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Partitioning Dynamics of Nutrients in Transition Dairy Cows: Metabolic, Hormonal, and Cellular Mechanisms Affecting Lactation and Fertility

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Abstract

This review critically examines nutrient partitioning dynamics in dairy cows during the transition phase, a period that profoundly affects lactation and reproductive performance. During this phase, cows experience extensive physiological changes that alter nutrient requirements and utilization, making effective management essential for health and productivity. The review synthesizes current research on mechanisms of nutrient partitioning, with particular attention to energy, protein, and mineral balance, which are crucial for optimizing milk yield, milk composition, and reproductive success. Proper nutrient management helps prevent negative energy balance, a common issue that can reduce milk production and impair reproductive efficiency. Metabolic disorders, including ketosis and milk fever, are discussed to highlight the importance of adequate nutrient provision in mitigating health risks. Environmental and management factors, such as housing, feeding strategies, and stress, are also examined, demonstrating the need for integrated approaches that address both nutrition and welfare. The review identifies gaps in existing knowledge, emphasizing opportunities for developing more precise feeding strategies and alternative feed resources to improve nutrient availability and utilization. Future research directions include the application of precision nutrition and the evaluation of novel feed ingredients to enhance transition-phase outcomes. By improving understanding of nutrient partitioning, dairy producers can implement strategies that support sustainable production, promote animal welfare, and increase economic efficiency. This comprehensive overview provides a foundation for advancing both scientific research and practical approaches in dairy cow nutrition and management, offering insights that are vital for optimizing performance during the critical transition period.

Keywords: Cellular signaling, endocrine regulation, fertility disorders, lactation performance, metabolic adaptation, nutrient partitioning, transition dairy cows

INTRODUCTION

The transition phase in dairy cows, which spans approximately three weeks before and after calving, represents a critical period characterized by profound physiological and metabolic changes [1–3]. During this time, cows experience significant alterations in their nutrient requirements and allocation, which directly impact both lactation and reproductive performance [4–6]. Understanding the dynamics of nutrient partitioning during this phase is essential for optimizing dairy cow health, milk yield, and fertility, ultimately enhancing productivity and sustainability within the dairy industry. Nutrient partitioning refers to the allocation of nutrients among various biological functions, including maintenance, lactation, reproduction, and body reserves [7–9]. In dairy

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cows, the transition phase poses unique challenges due to the simultaneous demands of lactation and the physiological adjustments required for reproduction. Proper management of nutrient partitioning during this period can mitigate risks associated with metabolic disorders, improve milk production efficiency, and enhance reproductive outcomes [10–13].

The physiological stress associated with parturition, coupled with the onset of lactation, often leads to negative energy balance (NEB), where the energy expended exceeds the energy intake. This state can adversely affect milk yield, composition, and overall health, resulting in increased susceptibility to disorders such as ketosis, displaced abomasum, and mastitis. Moreover, NEB can impair reproductive function, delaying the return to estrus and reducing conception rates [3, 4, 5]. Numerous factors influence nutrient partitioning in dairy cows during the transition phase, including dietary composition, body condition score (BCS), and management practices. Ensuring that cows receive adequate nutrition, particularly energy and protein, is critical for supporting both milk production and reproductive health. The interplay between these factors emphasizes the importance of a holistic approach to nutrition management, wherein the objective is to optimize nutrient allocation in a way that meets the demands of both lactation and reproduction [6, 14, 15].

This review aims to critically examine the partitioning dynamics of nutrients in dairy cows during the transition phase, highlighting the physiological changes, nutritional requirements, and mechanisms involved in nutrient allocation. The paper will explore how effective management of nutrient partitioning can enhance lactation and reproductive performance, while also addressing challenges and considerations that may arise in practical applications. Ultimately, the insights garnered from this review will contribute to advancing our understanding of nutrient management strategies that promote the health and productivity of dairy cows during this pivotal stage of their reproductive cycle.

Physiological Changes During the Transition Phase

The transition phase is marked by a series of physiological changes that profoundly influence nutrient partitioning in dairy cows. This period encompasses the last three weeks of gestation and the first three weeks postpartum, during which cows experience substantial metabolic adaptations.

Overview of the Transition Phase

In the transition phase, dairy cows undergo significant changes in hormonal, metabolic, and immune functions. These changes are critical for the successful initiation of lactation and the preparation for subsequent reproductive cycles. The transition phase is also a period of heightened vulnerability, as cows are at increased risk for various health issues due to the stress of calving and the demands of lactation [1–4].

Nutrient Partitioning Pathways

During the transition period, dairy cows undergo significant metabolic and physiological adjustments to support late gestation and early lactation. Nutrient partitioning pathways prioritize energy, protein, and minerals toward vital functions, such as fetal growth, mammary development, and milk synthesis, often at the expense of body reserves. Hormonal changes, including elevated growth hormone and reduced insulin sensitivity, redirect glucose and amino acids to the mammary gland. Lipolysis in adipose tissue releases non-esterified fatty acids for energy, while liver metabolism adapts to balance gluconeogenesis and ketone body production. Efficient partitioning is crucial for optimizing milk yield, reproductive recovery, and overall health (Figure 1).

Hormonal Changes Influencing Nutrient Partitioning

Hormonal regulation plays a crucial role in the metabolic adaptations that occur during the transition phase. Key hormones, such as insulin, glucagon, and cortisol, are involved in the regulation of energy metabolism. For example, insulin promotes glucose uptake and lipogenesis, while glucagon facilitates lipolysis and gluconeogenesis. The balance between these hormones is essential for maintaining energy homeostasis during periods of negative energy balance [5–7]. Moreover, the increased production of prolactin during lactation stimulates milk synthesis and alters nutrient partitioning by prioritizing energy for lactation over reproduction. The surge in reproductive hormones, including estrogen and progesterone, also influences nutrient allocation, as these hormones facilitate reproductive processes (Figure 1). Understanding these hormonal dynamics is vital for optimizing nutrient management strategies that support both lactation and reproductive success [8, 10–13].

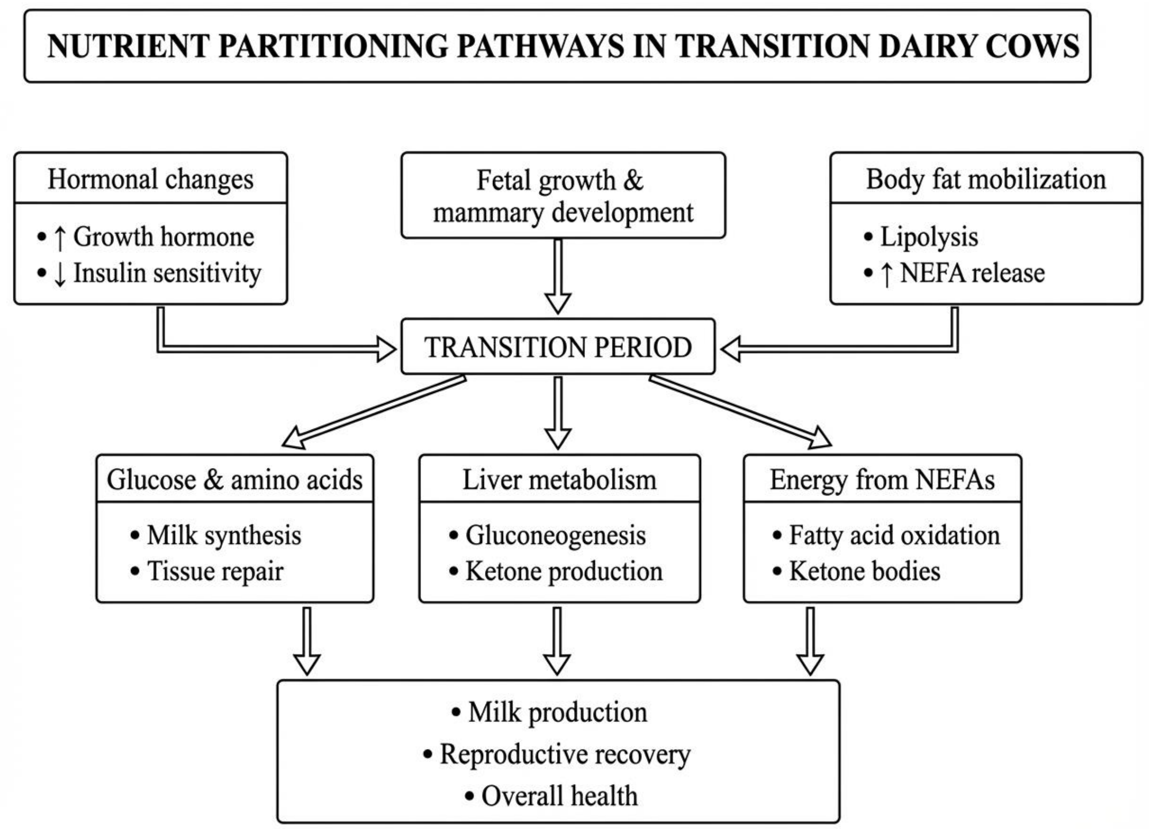

Figure 1. Nutrient partitioning pathways in transition dairy cows illustrate hormonal regulation, body fat mobilization, liver metabolism, glucose and amino acid allocation, and energy utilization from NEFAs, highlighting the coordinated processes supporting milk production, reproductive recovery, and overall health.

Metabolic Adaptations and Energy Balance

Metabolic indicators, such as non-esterified fatty acids (NEFA) and beta-hydroxybutyrate (BHBA), provide critical insight into the energy status of transition dairy cows. Elevated NEFA levels indicate increased mobilization of adipose tissue to supply energy during negative energy balance, while rising BHBA concentrations reflect hepatic ketone production resulting from incomplete oxidation of fatty acids. Monitoring these biomarkers enables early detection of metabolic stress and potential ketosis, allowing timely nutritional or management interventions. Together, NEFA and BHBA serve as reliable indicators for evaluating the efficiency of nutrient partitioning, guiding strategies to support milk production, reproductive recovery, and overall health during the transition period.

During the transition phase, dairy cows experience a shift in energy metabolism characterized by increased mobilization of body reserves [1, 3]. As the cow approaches calving, energy demands for fetal growth and lactogenesis rise, often leading to a negative energy balance. This condition prompts the cow to mobilize adipose tissue and muscle protein to meet energy requirements, affecting nutrient partitioning and overall health [16–18]. The extent of negative energy balance and subsequent mobilization of body reserves can vary based on factors such as genetics, body condition score, and nutrition. It is essential to monitor these metabolic changes closely, as excessive mobilization can lead to metabolic disorders, further complicating the transition process and negatively impacting milk production and reproductive performance [3, 14].

Importance of Body Condition Score

Body condition score (BCS) is a crucial indicator of the energy reserves available to a dairy cow and plays a significant role in the transition phase [19–21]. Cows with higher BCS entering the transition phase may have greater energy reserves, potentially mitigating the effects of negative energy balance. However, excessive body condition can lead to increased risk of metabolic disorders, emphasizing the need for optimal BCS management. Maintaining an appropriate BCS during the transition phase is critical for ensuring adequate nutrient partitioning. Research suggests that cows with a BCS of 3.0 to 3.5 (on a scale of 1 to 5) at calving achieve better reproductive performance and overall health compared to those with lower or higher scores [18, 19, 21, 22]. Therefore, careful monitoring and management of BCS can facilitate better nutrient utilization during lactation and improve reproductive outcomes.

NUTRITIONAL REQUIREMENTS DURING THE TRANSITION PHASE

Overview of Nutrient Requirements

The transition phase is characterized by marked increases in nutrient requirements, particularly for energy, metabolizable protein, vitamins, and minerals [23–28]. During the last 3 weeks before calving and the first 3 weeks after calving, dry matter intake typically declines by about 10 to 30 %, while energy demand may increase by 60 to 80 % due to the onset of lactation. A high producing dairy cow may require about 30 to 35 Mcal of net energy per day in early lactation compared with about 12 to 14 Mcal per day during the dry period. If this requirement is not met through diet, cows may enter a negative energy balance of about minus 3 to minus 6 Mcal per day during the first weeks postpartum.

Protein requirement also rises substantially during the transition phase. Metabolizable protein requirement may increase from about 900 to 1000 g per day during late gestation to about 1600 to 1800 g per day in early lactation to support milk protein synthesis and tissue repair. Calcium demand increases nearly two to three-fold at calving, with early lactation cows requiring about 1.2 to 1.6 % calcium in the diet dry matter, while phosphorus requirement is typically around 0.35 to 0.45 % of dry matter. Inadequate supply of these minerals increases the risk of hypocalcemia, retained placenta, and poor uterine recovery.

Energy balance during this phase is a critical determinant of performance. Cows that lose more than 0.5 to 1.0 body condition score units after calving often show reduced milk yield, delayed ovulation by 10 to 20 days, increased days open, and higher incidence of ketosis and fatty liver. Therefore, meeting the elevated nutrient requirements through properly balanced transition diets is essential for maintaining metabolic stability, optimizing milk production, and ensuring normal reproductive performance during early lactation [23, 24, 29].

Impact of Nutrition on Milk Production and Reproductive Performance

Proper nutrition during the transition phase is crucial for optimizing both milk production and reproductive performance. Studies have shown that providing adequate energy and protein during this time can enhance milk yield, improve milk composition, and support timely return to estrus [14, 18, 30]. Ensuring that cows have access to high-quality forages and concentrates can facilitate better nutrient utilization and overall health. Moreover, nutrition directly impacts hormonal regulation during the transition phase. For instance, adequate energy intake can help maintain insulin levels, promoting glucose availability for lactation. Conversely, insufficient nutrient intake can result in hormonal imbalances that adversely affect reproductive performance [31–33].

Dietary Strategies for Optimizing Nutrient Intake

To meet the heightened nutrient demands of transitioning cows, dietary strategies must focus on energy density and nutrient quality [28, 30, 34]. High-energy diets that include a balanced mix of forages and concentrates can help prevent negative energy balance. Formulating rations that provide an optimal balance of fiber, carbohydrates, and protein is essential for maximizing nutrient absorption and utilization. Additionally, incorporating feed additives such as rumen-protected fats and high-quality protein sources can enhance energy density and protein availability. These strategies not only support lactation but also promote better reproductive outcomes by ensuring that cows are well-nourished during this critical period [25, 27, 35].

MECHANISMS OF NUTRIENT PARTITIONING

Role of Insulin and Other Hormones

The endocrine system plays a pivotal role in regulating nutrient partitioning in dairy cows during the transition phase. Insulin is a key hormone that promotes glucose uptake in tissues and facilitates lipogenesis. During lactation, the increased insulin sensitivity in mammary tissues supports milk synthesis, directing nutrients toward lactation rather than body maintenance or reproduction. Other hormones, such as growth hormone (GH) and glucagon, also influence nutrient partitioning. GH stimulates lipolysis, promoting the mobilization of fat stores, while glucagon helps maintain blood glucose levels during periods of negative energy balance. Understanding these hormonal interactions is essential for developing nutritional strategies that optimize nutrient utilization [3, 36, 37].

Metabolic Pathways Involved in Nutrient Utilization

Nutrient partitioning during the transition phase involves complex metabolic and cellular signaling pathways that regulate how nutrients are allocated among maintenance, lactation, immune function, and reproduction. Carbohydrates are primarily utilized for energy production through glucose metabolism, proteins support tissue repair and milk protein synthesis, and lipids act as a major energy source, particularly during periods of negative energy balance. These metabolic processes are tightly controlled by intracellular signaling networks, including the mTOR signaling pathway, the AMPK pathway, and the Insulin signaling pathway, which together coordinate nutrient sensing, energy status, and anabolic versus catabolic activity. Activation of the mTOR signaling pathway promotes protein synthesis, cell growth, and milk component production when nutrient availability is adequate, whereas activation of the AMPK pathway occurs during energy deficiency and stimulates fatty acid oxidation, glucose conservation, and mobilization of body reserves to maintain energy homeostasis. The insulin signaling cascade plays a central role in regulating glucose uptake, lipid metabolism, and endocrine balance, thereby influencing both milk production and ovarian function. During early lactation, increased energy demand shifts signaling toward AMPK mediated catabolism and reduced insulin sensitivity, resulting in enhanced fat mobilization to support milk synthesis. Disruption or imbalance in these signaling pathways can impair nutrient utilization efficiency and increase the risk of metabolic disorders, highlighting the importance of precision nutrition strategies aimed at modulating cellular signaling to optimize health, productivity, and reproductive performance during the transition period [32, 38, 39].

Interaction Between Lactation and Reproductive Processes

The relationship between lactation and reproductive processes is complex, with nutrient partitioning playing a central role. Nutrient availability during lactation can influence reproductive success, as the energy required for lactation can compete with that needed for reproductive functions [23, 38, 40]. For instance, a cow that experiences severe negative energy balance during early lactation may have delayed return to estrus and reduced conception rates. Conversely, adequate nutrition during the transition phase can enhance reproductive outcomes. Studies have shown that cows with optimal body condition and nutrient intake during the transition period are more likely to conceive within the desired time frame. This underscores the importance of developing nutritional strategies that support both lactation and reproductive health [23, 38, 40].

IMPACT OF NUTRIENT PARTITIONING ON LACTATION PERFORMANCE

Effects of Nutrient Availability on Milk Yield and Composition

Nutrient availability during the transition phase has a direct influence on milk yield, milk composition, and key milk quality indicators such as fat percentage, protein percentage, lactose content, and fat to protein ratio [31, 41, 42]. Cows receiving balanced diets with adequate energy, metabolizable protein, and essential minerals during late gestation and early lactation generally produce higher milk yield with more stable milk components. In contrast, insufficient nutrient intake or severe negative energy balance can reduce milk production and alter milk composition, often resulting in decreased milk protein percentage, variable milk fat percentage, and an increased fat to protein ratio, which is commonly used as an indicator of metabolic imbalance.

Nutrient partitioning during early lactation determines how available energy is distributed between body reserve mobilization and milk synthesis. Excessive mobilization of adipose tissue increases circulating non esterified fatty acids, which can elevate milk fat percentage and widen the fat to protein ratio, frequently indicating negative energy balance or risk of ketosis. Conversely, inadequate rumen fermentable energy may reduce microbial protein synthesis, leading to lower milk protein content. Changes in glucose availability also affect lactose synthesis, which directly influences milk volume [15, 21, 32].

The relationship between nutrient partitioning and milk components is, therefore, critical for both metabolic health and economic return. Maintaining optimal dry matter intake, balanced energy to protein ratio, and proper transition feeding management help stabilize fat to protein ratio, supports normal milk composition, and improves overall production efficiency during the transition period. Ensuring precise nutritional management during this phase is essential for optimizing milk yield, milk quality, and metabolic stability in high producing dairy cows.

Relationship Between Nutrient Partitioning and Somatic Cell Count

Nutrient partitioning also influences somatic cell count (SCC), a key indicator of udder health. Elevated SCC is often associated with mastitis, which can negatively impact milk production and quality [13, 18, 43]. Proper nutrition during the transition phase can enhance immune function, thereby reducing the risk of mastitis and maintaining lower SCC levels. Cows that receive balanced diets during the transition phase are more likely to maintain better udder health, resulting in lower SCC and improved overall milk quality. This highlights the importance of managing nutrient intake to support both lactation performance and health.

Role of Nutrient Partitioning in the Prevention of Metabolic Disorders

Effective nutrient partitioning plays a critical role in preventing metabolic disorders such as ketosis and milk fever. Cows experiencing severe negative energy balance are at higher risk for these conditions, which can significantly affect milk production and reproductive performance [5, 44, 45]. By ensuring adequate nutrient intake, particularly energy and calcium, farmers can help mitigate the risks associated with these disorders. Nutrition management strategies that focus on maintaining energy balance and providing essential nutrients can reduce the incidence of metabolic disorders. This is crucial for maintaining the health and productivity of dairy cows during the transition phase [1, 10, 46].

IMPACT OF NUTRIENT PARTITIONING ON REPRODUCTIVE PERFORMANCE

Influence of Nutrient Status on Fertility and Conception Rates

Nutrient status during the transition phase has a direct influence on reproductive performance indicators such as days to first service, days open, conception rate, and calving interval in dairy cows. Cows that maintain optimal energy balance and adequate nutrient intake during late gestation and early lactation generally resume ovarian activity earlier, resulting in shorter days to first service and improved conception rate. In contrast, cows experiencing negative energy balance often show delayed return to estrus, reduced follicular development, and impaired luteal function, which contribute to prolonged days open and extended calving interval. Insufficient nutrient supply during this period alters metabolic hormone profiles, including insulin, IGF-1, and progesterone, thereby disrupting normal reproductive cyclicity. Studies have shown that cows with appropriate body condition score at calving and better dry matter intake during the transition phase tend to have fewer services per conception, shorter days open, and more optimal calving interval compared with cows under metabolic stress. These findings emphasize that efficient nutrient partitioning toward both lactation and reproductive recovery is essential for maintaining acceptable reproductive indices and overall herd productivity in modern dairy production systems [21, 47, 48].

Relationship Between Postpartum Body Condition and Reproductive Outcomes

The postpartum body condition of dairy cows plays a significant role in their reproductive success. Cows that lose excessive body condition after calving are at a higher risk for reproductive failure. Maintaining appropriate body condition during the transition phase is essential for promoting reproductive health [18, 45]. Studies have shown that cows with moderate BCS at calving tend to have better reproductive outcomes compared to those with extreme body condition scores. Effective management of body condition during this critical period can contribute to improved fertility and shorter calving intervals, ultimately enhancing overall herd productivity [18, 28, 45].

Effect of Dietary Interventions on Reproductive Performance

Dietary interventions aimed at optimizing nutrient intake during the transition phase can have a profound impact on reproductive performance. Implementing feeding strategies that enhance energy density and nutrient availability can support better reproductive outcomes. For instance, the inclusion of high-quality forages and protein sources can improve nutrient absorption and utilization [5, 21, 44, 47]. Moreover, specific feed additives, such as minerals and vitamins, play a vital role in reproductive health. Research indicates that providing adequate levels of key nutrients, including selenium, zinc, and vitamin E, can enhance reproductive function and reduce the incidence of reproductive disorders. Implementing targeted dietary interventions can help optimize nutrient partitioning and support both lactation and reproductive success [28, 48].

CHALLENGES AND CONSIDERATIONS IN MANAGING NUTRIENT PARTITIONING

Environmental and Management Factors Affecting Nutrient Dynamics

Heat stress and other environmental challenges are major determinants of nutrient partitioning in dairy cows during the transition phase, and their effects can now be monitored and managed through precision livestock farming approaches. Elevated ambient temperature alters feed intake, rumen function, endocrine balance, and metabolic priority, thereby shifting nutrients away from production toward maintenance and thermoregulation. Precision livestock farming technologies, including sensor-based monitoring of body temperature, activity, rumination, and feed intake, enable real time detection of heat stress and allow timely nutritional and managerial interventions to maintain metabolic stability. In addition, nutrigenomics provides new insight into how environmental stress modifies gene expression related to energy metabolism, immune response, oxidative stress, and milk synthesis, thereby influencing nutrient utilization efficiency at the molecular level. Understanding gene nutrient environment interactions makes it possible to design targeted feeding strategies using functional nutrients, amino acids, antioxidants, osmolytes, and micronutrients that support cellular resilience during heat stress. Integrating heat stress monitoring, precision livestock farming tools, and nutrigenomic knowledge can improve nutrient partitioning, sustain milk production, and protect reproductive and metabolic health of dairy cows during the transition period under changing climatic conditions.

Economic Implications of Nutrient Management Strategies

The economic implications of nutrient management strategies cannot be overlooked. Effective management of nutrient partitioning during the transition phase can lead to improved milk production and reproductive performance, ultimately enhancing profitability for dairy farmers. However, implementing these strategies may require investment in feed quality, additives, and improved management practices. Farmers must weigh the costs of implementing nutritional interventions against the potential benefits in terms of milk yield and reproductive success. Careful consideration of economic factors is essential for ensuring the sustainability and profitability of dairy operations.

Future Challenges in Optimizing Nutrient Partitioning for Sustainability

As the dairy industry faces increasing pressure to enhance sustainability, optimizing nutrient partitioning will be crucial. Future research should focus on developing innovative nutritional strategies that address the unique challenges of the transition phase. This includes exploring alternative feed sources, improving feed efficiency, and integrating precision nutrition practices. Furthermore, addressing the impact of climate change on dairy production will require adaptive management strategies that consider environmental factors influencing nutrient dynamics. By prioritizing research and development in this area, the dairy industry can move towards more sustainable practices that benefit both animal welfare and economic viability.

CONCLUSION

The partitioning dynamics of nutrients in dairy cows during the transition phase play a pivotal role in determining lactation performance, reproductive efficiency, and overall herd health. The profound physiological and metabolic adjustments occurring during late gestation and early lactation require precise regulation of nutrient allocation to support milk synthesis, immune function, and restoration of reproductive activity. Inadequate nutrient supply or improper partitioning can lead to negative energy balance, increased risk of metabolic disorders, reduced milk yield, prolonged days open, and extended calving interval, thereby affecting both biological efficiency and economic return.

From a practical perspective, these relationships highlight the importance of accurate diet formulation, strategic herd management, and adoption of precision nutrition approaches during the transition period. Ration formulation should ensure optimal balance of energy, metabolizable protein, fiber, and essential minerals to support rumen function, maintain dry matter intake, and minimize excessive body reserve mobilization. Group wise feeding, body condition score monitoring, and proper dry period management are essential herd level strategies to maintain uniform metabolic status among cows. Precision nutrition tools, including sensor-based monitoring of feed intake, milk components, body weight, activity, and rumination, allow early detection of metabolic imbalance and enable timely dietary adjustment at the individual cow level.

Integration of nutritional management with environmental control, heat stress mitigation, and health monitoring further improves nutrient utilization efficiency during the transition phase. Practical implementation of these strategies can stabilize milk fat to protein ratio, improve conception rate, reduce days open, and maintain optimal calving interval. Future research should emphasize precision feeding systems, nutrigenomic based diet formulation, and data driven herd management models to develop sustainable and climate resilient dairy production systems. A comprehensive understanding of nutrient partitioning, combined with modern precision livestock farming technologies, will be essential for improving productivity, reproductive performance, and long term sustainability of dairy herds.

REFERENCES

1. Ashar MJ, Gonzalez-Rivas PA, Dunshea FR, Marth CD, Chauhan SS. Integrative Insights into Metabolic, Oxidative, and Immune Adaptations During the Transition Period in Dairy Cows: Revisiting Nutritional Strategies and Emerging Roles of Injectable Trace Minerals. Dairy. 2026 Feb;7(1):15.
2. pHabel J, Sundrum A. Mismatch of glucose allocation between different life functions in the transition period of dairy cows. 2020. Available from: https://www.mdpi.com/2076-2615/10/6/1028.
3. Sundrum A. Metabolic disorders in the transition period indicate that the dairy cows' ability to adapt is overstressed. Animals. 2015;5(4):978–1020. doi: 10.3390/ani5040395.
4. Mann S. Transition cow metabolism in relation to plane of energy prepartum. 2016. Available from: https://ecommons.cornell.edu/bitstream/1813/43711/1/sm682.pdf.
5. Kour D, Sharma D, Sharma VK, Mahesh MS. Additives and nutritional supplements for transition cows. Feed Addit. 2024. doi: 10.1007/978-981-97-0794-2_15.

6. Marques RS. Evaluation of oxidative stress and immunity in Holstein cows supplemented with macro and trace minerals during the transition period. 2022. Available from: https://www.teses. usp.br/teses /disponiveis/10/10136/tde-05052023-115057/en.php.
7. Yasui T. Nutritional implications for oxidative status, immune function, and energy metabolism in transition dairy cows and relationships with postpartum performance. 2013. Available from: https://search.proquest.com/openview/301615f991ae8516c1285a4f3f19e991/1.
8. McCabe C. An evaluation of tissue mobilization and chronic circadian disruptions in transition dairy cows. 2020. Available from: https://search.proquest.com/openview/0e58828dd5d3ff63e4a3 faa6e1b523ef/1.
9. Gouveia K. Production and glucose metabolism responses related to late gestational muscle reserves and supplementation of branched-chain volatile fatty acids in transition dairy cattle [master's thesis]. Purdue University.
10. Mullins CR. Feeding behavior and metabolism of transition dairy cows supplemented with monensin. 2011. Available from: https://search.proquest.com/openview/699e706a121b8b2a7fcb 492b7431570e/1.
11. Losacco C, Pugliese G, Forte L, Tufarelli V, Maggiolino A, De Palo P. Digital transition as a driver for sustainable tailor-made farm management: An up-to-date overview on precision livestock farming. Agriculture. 2025 Jun 27;15(13):1383.
12. van Eys JE, Moreland S. Nutrition and immune status of the transition cow; the potential of feed additives. Available from: https://archivio2021-2022.ruminantia.it/wp-content/uploads/2016/06/ SNMC2015.pdf.
13. Oliveira RC. Prepartum CLA or postpartum ammonium lactate supplementation improves blood metabolite profile and lactation performance in transition dairy cows. 2019. Available from: https://search.proquest.com/openview/a0ce0e9d34255a710619677281c7b851/1.
14. Kotsampasi B, Karatzia MA, Tsiokos D, Chadio S. Nutritional strategies to alleviate stress and improve welfare in dairy ruminants. Animals. 2024;14(17):2573. doi: 10.3390/ani14172573.
15. Li M, Zhu S, Sun H, Huo Y, Cao Q, Deng Z, Li K, He Y, Lu X, Gao J, Xu C. Rumen microbiota modulates metabolic stress in high-yield dairy cows: insights from early to peak lactation. Microbiome. 2026 Dec;14(1):61.
16. Freire-Regatillo A, Argente-Arizon P, Argente J, García-Segura LM, Chowen JA. Non-neuronal cells in the hypothalamic adaptation to metabolic signals. Frontiers in Endocrinology. 2017 Mar 21;8:51.
17. Gagniuc E, Pîrvu AM, Nastac DI, Gagniuc PA, Gherghiceanu M, Militaru M. Adipocyte mitochondria in dairy cows reveals constraints in growth and signals adaptive metabolic responses. Scientific Reports. 2025 Aug 13;15(1):29705.
18. Useni BA, Muller CJC, Cruywagen CW. Pre- and postpartum effects of starch and fat in dairy cows: A review. S Afr J Anim Sci. 2018;48(3):413–426. doi: 10.4314/sajas.v48i3.2.
19. Wray-Cahen CD, Kerr DE, Evock-Clover CM, Steele NC. Redefining body composition: nutrients, hormones, and genes in meat production. Annual review of nutrition. 1998 Jul;18(1):63-92.
20. Aboragah AAA. Molecular and biochemical analyses of the role of nutrition and body condition in Holstein cows and the developing fetus. 2022. Available from: https://www.ideals.illinois.edu/ items/126601.
21. Rodríguez A, Mellado R, Bustamante H. Prepartum fat mobilization in dairy cows with equal body condition and its impact on health, behavior, milk production and fertility during lactation. 2020. Available from: https://www.mdpi.com/2076-2615/10/9/1478.
22. Firkins JL. Viewing a role for isoacids in dairy nutrition through a new lens. 2023. Available from: https://ecommons.cornell.edu/server/api/core/bitstreams/3dcd224d-12f4-40a7-a763- d4c99afb2a16/content.
23. Crovetto GM. Energy and protein metabolism and nutrition. 2023. Available from: https://books.google .com/books?id=DM77EAAAQBAJ
24. Brisson V. Mathematical modelling to predict B-vitamins supply in dairy cows. 2022. Available from: https://atrium.lib.uoguelph.ca/bitstream/10214/27223/1/Brisson_Vicki_202209_MSc.pdf.

25. Ponnampalam EN, Kiani A, Santhiravel S, Holman BW, Lauridsen C, Dunshea FR. The importance of dietary antioxidants on oxidative stress, meat and milk production, and their preservative aspects in farm animals: Antioxidant action, animal health, and product quality—Invited review. Animals. 2022 Nov 24;12(23):3279.
26. Castillo C, Abuelo A, Hernández J. Biotechnological approaches to improve sustainable milk and meat yield in bovines. 2017. Available from: https://www.researchgate.net/publication/318707180.
27. Wasana WP, Waterland M, Everett DW, Thum C. Functional significance of probiotic bacterial interactions with milk fat globules in a human host. 2025. Available from: https://www.mdpi.com/2076-2607/13/2/223.
28. Adriaens I, Saeys W, De Ketelaere B, Piepers S. Data-based monitoring of dairy cows-milk progesterone as a mirror of fertility. 2018. Available from: https://lirias.kuleuven.be/retrieve/945a92e1-6ca0-4c42-bfb6-94396174258a.
29. Chen LH, Hedemann MS, Purup S, Pfannkuche H, Canibe N. The impact of microbial-derived metabolites on gut function in weaned piglets under different levels of dietary crude protein and a surplus of dietary amino acids. In8th EAAP International Symposium on Energy and Protein Metabolism and Nutrition, ISEP 2025 2025 Sep 15.
30. Husseini Z, Gilbert C. Milk-derived extracellular vesicles and microRNAs: Potential modulators of intestinal homeostasis. FASEB J. 2025. doi: 10.1096/fj.202501630R.
31. Piantoni P, VandeHaar MJ. Symposium review: The impact of absorbed nutrients on energy partitioning throughout lactation. 2023. Available from: https://www.sciencedirect.com/science/article/pii/S0022030222007512.
32. Alhojaily SM. The effect of lactation and energy status on gene expression in the main reproductive tissues of lactating dairy cattle. 2019. Available from: https://search.proquest.com/openview/04143e55c7491bd9704611a4d2cf5537/1.
33. Rafael JB. LSTM models to support the selective antibiotic treatment strategy of dairy cows in the dry period. 2022. Available from: https://search.proquest.com/openview /e023011733dd092d952578b2b471d917/1.
34. Collier RJ, Baumgard LH, Lock AL, et al. Physiological limitations, nutrient partitioning. 2005. Available from: https://www.academia.edu/download/41804090.
35. Maheswari M, Das A, Datta M, Tyagi AK. Supplementation of tropical seaweed-based formulations improves antioxidant status, immunity and milk production in lactating Murrah buffaloes. J Appl Phycol. 2021. doi: 10.1007/s10811-021-02473-5.
36. Casal A, Garcia-Roche M, Cassina A, Soca P, et al. Cow–calf efficiency of beef cows grazing different herbage allowances of rangelands: Hepatic mechanisms related to energy efficiency. Anim Prod. 2022. Available from: https://connectsci.au/an/article-abstract/62/6/529/87377.
37. Mohammadi AT, Naderi N, Kenari PB, Mir A, Sabouri F, et al. Advancements in pharmacology: integrating molecular mechanisms, therapeutics, and drug development. 2025. Available from: https://books.google .com/books?id=4QpYEQAAQBAJ.
38. Horst EA, Kvidera SK, Al-Qaisi M, et al. Energy cost of inflammation in dairy cows. 2018. Available from: https://archivio.ruminantia.it/wp-content/uploads/2019/02/TRI-STATE-DAIRY-NUTRITION-CONFERENCE-2018.pdf.
39. Brown SA, Palmer KL, Whiteley M. Revisiting the host as a growth medium. Nat Rev Microbiol. 2008. Available from: https://www.nature.com/articles/nrmicro1955.
40. Abuajamieh MKA. Effects of heat stress or ketosis on metabolism and inflammatory biomarkers in ruminants and monogastrics. 2015. Available from: https://search.proquest.com/openview/9761cb050c2c567a492d648b00088c94/1.
41. Baumgard LH, Collier RJ, Bauman DE. A 100-year review: Regulation of nutrient partitioning to support lactation. 2017. Available from: https://www.sciencedirect.com/science/article/pii/S0022030217310342.
42. Vailati-Riboni M, Elolimy A, Loor JJ. Nutritional systems biology to elucidate adaptations in lactation physiology of dairy cows. 2016. doi: 10.1007/978-3-319-43332-5_5.
43. Wahlig JL. The impact of high fat diet and obesity on whole body and tissue specific metabolism during the metabolic challenge of lactation. 2011. Available from: https://search.proquest.com/openview /eef451aab689c9923595dad39f35619b/1.

44. Galhardo MS. Integrated analysis of transcript-level regulation of human adipogenesis and cell type-selective disease association of high regulatory load genes. 2015. Available from: https://orbilu.uni.lu/handle /10993/22949.
45. Mikkola M, Desmet KLJ, Kommisrud E, Riegler MA. Recent advancements to increase success in assisted reproductive technologies in cattle. Anim Reprod. 2024;21(3):e20240031. doi: 10.1590/1984-3143-AR2024-0031.
46. Rout PK, Behera BK. Factors influencing livestock way of life. 2021. doi: 10.1007/978-981-33-4343-6_5.
47. Friggens NC, Disenhaus C, Petit HV. Nutritional sub-fertility in the dairy cow: Towards improved reproductive management through a better biological understanding. Animal. 2010. Available from: https://www.cambridge.org/core/journals/animal/article/nutritional-subfertility-in-the-dairy-cow.
48 Mugwe J, Ngetich F, Otieno EO. Integrated soil fertility management in sub-Saharan Africa: Evolving paradigms toward integration. Zero Hunger. 2020. doi: 10.1007/978-3-319-95675-6_71.

