonatal health outcomes. This integrated approach, supported by robust multivariable modelling (AUC = 0.82), provides a comprehensive understanding of the determinants of calf health.

However, several limitations must be acknowledged. First, the study was conducted in a single region, which may limit generalisability. Second, maternal energy balance was inferred solely from body condition score (BCS) changes between drying-off and 24 hours post-calving. While practical for field conditions, BCS is a subjective measure that

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fails to capture the true postpartum nadir of negative energy balance. The absence of blood biochemical markers (e.g., NEFA and BHBA) likely resulted in an underestimation of subclinical metabolic disorders and their actual impact on colostrum quality. Third, bacteriological analyses were qualitative; future studies should incorporate quantitative load assessments (CFU/mL). Finally, the systematic exclusion of cows with severe peripartum pathologies, combined with the requirement for calves to survive until the 2–6 day sampling window, introduces a degree of selection and survival bias. While necessary to ensure internal validity, these criteria inevitably "soften" the data, meaning our reported rates of failure of passive transfer (39.6%) and neonatal mortality (24.0%) are likely conservative estimates of the true disease burden in unselected Algerian commercial herds.

Conclusion

This prospective study provides one of the first integrated evaluations of colostrum quality, bacteriological contamination, passive transfer of immunity and neonatal calf health in Algerian dairy herds. Although 58.0% of cows produced good-quality colostrum, 42.0% produced colostrum containing less than the recommended IgG concentration, while 28.7% of samples were bacteriologically contaminated. Consequently, 39.6% of calves experienced failure of passive transfer, which was associated with increased risks of neonatal diarrhoea and mortality.

Multivariable analyses demonstrated that dystocia and maternal energy balance were the principal determinants of colostrum quality, whereas poor-quality colostrum, bacteriological contamination, delayed first suckling and insufficient colostrum intake were the main independent predictors of failure of passive transfer. These findings emphasise that successful passive immunity depends on the combined effects of maternal health, colostrum quality, hygienic practices and early calf management rather than on a single intervention.

From a practical perspective, routine assessment of colostrum quality using a Brix refractometer, improvement of transition-cow nutrition, effective mastitis control, hygienic colostrum collection and storage, and administration of an adequate volume of colostrum within the first two hours after birth should become standard management practices on Algerian dairy farms. Implementation of these evidence-based measures is expected to improve passive immunity, reduce neonatal morbidity and mortality, decrease antimicrobial use and enhance the sustainability and profitability of dairy production.

Finally, the predictive performance of the multivariable model (AUC = 0.82) highlights its potential value as a practical decision-support tool for identifying calves at increased risk of failure of passive transfer under field conditions. Future multicentre studies including larger and more diverse dairy populations are warranted to externally validate these findings and to support the development of national guidelines for colostrum management and calf health in Algeria.

Acknowledgments

The authors gratefully acknowledge the dairy farmers of the municipalities of Freha, Larbaa Nath Irathen and Tizi-Rached (wilaya of Tizi-Ouzou, Algeria) who kindly agreed to participate in this study and granted access to their herds, as well as the field veterinarians and technical staff who assisted with data collection, colostrum and blood sampling, and calf follow-up. Their cooperation, trust and daily commitment were essential to the successful completion of this work.

Ethical approval

All procedures complied with internationally recognised guidelines for animal welfare and veterinary research. The study protocol was reviewed and approved by the institutional ethics committee of the University of Blida 1, Algeria (approval No. ISV-2025-014). Written informed consent was obtained from each participating farmer before enrolment.

Conflict of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper

Author Contributions

Conceptualisation: AK, NAKT, NO; Methodology: AK, NAKT, NO; Formal analysis: AK, NAKT, NO, GH, DP; Investigation: AK, NAKT, NO; Writing—original draft preparation: AK, NAKT, NO; Writing—review and editing: AK, NAKT, NO; Supervision: AK; Project administration: AK; All authors have read and agreed to the published version of the manuscript.

Data availability

Data are available upon request from the corresponding author.

Funding

No funding was received for this study.

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