



# Metabolic disorders in dairy cows during the transition period: Effects on health and productivity

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**Abstract.** Metabolic disorders represent a major challenge for the health, productivity, and longevity of dairy cows, causing significant economic losses worldwide. The transition period is characterized by profound physiological and metabolic changes, during which the imbalance between energy requirements and feed intake frequently leads to negative energy balance and excessive mobilization of body reserves. As a consequence, dairy cows are highly predisposed to metabolic diseases such as fatty liver syndrome, ketosis, and hypocalcemia, which are closely interconnected and often act as predisposing factors for other production and infectious diseases. This paper provides a comprehensive review of the main metabolic disorders affecting dairy cows during the transition period, focusing on their pathogenesis, clinical manifestations, and diagnostic approaches. Particular emphasis is placed on the role of nutrition and transition management in the development and control of these conditions. Modern prevention and control strategies are discussed, including nutritional optimization, monitoring of metabolic indicators, and proactive herd management practices. The implementation of these strategies is essential to reduce the incidence of metabolic disorders, improve animal welfare, and enhance the productive performance and sustainability of dairy herds.

**Key Words:** dairy cows, fatty liver, hypocalcemia, ketosis, metabolic disorders, negative energy balance, transition period.

**Introduction.** The transition period represents one of the most critical phases in the productive cycle of dairy cows and is frequently associated with the occurrence of major metabolic disorders, including hypomagnesemia, postpartum hypocalcemia (milk fever), ketosis, and fatty cow syndrome (Kang et al 2025). Even under well-managed farm conditions, these disorders can lead to substantial economic losses through reduced milk yield and compromised milk quality (Sundrum 2015).

The intense physiological adaptations characteristic of this stage—such as decreased dry matter intake, rapid fetal growth, and the onset of lactation—often result in a mismatch between energy requirements and actual nutrient intake (Sun et al 2016). Consequently, negative energy balance commonly develops, accompanied by excessive mobilization of body reserves and profound metabolic alterations (Sundrum 2015).

This metabolic state is characterized by increased concentrations of non-esterified fatty acids and  $\beta$ -hydroxybutyrate, alongside decreased serum calcium and phosphorus levels, enhanced inflammatory responses, and impaired immune function (Wankhade et al 2017). These changes significantly increase the risk of ketosis, hepatic lipidosis, and hypocalcemia, while also predisposing cows to infectious diseases such as metritis and mastitis (Sundrum 2015).

The severity of these metabolic disturbances is further exacerbated by oxidative stress and endocrine imbalances typical of early lactation (Ayemele et al 2021). It is estimated that approximately 30–60% of dairy cows experience at least one metabolic disorder during the transition period, with many of these conditions being interconnected and contributing to a cumulative increase in disease susceptibility (Loiklung et al 2022).

Metabolic disorders represent a major challenge in modern dairy production systems, exerting profound effects on animal health, reproductive efficiency, longevity, and overall productive performance (Ingvarsen & Moyes 2013). These disorders compromise not only individual cow welfare but also farm profitability and the long-term sustainability of the dairy industry (Raboisson et al 2014). Among them, negative energy balance (NEB) is a central metabolic condition that typically arises during the early postpartum period, when energy demands for lactation exceed dietary energy intake (Drackley 1999). Consequently, cows are forced to mobilize substantial amounts of body fat and, to a lesser extent, body protein to meet their energetic requirements (Drackley 1999).

The excessive mobilization of adipose tissue leads to increased circulating concentrations of non-esterified fatty acids (NEFA), which are taken up by the liver (Adewuyi et al 2005). When hepatic oxidative capacity is exceeded, NEFA are incompletely oxidized, resulting in the accumulation of ketone bodies, particularly  $\beta$ -hydroxybutyrate (BHBA), and triglycerides within hepatocytes (Grummer 1993). This metabolic overload contributes to the development of subclinical ketosis, fatty liver syndrome, and impaired liver function (Zhao et al 2020). Subclinical ketosis is the most prevalent metabolic disorder in high-producing dairy cows and is associated with significant reductions in dry matter intake—often reaching up to 20%—as well as measurable declines in milk yield, commonly estimated at approximately 2 L per cow per day (Zhao et al 2020).

Beyond its direct effects on production, subclinical ketosis exerts systemic consequences by disrupting endocrine regulation and immune competence (Esposito et al 2014). Elevated ketone body concentrations and insulin resistance impair glucose availability for peripheral tissues and the mammary gland, while simultaneously compromising leukocyte function (Bisinotto et al 2012). This immunosuppressive state increases susceptibility to infectious and inflammatory diseases, including mastitis, metritis, retained placenta, and displaced abomasum (Bisinotto et al 2012). Furthermore, metabolic stress negatively affects ovarian activity, leading to delayed ovulation, reduced conception rates, extended calving intervals, and overall declines in reproductive performance (Bisinotto et al 2012).

From an economic perspective, the cumulative impact of metabolic disorders is substantial (McArt et al 2015). Losses arise from reduced milk production efficiency, increased veterinary and treatment costs, higher labor requirements, premature culling, and diminished lifetime productivity (McArt et al 2015). These hidden costs often exceed those associated with clinically apparent diseases, making subclinical metabolic disorders particularly detrimental at the herd level (McArt et al 2015).

Despite significant advances in nutritional formulation, transition cow management, and precision feeding technologies, the continued genetic intensification of milk production has amplified metabolic demands beyond the adaptive capacity of many cows (Overton & McArt 2017). This imbalance underscores the necessity for integrated management approaches that prioritize early detection, continuous metabolic monitoring, and proactive intervention strategies (Overton & McArt 2017). The use of metabolic biomarkers such as NEFA and BHBA, combined with body condition scoring, feed intake monitoring, and herd-level data analysis, enables timely identification of at-risk animals (Overton & McArt 2017).

Appropriately designed nutritional strategies—focusing on energy density, rumen health, controlled body condition at calving, and optimized transition diets—are essential to mitigate the severity of NEB and its downstream consequences (Kerwin et al 2023). Ultimately, improving metabolic resilience during the transition period is a key determinant of sustainable dairy production, ensuring optimal health, productivity, and welfare of high-yielding dairy herds (Kerwin et al 2023).

In addition to classical metabolic and endocrine alterations, increasing evidence indicates that biological matrices such as milk, blood, and other animal-derived products reflect not only physiological adaptations but also broader systemic and environmental influences. Recent ICP-MS-based investigations of milk and dairy products have demonstrated that elemental and compositional profiles vary across production systems,

highlighting milk as an integrative indicator of metabolic status and environmental exposure in food-producing animals. Similar bioaccumulation-oriented approaches applied in animal models have shown that systemic metabolic stress and inflammatory activation are accompanied by measurable changes in biological matrices, supporting their use as sentinels of physiological imbalance (Fechete et al 2024; Popescu et al 2025). Comparative studies in large animal species further suggest that nutritional inputs and metabolic adaptations are closely linked to endocrine and morphometric responses, reinforcing the concept that metabolic stress produces coordinated systemic effects across tissues and outputs (Daradics et al 2025). At the cellular level, experimental evidence indicates that metabolic and inflammatory stressors modulate biological responses in a dose- and context-dependent manner, emphasizing the tight interconnection between metabolism, inflammation, and functional adaptation (Bungărdean et al 2025). Together, these findings support an integrative framework for evaluating metabolic disorders during the transition period, in which metabolic biomarkers, inflammatory responses, and milk-related parameters are jointly considered to improve the early identification and management of cows at risk.

The aim of this research is to provide an integrated analysis of the main metabolic disorders affecting dairy cattle during the transition period, with particular emphasis on fatty liver syndrome, ketosis, and milk fever. The study focuses on elucidating the underlying pathophysiological mechanisms, nutritional and management-related risk factors, as well as the impact of these disorders on animal health, productivity, and reproductive performance. Furthermore, this research aims to evaluate current strategies for prevention, early diagnosis, and nutritional and veterinary interventions in order to reduce the incidence and severity of metabolic disorders and to improve the overall health and efficiency of dairy herds.

## **Material and Method**

***Farm setting and herd management.*** The investigation was carried out during the summer of 2024, between June and August, on a commercial dairy farm located in Braşov County, Romania. The farm specialized in Holstein cattle and operated under an intensive dairy production system representative of modern commercial conditions. Cows were kept in free-stall housing facilities that allowed unrestricted movement and access to feed and water.

Herd management practices, including feeding, housing, and health care, followed standardized protocols routinely applied across the farm. All animals received the same total mixed ration formulated to meet the nutritional requirements of early lactation. Veterinary supervision was conducted on a regular basis as part of the farm's herd health program, ensuring continuous monitoring of animal well-being. All management procedures and handling of animals were carried out in accordance with current national legislation on animal welfare and protection.

Following routine clinical assessments performed as part of the farm's herd health program, a subset of multiparous dairy cows was identified for inclusion in the study. Eligibility was limited to animals in their second or subsequent lactations and within the early postpartum period, defined as approximately  $17 \pm 3$  days after calving. This selection strategy was adopted to reduce variability related to parity and physiological stage.

Only cows presenting a normal general clinical status at the time of enrollment were considered. Animals that had undergone an uncomplicated calving and showed no clinical signs suggestive of metabolic, infectious, or reproductive disorders were included. Cows with a history of postpartum complications or those that received pharmacological treatments during the periparturient period were excluded from the study in order to avoid potential confounding effects on metabolic measurements.

Table 1 presents an overview of the basic characteristics of the multiparous Holstein cows evaluated in this study. The study group was selected from a commercial dairy herd using predefined inclusion criteria aimed at limiting differences related to parity and physiological status. Enrollment was restricted to clinically normal cows

examined during the early postpartum period, resulting in a relatively homogeneous group and reducing the potential influence of confounding factors associated with post-calving metabolic adjustments.

Table 1

Baseline characteristics of the study group

<i>Parameter</i>	<i>Value</i>
Number of cows	20
Breed	Holstein
Lactation (mean $\pm$ SD)	2.8 $\pm$ 0.9
Days postpartum (range)	5–21 days
Body condition score (mean $\pm$ SD)	3.25 $\pm$ 0.4

**Study framework and management conditions.** The inclusion of only clinically normal cows with an uncomplicated calving history allowed the evaluation of metabolic indicators under non-pathological conditions. By excluding animals affected by clinical disorders or subjected to medical treatments, the observed variations in metabolic parameters were more likely related to physiological adaptation after calving. Uniform housing conditions and consistent feeding practices were maintained throughout the study, reducing external sources of variation and supporting the reliability of the collected data. This approach provided an appropriate context for the descriptive assessment of metabolic status during the early postpartum period, when dairy cows experience increased metabolic demands.

The early postpartum phase is associated with substantial metabolic pressure as milk production begins and the cow's physiology adjusts to the demands of lactation. During this time, energy and nutrient requirements increase markedly, whereas voluntary feed intake rises more progressively. As a result, short-term metabolic fluctuations commonly occur and are regarded as part of the normal physiological response following calving. Such changes can be captured through the assessment of metabolic indicators obtained shortly after parturition.

For the purposes of this study, observations were confined to the early postpartum period and did not involve prolonged or repeated follow-up over time. Data related to parity and calving events were retrieved from routinely maintained farm records used in daily herd management. All cows were maintained under the same commercial management conditions throughout the study. Housing, health care, and general handling practices were applied uniformly across the study group. Animals were fed a total mixed ration designed for early lactation, and no intentional modifications to feeding strategy or management routines were introduced during the observation period, thereby minimizing the influence of external and environmental variation on the recorded measurements.

**Data collection and descriptive evaluation.** Data acquisition was restricted to essential clinical observations and basic laboratory measurements performed during the early postpartum stage. Body condition was evaluated by visual scoring based on a standardized five-point scale. Blood sampling was carried out under routine farm procedures, and serum samples were subsequently analyzed for beta-hydroxybutyrate (BHBA) and total calcium using conventional biochemical assays.

The recorded variables were compiled and reported using descriptive statistical measures. Results are expressed as mean values with corresponding standard deviations or as absolute and relative frequencies, depending on the nature of the data. No continuous monitoring technologies, automated analytical systems, or extended data processing approaches were employed in this study.

**Statistical approach and data presentation.** The data obtained in the present study were analyzed using descriptive statistical methods. Results are presented as mean values accompanied by standard deviation or as absolute and relative frequencies, where

appropriate. No inferential statistical tests or multivariate analyses were applied, given the descriptive and exploratory nature of the study.

This analytical approach was chosen to provide an objective overview of the observed metabolic parameters without attempting to draw conclusions regarding statistical significance or causal relationships.

## Results and Discussion

**Serum metabolic parameters in early postpartum cows.** The metabolic parameters evaluated in the present study provide insight into the physiological adaptation of dairy cows during the early postpartum period. The mean values of beta-hydroxybutyrate (BHBA) and serum calcium, summarized in Table 2, reflect the metabolic adjustments that typically accompany the onset of lactation and the increased energetic and mineral demands during this stage.

The observed mean BHBA concentration of  $1.3 \pm 0.4$  mmol L<sup>-1</sup> indicates a moderate inter-individual variability in energy balance among the cows included in the study. The recorded range (0.7–2.4 mmol L<sup>-1</sup>) suggests that while most animals exhibited BHBA levels consistent with physiological adaptation to early lactation, a subset of cows reached higher concentrations commonly associated with increased mobilization of body fat reserves. Such variability is well documented in the literature and is characteristic of the transition period, during which milk production increases more rapidly than feed intake, leading to transient alterations in energy metabolism.

BHBA is widely regarded as a practical indicator of energy balance in dairy cows, and the values reported in this study highlight its usefulness for identifying metabolic trends at the herd level. Importantly, the moderate BHBA concentrations observed do not necessarily indicate pathological conditions but rather reflect differences in individual metabolic responses to the energetic challenges of early lactation. Within the descriptive framework of the present study, these findings emphasize the relevance of BHBA monitoring as part of routine metabolic assessment in high-producing dairy herds.

**Distribution of cows according to metabolic thresholds.** Regarding mineral metabolism, the mean serum calcium concentration was  $8.4 \pm 0.6$  mg dL<sup>-1</sup>, with individual values ranging from 7.2 to 9.6 mg dL<sup>-1</sup> (Table 2). These results suggest that overall calcium homeostasis was maintained in the study group, although noticeable individual variation was present. Such fluctuations are expected during the early postpartum period, when the sudden demand for calcium associated with colostrum and milk synthesis challenges the cow's regulatory mechanisms.

Table 2

Serum metabolic parameters measured in the study group

<i>Parameter</i>	<i>Mean ± SD</i>	<i>Minimum</i>	<i>Maximum</i>	<i>Clinical relevance*</i>
BHBA (mmol L <sup>-1</sup> )	1.3±0.4	0.7	2.4	Indicator of energy balance
Serum calcium (mg dL <sup>-1</sup> )	8.4±0.6	7.2	9.6	Indicator of mineral homeostasis

Calcium plays a critical role in neuromuscular function and mammary gland activity, and even subtle changes in circulating calcium concentrations may influence metabolic and productive performance. The absence of extreme deviations in serum calcium values in this study suggests effective physiological adaptation at the group level, while the observed variability underscores the sensitivity of this parameter during the immediate post-calving phase.

The combined evaluation of BHBA and serum calcium underscores the multifactorial nature of metabolic adaptation during early lactation. Even in clinically healthy cows, variations in these parameters may reflect differences in metabolic resilience and the efficiency of physiological adjustment to increased nutrient demands.

From a herd health perspective, the descriptive assessment of such metabolic indicators can provide valuable information for identifying animals that may benefit from closer monitoring during the postpartum period.

**Descriptive relationship between body condition score and BHBA.** The distribution of cows according to metabolic threshold values is presented in Table 3 and highlights the presence of subclinical metabolic alterations within the study group. Despite the inclusion of only clinically healthy animals, a proportion of cows exceeded commonly accepted reference thresholds for key metabolic indicators during the early postpartum period.

Table 3

Distribution of cows according to metabolic thresholds

<i>Parameter</i>	<i>Threshold applied</i>	<i>Number of cows</i>	<i>Percentage (%)</i>	<i>Parameter</i>
Elevated BHBA	>1.2 mmol L <sup>-1</sup>	5	25	Elevated BHBA
Low serum calcium	<8.0 mg dL <sup>-1</sup>	4	20	Low serum calcium

In the present study, 25% of the cows exhibited serum beta-hydroxybutyrate (BHBA) concentrations above 1.2 mmol L<sup>-1</sup>, a cut-off frequently used in field conditions to identify cows with increased ketone body production. Although these animals did not display overt clinical signs, elevated BHBA values may reflect a greater degree of lipid mobilization associated with the increased energetic demands of early lactation. Such findings are consistent with the concept that subclinical metabolic changes can occur even in the absence of obvious clinical disease.

Similarly, 20% of the cows showed serum calcium concentrations below 8.0 mg dL<sup>-1</sup> (Table 3), indicating a degree of reduced calcium availability during the postpartum period. This observation is particularly relevant given the well-documented challenge to calcium homeostasis that accompanies the onset of lactation. While none of the cows exhibited clinical manifestations of hypocalcemia, the presence of lower serum calcium values suggests individual variation in the efficiency of physiological adaptation following calving.

The simultaneous occurrence of elevated BHBA and reduced serum calcium in subsets of the study population underscores the multifactorial nature of metabolic adaptation during early lactation. Even under standardized management and feeding conditions, individual cows may differ in their metabolic resilience and capacity to respond to increased energy and mineral demands. From a herd health perspective, the descriptive identification of such metabolic patterns can be valuable for early recognition of animals that may be at higher risk of developing metabolic disorders later in lactation.

It is important to emphasize that the findings presented in Table 3 are based on a limited number of animals and are interpreted descriptively. The study design does not allow for causal inference or statistical comparison between groups. Nevertheless, these results provide practical insight into the frequency of subclinical metabolic deviations in early postpartum cows and support the use of simple metabolic thresholds as a tool for herd-level monitoring.

**Implications for herd-level metabolic monitoring.** The descriptive relationship between body condition score (BCS) and serum beta-hydroxybutyrate (BHBA) concentrations is presented in Table 4. The results indicate a tendency toward higher mean BHBA values in cows with a higher body condition score compared with cows with lower BCS during the early postpartum period.

Cows with a BCS of ≤3.0 showed a mean BHBA concentration of 1.1±0.3 mmol L<sup>-1</sup>, whereas cows with a BCS of ≥3.5 exhibited a higher mean BHBA value of 1.5±0.4 mmol L<sup>-1</sup> (Table 4). Although no statistical testing was performed, this descriptive pattern suggests that cows with greater body condition at the onset of lactation may experience a higher degree of lipid mobilization shortly after calving.

Table 4

Descriptive distribution of BHBA values according to body condition score (BCS)

<i>BCS group</i>	<i>Number of cows</i>	<i>Mean BHBA (mmol L<sup>-1</sup>)</i>	<i>BCS group</i>
≤3.0	9	1.1±0.3	≤3.0
≥3.5	11	1.5±0.4	≥3.5

This observation is consistent with the physiological concept that over conditioned cows are more susceptible to negative energy balance in early lactation. Increased adipose tissue reserves can predispose such animals to greater mobilization of body fat when energy requirements for milk production rise rapidly and feed intake does not immediately meet these demands. Therefore, higher circulating concentrations of ketone bodies, such as BHBA, may be observed even in the absence of clinical signs.

It is important to emphasize that the findings presented in Table 4 reflect a descriptive tendency rather than a confirmed association. The limited sample size and the exploratory nature of the study do not allow for inferential conclusions regarding the relationship between BCS and BHBA. Nevertheless, the observed trend highlights the potential relevance of body condition assessment as a practical on-farm tool for identifying cows that may be at increased metabolic risk during the postpartum period.

From a herd management perspective, the combined evaluation of BCS and basic metabolic indicators such as BHBA may contribute to a better understanding of individual variability in metabolic adaptation following calving. The results of the present study support the value of descriptive monitoring approaches in early lactation, particularly in pilot studies aimed at generating hypotheses for future, more extensive investigations.

***Integrated interpretation of metabolic indicators in early postpartum dairy cows.*** The integrated evaluation of serum beta-hydroxybutyrate (BHBA), serum calcium concentration, and body condition score (BCS) provides a comprehensive overview of metabolic adaptation in dairy cows during the early postpartum period. Although all animals included in the present study were clinically healthy and managed under uniform conditions, the results revealed considerable inter-individual variability in key metabolic indicators, highlighting the heterogeneous nature of physiological adjustment following calving.

The mean serum BHBA concentration observed in this study (1.3±0.4 mmol L<sup>-1</sup>) reflects the increased energetic challenge associated with the onset of lactation. The recorded range of values indicates that, while most cows exhibited BHBA concentrations consistent with normal metabolic adaptation, a subset of animals reached higher levels commonly associated with enhanced mobilization of body fat reserves. Importantly, these elevated values occurred in the absence of clinical signs, emphasizing that variations in energy metabolism can remain subclinical during early lactation. Within this descriptive framework, BHBA proved to be a sensitive indicator of individual differences in energy balance among postpartum cows.

In parallel, serum calcium concentrations demonstrated an overall maintenance of mineral homeostasis at the group level, with a mean value of 8.4±0.6 mg dL<sup>-1</sup>. Nevertheless, individual values varied considerably, and a proportion of cows exhibited serum calcium concentrations below commonly accepted reference thresholds. This finding reflects the substantial physiological demand placed on calcium regulatory mechanisms immediately after calving, when colostrum and milk synthesis rapidly increase calcium requirements. The absence of extreme hypocalcemic values suggests effective adaptation in most animals, while the observed variability underscores the vulnerability of calcium metabolism during this period.

Table 5

Integrated summary table of metabolic parameters, threshold-based distribution, and body condition score (BCS) relationships in early postpartum dairy cows

<i>Analytical domain</i>	<i>Parameter evaluated</i>	<i>Key descriptive results (from present study)</i>	<i>Observed variability</i>	<i>Physiological interpretation (based on results)</i>	<i>Academic and practical relevance</i>
Energy status	Serum BHBA (mmol L <sup>-1</sup> )	1.3±0.4 (range: 0.7–2.4)	Moderate inter-individual variability	Reflects metabolic adaptation to early lactation, with variable mobilization of body fat reserves	Confirms BHBA as a sensitive indicator of energy balance during the postpartum transition period
Mineral status	Serum calcium (mg dL <sup>-1</sup> )	8.4±0.6 (range: 7.2–9.6)	Noticeable individual fluctuations	Indicates increased demand on calcium homeostatic mechanisms associated with colostrum and milk synthesis	Highlights the physiological sensitivity of calcium regulation in early postpartum cows
Threshold-based distribution	Elevated BHBA	25% of cows >1.2 mmol L <sup>-1</sup>	Distinct subgroup above reference threshold	Suggests increased lipid mobilization in a subset of clinically healthy cows	Demonstrates the occurrence of subclinical metabolic alterations at herd level
Threshold-based distribution	Low serum calcium	20% of cows <8.0 mg dL <sup>-1</sup>	Subgroup with reduced calcium availability	Indicates incomplete or delayed mineral adaptation in some individuals	Supports the relevance of monitoring subclinical hypocalcemia postpartum
Metabolic heterogeneity	BHBA and calcium combined	Elevated BHBA and/or reduced calcium observed in different subsets	Non-uniform metabolic response	Reflects the multifactorial nature of metabolic adaptation during early lactation	Emphasizes individual variability despite uniform management and absence of clinical disease
Body condition status	BCS ≤3.0	Mean BHBA: 1.1±0.3 mmol L <sup>-1</sup>	Lower variability	Suggests more moderate lipid mobilization	Indicates a potentially more stable metabolic adaptation in leaner cows
Body condition status	BCS ≥3.5	Mean BHBA: 1.5±0.4 mmol L <sup>-1</sup>	Greater variability	Indicates increased mobilization of adipose tissue reserves	Supports the concept that higher BCS may predispose cows to greater negative energy balance
BCS–metabolism relationship	Descriptive BCS–BHBA trend	Higher BHBA values in cows with higher BCS	Descriptive tendency only	Consistent with physiological mechanisms of energy metabolism in early lactation	Justifies the combined use of BCS and BHBA as practical on-farm monitoring tools
Herd-level implications	Integrated metabolic monitoring	BHBA, calcium, and BCS assessed together	Identification of at-risk subgroups	Enables early recognition of cows with reduced metabolic resilience	Provides a descriptive basis for targeted monitoring and future hypothesis-driven studies
Analytical domain	Parameter evaluated	Key descriptive results (from present study)	Observed variability	Physiological interpretation (based on results)	Academic and practical relevance
Energy status	Serum BHBA (mmol L <sup>-1</sup> )	1.3±0.4 (range: 0.7–2.4)	Moderate inter-individual variability	Reflects metabolic adaptation to early lactation, with variable mobilization of body fat reserves	Confirms BHBA as a sensitive indicator of energy balance during the postpartum transition period

The threshold-based analysis further emphasized the presence of subclinical metabolic alterations within the study population. Specifically, 25% of the cows exhibited BHBA concentrations exceeding  $1.2 \text{ mmol L}^{-1}$ , and 20% showed serum calcium concentrations below  $8.0 \text{ mg dL}^{-1}$ . Although these cows did not display overt clinical disorders, the identification of such subgroups highlights that metabolic challenges can be present even in apparently healthy animals. These findings reinforce the concept that descriptive metabolic screening can reveal early deviations that may not be detectable through clinical examination alone.

The relationship between body condition score and BHBA concentrations provided additional insight into individual metabolic responses. Cows with higher BCS values ( $\geq 3.5$ ) showed higher mean BHBA concentrations compared with cows with lower BCS ( $\leq 3.0$ ), suggesting a tendency toward greater lipid mobilization in better-conditioned animals during early lactation. While no statistical inference was applied, this descriptive pattern aligns with established physiological principles indicating that cows with greater adipose tissue reserves may experience a more pronounced negative energy balance postpartum. The results therefore support the relevance of BCS as a practical, non-invasive indicator that complements biochemical measurements in metabolic assessment.

Taken together, the combined analysis of energy-related and mineral-related indicators illustrates the multifactorial nature of metabolic adaptation in early postpartum dairy cows. Even under standardized management conditions, individual animals differed in their capacity to respond to the increased nutritional demands of lactation. From a herd health perspective, these findings support the value of integrated, descriptive monitoring approaches that combine body condition evaluation with basic metabolic profiling. Such strategies may facilitate the early identification of cows with reduced metabolic resilience and provide a foundation for more targeted monitoring and future hypothesis-driven research.

**Conclusions.** Metabolic disorders in dairy cows represent a major challenge to animal health, productivity, and farm profitability, particularly during the transition period, when profound physiological and metabolic adaptations occur. This review highlights that negative energy balance is the central pathogenic mechanism underlying the most important metabolic diseases, including fatty liver syndrome, ketosis, and milk fever, which are closely interconnected and frequently occur simultaneously.

Excessive mobilization of body fat reserves, increased circulating non-esterified fatty acids, and hepatic lipid accumulation severely impair metabolic, immune, and reproductive functions. These alterations lead to reduced milk yield, compromised fertility, increased susceptibility to infectious diseases, and a higher risk of culling. Subclinical forms of metabolic disorders, especially subclinical ketosis and hypocalcemia, are highly prevalent and often remain undetected, yet they exert significant negative effects on herd performance and economic efficiency.

Effective prevention and control of metabolic disorders rely primarily on optimal nutritional management and careful monitoring of the transition period. Maintaining an appropriate body condition score at calving, formulating well-balanced transition diets, ensuring adequate mineral and vitamin supply, and minimizing environmental and management-related stressors are essential strategies for reducing disease incidence. Early detection through metabolic profiling and the use of modern monitoring tools allows timely intervention and limits the progression toward clinical disease.

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**Conflict of Interest.** The authors declare that there is no conflict of interest.

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