Nutritional Interventions Can Improve the Immune Status of Dairy Calves

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Abstract

Neonatal diseases significantly impact dairy operations due to calf losses, treatment costs, and long-term performance effects. Despite advancements, calf morbidity and mortality rates remain high globally, with U.S. pre-weaning mortality rates ranging from 7 to 11%, primarily due to diarrhea and pneumonia. Post-weaning, mortality and culling rates continue to affect dairy farm sustainability. The calf's immune system begins developing during gestation but remains immature at birth, making neonates susceptible to pathogens. Maternal conditions during late pregnancy, such as heat stress, can have lasting effects on calf health and productivity. Improving calf immunity during the pre-weaning period is crucial for reducing morbidity and mortality rates. Nutritional interventions, including transition milk feeding, adequate nutrition, antioxidant supplementation, and nutraceuticals like prebiotics, probiotics, and *Saccharomyces cerevisiae* fermentation products **(SCFP)**, enhance calf immune responses and overall health. Transition milk provides essential nutrients and bioactive compounds supporting gastrointestinal development and immune function. Adequate nutrition prevents deficiencies that impair immunity, while antioxidant supplementation mitigates oxidative stress, which compromises immune function. Nutraceuticals, including prebiotics, probiotics, and SCFP, offer promising benefits for calf health, with SCFP showing improvements in performance and immune function during stress and illness. However, the efficacy of nutraceuticals varies, and scientific evaluation is essential. In conclusion, calf health and immunity are influenced by maternal conditions, nutrition, and management practices. Effective nutritional interventions can enhance immune responses and reduce disease incidence, improving dairy operations' sustainability and profitability.

Introduction

Calves are particularly vulnerable to diseases during the first weeks of life (Urie et al., 2018). This is attributed to the inability of calves to mount protective immune responses early in life due to their immature immune system (Chase et al., 2008). The immune responses of calves reach maturity at around 6 months of age (Cortese, 2009). Nutrition has profound effects on immune function (Beisel, 1996; Calder, 2013). This presentation will focus on calf immune development and the evidence supporting the impact of various nutritional interventions that can improve immune function in calves during the preweaning phase.

Relevance of Neonatal Diseases of Calves

Calfhood diseases have a major impact on the economic viability of dairy operations due to

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the costs associated with calf losses, treatments, and the long-term effects on performance (Donovan et al., 1998). Despite advances in veterinary medicine and farm management practices in recent years, calf morbidity and mortality rates continue to be high worldwide (Mee, 2013; Windeyer et al., 2014; Abuelo et al., 2019). In the U.S., reported pre-weaning mortality rates on dairy farms vary between 7 to 11% (NAHMS, 2014). Infectious diseases, such as diarrhea or pneumonia, are responsible for the majority of preweaned calf deaths at 56.5 and 22.5%, respectively (NAHMS, 2014). After weaning, mortality and culling rates continue to be high, with 11% of weaned heifers failing to reach their first calving (Brickell and Wathes, 2011). Indeed, only 40% of U.S. dairy farms can supply an adequate number of replacements from their own herd (NAHMS, 2014). Since rearing costs represent between 15 to 20% of total dairy production (Heinrichs, 1993), health disorders of replacement stock significantly impact the dairy industry's sustainability. Hence, innovative practices are needed on dairy farms to reduce neonatal morbidity and mortality rates more effectively. Thus, calf management practices that prevent infections and boost the ability of calves to fight infections (immunity) are needed.

The period up to 60 days of age is when the greatest neonatal morbidity and mortality rates are observed on dairy farms (Windeyer et al., 2014). Interestingly, this pre-weaning period is critical for greater body weight and growth, shortened time to first calving, and enhanced future milk production potential (Moallem et al., 2010; Soberon and Van Amburgh, 2013); all of which are negatively affected if neonatal diseases occur (Windeyer et al., 2014; Teixeira et al., 2017; Abuelo et al., 2021). Hence, this period is paramount in the productive life of dairy cows entering a herd (Bach, 2011) and should be the main focus of preventive interventions.

Calf Immune System Development

The development of the calf's immune system begins during gestation, during which the fetus is protected predominantly by the innate immune system. Fetal neutrophils and macrophages remain at their sites of origin until approximately 130 days of gestation, after which they are released into the bloodstream. As gestation progresses, these fetal cells gain the ability to phagocytose pathogens but with decreased bactericidal activity relative to adult phagocytes (Barrington and Parish, 2001). However, the capacity of fetal phagocytes to engulf and destroy pathogens decreases around the time of calving due to fetal release of glucocorticoids (Barrington and Parish, 2001). After birth, neutrophils and macrophages can also have reduced functionality due to stress, malnutrition, low-level infection, or exposure to toxins.

All the cellular components of the acquired immune system (lymphocytes) are present in fetal calves but take longer to mount a generally weaker response. An important feature of the calves' immune system is the complete absence of antibodies unless an infection in utero has been acquired. At birth, the calf's immune response is typically slower and weaker, with decreased immunoglobulin concentrations. Many of the immune system components are present at birth but do not become functional until the calf is 2 to 4 weeks of age, after which they continue to develop until puberty (Reber et al., 2006). Therefore, the newborn calf's immune system is functional but naïve and immature. This also means that neonates are more susceptible to pathogens and respond differently to vaccination than adults.

We continue to learn more about the impact of late-gestation maternal status on the calves' health. For example, calves born to cows that experience heat stress during late gestation have lighter birth weights, exhibit compromised immune function and altered metabolism until weaning, and decreased fertility and lower milk yields in their first lactations (Tao and Dahl, 2013; Monteiro et al., 2014; Tao et al., 2014; Dahl et al., 2016; Guo et al., 2016; Monteiro et al., 2016a; Monteiro et al., 2016b). Also, a higher degree of exposure to metabolic stress (excessive fat breakdown, inflammation, and oxidative stress) *in utero* was associated with conditions in calves linked to impaired health and production in adult cows (Ling et al., 2018). Additionally, dietary supplementation of limiting amino acids to the dams during the dry period enhanced innate immune responses and growth (Jacometo et al., 2016; Alharthi et al., 2017). Taken together, these studies indicate that maternal conditions during late pregnancy have long-lasting carryover effects in the offspring; therefore, calf health starts with managing the pregnant cow.

Improving calf immunity during the pre-weaning period is essential for reducing neonatal morbidity and mortality rates on dairy farms and ensuring lifelong, healthier, and more productive replacement heifers. This process requires a multi-pronged approach that starts with managing the dam during pregnancy and continues after birth by ensuring adequate colostrum intake by the calf and the appropriate use of vaccines. However, new strategies that improve calves' innate immunity and vaccine responsiveness during the pre-weaning phase are still needed.

Nutritional Interventions Affecting Calf Immune Status

There are multiple ways in which nutrition can affect immunity in calves, but below is not a comprehensive description of approaches that are commonly utilized in dairy farms in the US.

Transition milk feeding

The National Academies of Science, Engineering, and Medicine (NASEM, 2021) emphasizes the importance of administering transition milk as a key component of early feeding management in calf rearing. Transition milk, collected after colostrum milking, spans from the second to sixth milking post-parturition (Godden, 2008). The concentrations of immunoglobulins and bioactive compounds in transition milk gradually decrease compared to colostrum, eventually resembling mature milk composition (Inabu et al., 2019; Fahey et al., 2020; Fischer-Tlustos et al., 2020). Research indicates that feeding 5.7 L/day of transition milk in the first 3 days leads to greater weight gain throughout the rearing period compared to milk replacer (Van Soest et al., 2020), or when 6 L of whole milk is partially substituted with transition milk over 21 days (Kargar et al., 2021). Additionally, feeding 4 L/day of transition milk over 2 days reduces the likelihood of poorer eye/ear or nose scores (Conneely et al., 2014) over a 56-day rearing period, and feeding 5.7 L/day lowers the chances of poorer fecal scores (Van Soest et al., 2022). Furthermore, feeding 4 L/day of transition milk for 2 weeks diminishes the risk of *Cryptosporidium* spp. infection during this period (Zolova et al., 2022). Previous studies have also demonstrated that transition milk feeding supports the calf's developing gastrointestinal tract by providing essential nutrients, growth factors, and bioactive compounds that stimulate intestinal epithelium development and immune cell infiltration (Pyo et al., 2020; Van Soest et al., 2022).

Early calf nutrition plays a vital role in establishing the foundation for future development (Soberon et al., 2012a). Lactocrine programming suggests that bioactive, non-nutritive components in milk are transferred from dams to their suckling offspring, impacting postnatal development and having lasting effects into adulthood (Bagnell and Bartol, 2019). Despite the immediate benefits mentioned, no long-term effects of transition milk feeding have been observed (Ostendorf et al., 2025). Therefore, further research is needed to assess the return on investment of transition calf feeding in terms of heifer health and future productivity.

Plane of nutrition

It has been well established that deficiencies in several nutrients (e.g., protein, energy, minerals) can impair immunity in calves. The immune response is usually restored when the deficiency is corrected. Conversely, supplementation in excess of the same nutrients does not always result in improved immune outcomes. For example, Holstein calves fed 50% of their maintenance requirements for energy and protein exhibited a decreased lymphocyte response to stimulation and reduced antibody production following vaccination (Griebel et al., 1987). These responses returned to normal once the deficit was corrected. In contrast, adaptive immune responses were minimally affected by growth rate in calves randomly assigned to dietary treatments aimed at achieving 0.0, 0.55, or 1.2 kg/day growth over an 8-week period (Foote et al., 2007). In addition, increased dietary protein and energy decreased the mitogen-induced proliferative responses of CD4+, CD8+, and γδTCR+ cells compared to those of the same cell populations from standard-fed calves and mature steers (Foote et al., 2005). These findings suggest that a standard milk replacer (i.e., 20% crude protein, 20% fat, 0.45 kg/day) provides sufficient nutrition to support normal immune cell function, and an oversupply of nutrients could have detrimental effects on the immune response. However, this study did not evaluate the extent to which these changes in immune cell function are associated with an increased susceptibility of the calf to infection.

Another study compared *ad libitum* milk replacer feeding with a more restricted feeding regime (2.5 L/2x/day for 21 days and 3 L/2x/day until 56 days), finding that calves fed *ad libitum* had greater odds of developing diarrhea and pneumonia (Curtis et al., 2018). However, in this study, the feeding regime was confounded by housing type (group in *ad libitum*-fed calves vs. individual in restricted housing), making it impossible to evaluate whether the differences in odds of disease are attributed to nutrition or housing.

Antioxidants (trace minerals and vitamins)

Oxidative stress **(OS)** during the preweaning stage can negatively impact host defense mechanisms and, therefore, contribute to the increased disease susceptibility observed during this phase. A few studies have indicated higher OS during the first few weeks of calves' life compared to later in life (Gaal et al., 2006; Abuelo et al., 2014). During these first weeks, calves exhibit higher pro-oxidant status than periparturient cows (Abuelo et al., 2014). Several factors are known to influence the oxidant status of newborn calves, which might contribute to their OS during the preweaning stage: (1) the OS status of the dam, as cows with greater OS give birth to calves with higher OS and less robust innate immune responses (Ling et al., 2018); (2) birth, as the initiation of breathing results in an increase in reactive oxygen species **(ROS)** production that induces a relatively long-lasting OS status (Saugstad, 2003); (3) colostrum intake, as it is a source of both pro- and anti-oxidants but with a more pro-oxidant profile than mature milk (Kankofer and Albera, 2008; Albera and Kankofer, 2011); (4) milk replacer feeding, as milk replacers have a low antioxidant capacity (Soberon et al., 2012b), and calves fed milk replacer show decreased antioxidant status during the first weeks of life (Abuelo et al., 2014), whereas calves fed whole milk show no temporal changes in antioxidant capacity (Ranade et al., 2014); (5) elevated average daily gain **(ADG)**, as the metabolic activity needed to support weaning growth goals > 0.7 kg/day (DCHA, 2020) likely results in increased ROS/reactive nitrogen species **(RNS)** production.

Calf immune responses are affected by OS in several ways. Our research has shown, *in vivo* and *in vitro*, how OS modulates immune responses toward the Th2 phenotype and its negative impact on critical lymphocyte functions, such as activation, antibody synthesis, and cytokine production (Cuervo et al., 2021). These affected functions are crucial for calves to fight infections and mount protective responses following immunization, contributing to the high disease susceptibility seen in these animals. Thus, it is unsurprising that OS is key in initiating and maintaining calf diseases, such as diarrhea or respiratory disease (Ranjan et al., 2006; Lykkesfeldt and Svendsen, 2007).

Antioxidant therapy via parenteral or dietary administration of vitamins and trace minerals is a routine management practice in many farms that increases the antioxidant potential of calves and reduces their OS risk. We recently reviewed the literature relative to antioxidant supplementation to dairy calves (Carlson and Abuelo, 2024; Kesler and Abuelo, 2024), concluding that antioxidant supplementation can improve calf immunity throughout the pre-and postweaning periods but with conflicting evidence on the effect on calf health and growth. For example, the parenteral administration of antioxidants at birth consistently improved redox balance and intranasal vaccine responsiveness (Nayak and Abuelo, 2021; Carlson et al., 2024); however, this enhanced immune response translated into lower morbidity in some studies (Teixeira et al., 2014; Bates et al., 2019) but not others (Carlson et al., 2024; Reid et al., 2025). The differences in the impact on health events observed in these studies are likely a reflection of other management practices (e.g., feeding regimes, housing, etc.) influencing the magnitude of the effect of supplementation. For example, in herds where heifers experience more OS, the same degree of supplementation will have greater beneficial effects than in herds where OS is less prevalent.

It is crucial to recognize that the NASEM (2021) nutritional requirements for antioxidant micronutrients are established to prevent deficiencies, and there are no explicit guidelines on levels of antioxidant supplementation for optimal immunity and health. Given that excessive antioxidant supplementation, as observed in adult cows, can likely negatively impact calf health and performance, it is essential to exercise caution when supplementing antioxidants beyond scientifically recommended safe levels. Indeed, there have been reports of toxicosis due to over-supplementation (MacDonald et al., 1981). This concern is particularly pertinent for antioxidants like Se, which can be transferred through the placenta.

Nutraceuticals

The term "nutraceutical" was introduced in 1976 but remains controversial (Aronson, 2017). A broadly accepted definition is *"a functional food that aids in preventing and treating disease(s) and/or disorders"* (Kalra, 2003). There are several nutraceuticals available in the market for use in calves. Here, we will review some of the major classes of nutraceuticals used in calf management in dairy farms.

Prebiotics and probiotics have been investigated for their potential to enhance gut health and reduce diarrhea in young calves. Additionally, the shift in calf diet from primarily milk to solid foods rich in rapidly fermentable carbohydrates presents an opportunity to utilize microbial-based products. This approach could help protect the developing rumen from harsh conditions and prevent health and growth issues during and after weaning. Probiotics are live strains of carefully chosen microorganisms that, when given in sufficient quantities, provide health benefits to the host, such as reducing the incidence of diarrhea (Markowiak and Śliżewska, 2017). These probiotics can include specific bacterial or fungal strains, microbial cultures, enzyme preparations, culture extracts, or combinations thereof (Yoon and Stern, 1995). Prebiotics are substrates selectively utilized by host microorganisms, providing health benefits to the host (Markowiak and Śliżewska, 2017). Unlike probiotics, prebiotics are non-living substrates that act as nutrients for beneficial microbes, such as lactic acid bacteria and *Bifidobacteria*. These prebiotics can help protect against pathogens and regulate the immune system (Gibson et al., 2017). Common examples of prebiotic supplements used in calves include fructooligosaccharides and galactooligosaccharides.

Some recent reviews evaluated the different trials conducted to date feeding pre- and probiotics to calves (Cangiano et al., 2020; Branco-Lopes et al., 2023). Notably, there was important variation in intervention design (i.e., mode of administration, dose, and duration of treatment) and outcomes measured to make substantial comparisons. However, the majority of responses in growth, feed efficiency, and health have either been nonsignificant or positive, with limited negative effects reported. Thus, pre- and probiotic supplementation to caves was deemed low risk with potentially positive benefits.

Saccharomyces cerevisiae fermentation products **(SCFP)** are postbiotic feed additives comprising functional metabolites and bioactive compounds created through a controlled fermentation process. Supplementing with SCFP has demonstrated improvements in the performance of both calves and adult cattle across various production environments and positive effects on immune function during periods of stress and illness (Brewer et al., 2014; Klopp et al., 2022). For example, supplementation with SCFP improved the outcome of a *Salmonella Typhimurium* challenge in preweaning calves (Brewer et al., 2014; Harris et al., 2017) by reducing clinical disease, including rectal temperatures. Holstein bull calves fed SCFP showed a reduced incidence of bovine respiratory disease **(BRD)** postweaning and the number of antibiotic treatment events, improved body weight and ADG postweaning (Klopp et al., 2022). Neonatal calves supplemented with SCFP developed less severe clinical disease and lung pathology compared with control calves following an experimental bovine respiratory syncytial virus **(BRSV)** infection (Mahmoud et al., 2020) and a BRSV-*Pasterurella multocida* co-infection (McDonald et al., 2021). Circulating immune cells from SCFP-treated calves had an increased capacity to secrete the proinflammatory cytokines tumor necrosis factor α, IL-1β, and IL-6 in response to toll-like receptor stimulation (Maina et al., 2024). These findings suggest that SCFP feeding could influence controlled inflammation and increase resistance to bovine respiratory disease.

It is important to remember that nutraceuticals, as dietary supplements, do not require efficacy studies for commercialization, unlike drugs or vaccines. Thus, consultants and producers should always request manufacturers the efficacy results from studies using their products. The composition of nutraceutical products can vary greatly, and even if they belong to a similar class to a tested product, there is no guarantee that the effects would be similar without evidence.

Conclusions

A high prevalence of calf diseases continues to burden dairy farm profitability. Calves are born with a fully equipped but naïve immune system that requires maturation, making them vulnerable to infectious diseases during the first weeks of life. Adequate nutrition is essential for supporting the maturation of the calves' immune system, as several strategies have been proven to enhance both innate and adaptive immune responses in calves. However, although improvements in immune responses have been consistently observed in studies, these have only occasionally translated into benefits in terms of disease incidence or calf growth. This highlights the complex interactions between nutrition, the immune system, other management practices, and infectious agents that must be considered when managing dairy calves.

References

Abuelo, A., F. Cullens, and J. L. Brester. 2021. Effect of preweaning disease on the reproductive performance and first-lactation milk production of heifers in a large dairy herd. J. Dairy Sci. 104(6):7008-7017. http://doi.org/10.3168/jds.2020-19791

Abuelo, A., P. Havrlant, N. Wood, and M. Hernandez-Jover. 2019. An investigation of dairy calf management practices, colostrum quality, failure of transfer of passive immunity, and occurrence of enteropathogens among Australian dairy farms. J. Dairy Sci. 102(9):8352-8366. http://doi.org/10.3168/jds.2019-16578

Abuelo, A., M. Perez-Santos, J. Hernandez, and C. Castillo. 2014. Effect of colostrum redox balance on the oxidative status of calves during the first 3 months of life and the relationship with passive immune acquisition. Vet. J. 199(2):295-299. http://doi.org/10.1016/j.tvjl.2013.10.032

Albera, E. and M. Kankofer. 2011. The comparison of antioxidative/oxidative profile in blood, colostrum and milk of early post-partum cows and their newborns. Reprod. Domest. Anim. 46(5):763-769. http://doi.org/10.1111/j.1439-0531.2010.01737.x

Alharthi, A.S.M., F. Batistel, C. Parys, A. Helmbrecht, and J. Loor. 2017. Maternal rumen-protected methionine supplementation during late-pregnancy affects calf development and growth during early postnatal life. FASEB Journal 31(1_supplement):lb293-lb293. http://doi.org/10.1096/fasebj.31.1_supplement.lb293

Aronson, J.K. 2017. Defining 'nutraceuticals': Neither nutritious nor pharmaceutical. Br. J. Clin. Pharmacol. 83(1):8-19. http://doi.org/10.1111/bcp.12935

Bach, A. 2011. Associations between several aspects of heifer development and dairy cow survivability to second lactation. J. Dairy Sci. 94(2):1052-1057. http://doi.org/10.3168/jds.2010-3633

Bagnell, C.A. and F.F. Bartol. 2019. Relaxin and the 'Milky Way': The lactocrine hypothesis and maternal programming of development. Molecular and Cellular Endocrinology 487:18-23. http://doi.org/https://doi.org/10.1016/j.mce.2019.01.003

Barrington, G.M,. and S.M. Parish. 2001. Bovine neonatal immunology. Vet. Clin. North Am. Food Anim Pract. 17(3):463-476. http://doi.org/10.1016/s0749-0720(15)30001-3

Bates, A., M. Wells, R.A. Laven, and M. Simpson. 2019. Reduction in morbidity and mortality of dairy calves from an injectable trace mineral supplement. Vet. Rec. 184(22):680. http://doi.org/10.1136/vr.105082

Beisel, W.R. 1996. Nutrition in pediatric HIV infection: Setting the research agenda. Nutrition and immune function: Overview. J. Nutr. 126(10 Suppl):2611s-2615s. http://doi.org/10.1093/jn/126.suppl_10.2611S

Branco-Lopes, R., C. Bernal-Córdoba, A. Valldecabres, C. Winder, M.E. Canozzi, and N. Silva-Del-Río. 2023. Characterization of controlled trials on probiotic supplementation to dairy calves: A scoping review. J. Dairy Sci. 106(8):5388-5401. http://doi.org/10.3168/jds.2022-23017

Brewer, M.T., K.L. Anderson, I. Yoon, M.F. Scott, and S.A. Carlson. 2014. Amelioration of salmonellosis in pre-weaned dairy calves fed *Saccharomyces cerevisiae* fermentation products in feed and milk replacer. Veterinary Microbiology 172(1):248-255. http://doi.org/https://doi.org/10.1016/j.vetmic.2014.05.026

Brickell, J.S. and D.C. Wathes. 2011. A descriptive study of the survival of Holstein-Friesian heifers through to third calving on English dairy farms. J. Dairy Sci. 94(4):1831-1838. http://doi.org/10.3168/jds.2010-3710

Calder, P.C. 2013. Feeding the immune system. Proc. Nutr. Soc. 72(3):299-309. http://doi.org/10.1017/s0029665113001286

Cangiano, L.R., T.T. Yohe, M.A. Steele, and D. L. Renaud. 2020. Invited Review: Strategic use of microbial-based probiotics and prebiotics in dairy calf rearing. Applied Animal Science 36(5):630-651. http://doi.org/10.15232/aas.2020-02049

Carlson, H. and A. Abuelo. 2024. Graduate Student Literature Review: Role of antioxidants in calf immunity, growth, and health. J. Dairy Sci. 107(7):4844-4854. http://doi.org/10.3168/jds.2023-23988

Carlson, H., F. . Cullens-Nobis, E. . Owczarzak, and A. Abuelo. 2024. Effect of parenteral micronutrient supplementation at birth on immunity, growth, and health in preweaning dairy heifers. J. Dairy Sci. 107(7):4926-4941. http://doi.org/10.3168/jds.2023-24292

Chase, C.C., D.J. Hurley, and A.J. Reber. 2008. Neonatal immune development in the calf and its impact on vaccine response. Vet. Clin. North Am. Food Anim. Pract. 24(1):87-104. http://doi.org/10.1016/j.cvfa.2007.11.001

Conneely, M., D.P. Berry, J.P. Murphy, I. Lorenz, M.L. Doherty, and E. Kennedy. 2014. Effect of feeding colostrum at different volumes and subsequent number of transition milk feeds on the serum immunoglobulin G concentration and health status of dairy calves. J. Dairy Sci. 97(11):6991-7000. http://doi.org/10.3168/jds.2013-7494

Cortese, V.S. 2009. Neonatal immunology. Vet. Clin. North Am. Food Anim. Pract. 25(1):221-227. http://doi.org/10.1016/j.cvfa.2008.10.003

Cuervo, W., L.M. Sordillo, and A. Abuelo. 2021. Oxidative stress compromises lymphocyte function in neonatal dairy calves. Antioxidants (Basel) 10(2):255. http://doi.org/10.3390/antiox10020255

Curtis, G., C. McGregor Argo, D. Jones, and D. Grove-White. 2018. The impact of early life nutrition and housing on growth and reproduction in dairy cattle. PLoS One 13(2):e0191687. http://doi.org/10.1371/journal.pone.0191687

Dahl, G.E., S. Tao, and A.P.A. Monteiro. 2016. Effects of late-gestation heat stress on immunity and performance of calves. J. Dairy Sci. 99(4):3193-3198. http://doi.org/10.3168/jds.2015-9990

DCHA, Dairy Calf and Heifer Association. 2020. Dairy Calf and Heifer Association Gold Standards. https://calfandheifer.org/wp-content/uploads/2020/09/DCHA_GoldStandards_2020_En_WEB-final.pdf. Accessed on: 04/01/2025

Donovan, G.A., I.R. Dohoo, D.M. Montgomery, and F.L. Bennett. 1998. Calf and disease factors affecting growth in female Holstein calves in Florida, USA. Prev. Vet. Med. 33(1-4):1-10. http://doi.org/10.1016/s0167-5877(97)00059-7

Fahey, M.J., A.J. Fischer, M.A. Steele, and S.L. Greenwood. 2020. Characterization of the colostrum and transition milk proteomes from primiparous and multiparous Holstein dairy cows. J. Dairy Sci. 103(2):1993-2005. http://doi.org/10.3168/jds.2019-17094

Fischer-Tlustos, A.J., K. Hertogs, J.K. van Niekerk, M. Nagorske, D.M. Haines, and M.A. Steele. 2020. Oligosaccharide concentrations in colostrum, transition milk, and mature milk of primi- and multiparous Holstein cows during the first week of lactation. J. Dairy Sci. 103(4):3683-3695. http://doi.org/10.3168/jds.2019-17357

Foote, M.R., B.J. Nonnecke, D.C. Beitz, and W.R. Waters. 2007. High growth rate fails to enhance adaptive immune responses of neonatal calves and is associated with reduced lymphocyte viability. J. Dairy Sci. 90(1):404-417. http://doi.org/10.3168/jds.S0022-0302(07)72641-3

Foote, M.R., B.J. Nonnecke, M.A. Fowler, B.L. Miller, D.C. Beitz, and W.R. Waters. 2005. Effects of age and nutrition on expression of CD25, CD44, and L-selectin (CD62L) on T-cells from neonatal calves. J. Dairy Sci. 88(8):2718-2729. http://doi.org/10.3168/jds.S0022-0302(05)72951-9

Gaal, T., P. Ribiczeyne-Szabo, K. Stadler, J. Jakus, J. Reiczigel, P. Kover, M. Mezes, and L. Sumeghy. 2006. Free radicals, lipid peroxidation and the antioxidant system in the blood of cows and newborn calves around calving. Comp. Biochem. Physiol. B. Biochem. Mol. Biol. 143(4):391-396. http://doi.org/10.1016/j.cbpb.2005.12.014

Gibson, G.R., R. Hutkins, M.E. Sanders, S.L. Prescott, R.A. Reimer, S.J. Salminen, K. Scott, C. Stanton, K.S. Swanson, P.D. Cani, K. Verbeke, and G. Reid. 2017. Expert consensus document: The International Scientific Association for Probiotics and Prebiotics (ISAPP) consensus statement on the definition and scope of prebiotics. Nat. Rev. Gastroenterol. Hepatol. 14(8):491-502. http://doi.org/10.1038/nrgastro.2017.75

Godden, S. 2008. Colostrum management for dairy calves. Vet. Clin. North Am. Food Anim. Pract. 24(1):19-39. http://doi.org/10.1016/j.cvfa.2007.10.005

Griebel, P.J., M. Schoonderwoerd, and L.A. Babiuk. 1987. Ontogeny of the immune response: Effect of protein energy malnutrition in neonatal calves. Can. J. Vet. Res. 51(4):428-435.

Guo, J.R., A.P.A. Monteiro, X.S. Weng, B.M. Ahmed, J. Laporta, M.J. Hayen, G.E. Dahl, J.K. Bernard, and S. Tao. 2016. Short communication: Effect of maternal heat stress in late gestation on blood hormones and metabolites of newborn calves. J. Dairy Sci. 99(8):6804-6807. http://doi.org/10.3168/jds.2016-11088

Harris, T.L., Y. Liang, K.P. Sharon, M.D. Sellers, I. Yoon, M.F. Scott, J.A. Carroll, and M.A. Ballou. 2017. Influence of Saccharomyces cerevisiae fermentation products, SmartCare in milk replacer and Original XPC in calf starter, on the performance and health of preweaned Holstein calves challenged with Salmonella enterica serotype Typhimurium. J.Dairy Sci. 100(9):7154-7164. http://doi.org/https://doi.org/10.3168/jds.2016-12509

Heinrichs, A.J. 1993. Raising dairy replacements to meet the needs of the 21st century. J. Dairy Sci .76(10):3179-3187. http://doi.org/10.3168/jds.S0022-0302(93)77656-0

Inabu, Y., J. Pyo, S. Pletts, L.L. Guan, M.A. Steele, and T. Sugino. 2019. Effect of extended colostrum feeding on plasma glucagon-like peptide-1 concentration in newborn calves. J. Dairy Sci. 102(5):4619-4627. http://doi.org/10.3168/jds.2018-15616

Jacometo, C.B., Z. Zhou, D. Luchini, E. Trevisi, M.N. Correa, and J.J. Loor. 2016. Maternal rumen-protected methionine supplementation and its effect on blood and liver biomarkers of energy metabolism, inflammation, and oxidative stress in neonatal Holstein calves. J. Dairy Sci. 99(8):6753-6763. http://doi.org/10.3168/jds.2016-11018

Kalra, E.K. 2003. Nutraceutical--definition and introduction. AAPS Pharm. Sci. 5(3):E25. http://doi.org/10.1208/ps050325

Kankofer, M. and E. Albera. 2008. Postpartum relationship of beta carotene and vitamin A between placenta, blood and colostrum in cows and their newborns. Exp. Clin. Endocrinol. Diabetes 116(7):409-412.

Kargar, S., M. Bahadori-Moghaddam, S.M. Ghoreishi, A. Akhlaghi, M. Kanani, A. Pazoki, and M.H. Ghaffari. 2021. Extended transition milk feeding for 3 weeks improves growth performance and reduces the susceptibility to diarrhea in newborn female Holstein calves. Animal 15(3):100151. http://doi.org/10.1016/j.animal.2020.100151

Kesler, K.W. and A. Abuelo. 2024. Zinc about it - zinc and calf immunity. Front. Immunol. 15:1387950. http://doi.org/10.3389/fimmu.2024.1387950

Klopp, R.N., R.E. Centeno-Martinez, I. Yoon, T.A. Johnson, and J.P. Boerman. 2022. Effects of feeding Saccharomyces cerevisiae fermentation products on the health and growth performance of Holstein dairy calves. JDS Communications 3(3):174-179. http://doi.org/https://doi.org/10.3168/jdsc.2021-0172

Ling, T., M. Hernandez-Jover, L.M. Sordillo, and A. Abuelo. 2018. Maternal late-gestation metabolic stress is associated with changes in immune and metabolic responses of dairy calves. J. Dairy Sci. 101(7):6568-6580. http://doi.org/10.3168/jds.2017-14038

Lykkesfeldt, J. and O. Svendsen. 2007. Oxidants and antioxidants in disease: Oxidative stress in farm animals. Vet. J. 173(3):502-511. http://doi.org/10.1016/j.tvjl.2006.06.005

MacDonald, D.W., R.G. Christian, K I. Strausz, and J. Roff. 1981. Acute selenium toxicity in neonatal calves. Can. Vet. J. 22(9):279-281.

Mahmoud, A.H.A., J.R. Slate, S. Hong, I. Yoon, and J.L. McGill. 2020. Supplementing a Saccharomyces cerevisiae fermentation product modulates innate immune function and ameliorates bovine respiratory syncytial virus infection in neonatal calves. J. Anim. Sci. 98(8). http://doi.org/10.1093/jas/skaa252

Maina, T.W., P.O. McDonald, B.E. Rani Samuel, M.I. Sardi, I. Yoon, A. Rogers, and J.L. McGill. 2024. Feeding Saccharomyces cerevisiae fermentation postbiotic products alters immune function and the lung transcriptome of preweaning calves with an experimental viral-bacterial coinfection. J. Dairy Sci. 107(4):2253-2267. http://doi.org/https://doi.org/10.3168/jds.2023-23866

Markowiak, P. and K. Śliżewska. 2017. Effects of probiotics, prebiotics, and synbiotics on human health. Nutrients 9(9). http://doi.org/10.3390/nu9091021

McDonald, P.O., C. Schill, T.W. Maina, B. Samuel, M. Porter, I. Yoon, and J.L. McGill. 2021. Feeding Saccharomyces cerevisiae fermentation products lessens the severity of a viral–bacterial coinfection in preweaned calves. J. Anim. Sci. 99(11). http://doi.org/10.1093/jas/skab300

Mee, J.F. 2013. Why do so many calves die on modern dairy farms and what can we do about calf welfare in the future? Animals (Basel) 3(4):1036-1057. http://doi.org/10.3390/ani3041036

Moallem, U., D. Werner, H. Lehrer, M. Zachut, L. Livshitz, S. Yakoby, and A. Shamay. 2010. Long-term effects of ad libitum whole milk prior to weaning and prepubertal protein supplementation on skeletal growth rate and first-lactation milk production. J. Dairy Sci. 93(6):2639-2650. http://doi.org/10.3168/jds.2009-3007

Monteiro, A.P.A., J.R. Guo, X.S. Weng, B.M. Ahmed, M.J. Hayen, G.E. Dahl, J.K. Bernard, and S. Tao. 2016a. Effect of maternal heat stress during the dry period on growth and metabolism of calves. J. Dairy Sci. 99(5):3896-3907. http://doi.org/10.3168/jds.2015-10699

Monteiro, A.P.A., S. Tao, I.M.T. Thompson, and G.E. Dahl. 2016b. In utero heat stress decreases calf survival and performance through the first lactation. J. Dairy Sci. 99(10):8443-8450. http://doi.org/10.3168/jds.2016-11072

Monteiro, A.P., S. Tao, I.M. Thompson, and G.E. Dahl. 2014. Effect of heat stress during late gestation on immune function and growth performance of calves: Isolation of altered colostral and calf factors. J. Dairy Sci. 97(10):6426-6439. http://doi.org/10.3168/jds.2013-7891

NAHMS, National Animal Health Monitoring Service. 2014. Dairy 2014. Part 1: Reference of Dairy Health and Management in the United States. https://www.aphis.usda.gov/animal_health/nahms/dairy/downloads/dairy14/Dairy14_dr_PartI.pdf. Accessed on: 04/03/2025

NASEM, National Academies of Sciences, Engineering, Medicine. 2021. Nutrient Requirements of Dairy Cattle. The National Academies Press, Washington, DC.

Nayak, A. and A. Abuelo. 2021. Parenteral antioxidant supplementation at birth improves the response to intranasal vaccination in newborn dairy calves. Antioxidants (Basel) 10(12):1979. http://doi.org/10.3390/antiox10121979

Ostendorf, C.S., M.H. Ghaffari, I. Cohrs, C. Koch, and H. Sauerwein. 2025. Long-term effects of transition milk feeding on feed intake, growth performance, feeding behavior, and oxidative status of Holstein calves. J. Dairy Sci. 108(1):464-484. http://doi.org/10.3168/jds.2024-25435

Pyo, J., K. Hare, S. Pletts, Y. Inabu, D. Haines, T. Sugino, L.L. Guan, and M. Steele. 2020. Feeding colostrum or a 1:1 colostrum:milk mixture for 3 days postnatal increases small intestinal development and minimally influences plasma glucagon-like peptide-2 and serum insulin-like growth factor-1 concentrations in Holstein bull calves. J. Dairy Sci. 103(5):4236-4251. http://doi.org/10.3168/jds.2019-1721

Ranade, R., S. Talukder, G. Muscatello, and P. Celi. 2014. Assessment of oxidative stress biomarkers in exhaled breath condensate and blood of dairy heifer calves from birth to weaning. Vet. J. 202(3):583-587. http://doi.org/10.1016/j.tvjl.2014.10.025

Ranjan, R., R. Naresh, R.C. Patra, and D. Swarup. 2006. Erythrocyte lipid peroxides and blood zinc and copper concentrations in acute undifferentiated diarrhoea in calves. Vet. Res. Commun. 30(3):249-254. http://doi.org/10.1007/s11259-006-3185-8

Reber, A.J., A. Lockwood, A.R. Hippen, and D.J. Hurley. 2006. Colostrum induced phenotypic and trafficking changes in maternal mononuclear cells in a peripheral blood leukocyte model for study of leukocyte transfer to the neonatal calf. Vet. Immunol. Immunopathol. 109(1):139-150. http://doi.org/https://doi.org/10.1016/j.vetimm.2005.08.014

Reid, A., H. Carlson, N. Prichard, F. Cullens-Nobis, and A. Abuelo. 2025. Effect of antioxidant supplementation on health and growth of pre-weaned dairy calves in a multi-herd study. Page 64 in Proc. Conference of Research Workers on Animal Diseases, Chicago, IL.

Saugstad, O.D. 2003. Oxygen toxicity at birth: The pieces are put together. Pediatric Research 54(6):789-789. http://doi.org/10.1203/01.Pdr.0000103390.01854.0e

Soberon, M.A., R.H. Liu, and D.J. Cherney. 2012b. Short communication: Antioxidant activity of calf milk replacers. J. Dairy Sci. 95(5):2703-2706. http://doi.org/10.3168/jds.2011-5099

Soberon, F., E. Raffrenato, R.W. Everett, and M.E. Van Amburgh. 2012a. Preweaning milk replacer intake and effects on long-term productivity of dairy calves. J. Dairy Sci. 95(2):783-793. http://doi.org/10.3168/jds.2011-4391

Soberon, F. and M.E. Van Amburgh. 2013. Lactation Biology Symposium: The effect of nutrient intake from milk or milk replacer of preweaned dairy calves on lactation milk yield as adults: a meta-analysis of current data. J. Anim Sci. 91(2):706-712. http://doi.org/10.2527/jas.2012-5834

Tao, S. and G.E. Dahl. 2013. Invited review: Heat stress effects during late gestation on dry cows and their calves. J. Dairy Sci. 96(7):4079-4093. http://doi.org/10.3168/jds.2012-6278

Tao, S., A.P. Monteiro, M.J. Hayen, and G.E. Dahl. 2014. Short communication: Maternal heat stress during the dry period alters postnatal whole-body insulin response of calves. J. Dairy Sci. 97(2):897-901. http://doi.org/10.3168/jds.2013-7323

Teixeira, A.G., F.S. Lima, M.L. Bicalho, A. Kussler, S.F. Lima, M.J. Felippe, and R.C. Bicalho. 2014. Effect of an injectable trace mineral supplement containing selenium, copper, zinc, and manganese on immunity, health, and growth of dairy calves. J. Dairy Sci. 97(7):4216-4226. http://doi.org/10.3168/jds.2013-7625

Teixeira, A.G., J.A. McArt, and R.C. Bicalho. 2017. Efficacy of tildipirosin metaphylaxis for the prevention of respiratory disease, otitis and mortality in pre-weaned Holstein calves. Vet. J. 219:44-48. http://doi.org/10.1016/j.tvjl.2016.12.004

Urie, N.J., J.E. Lombard, C.B. Shivley, C.A. Kopral, A.E. Adams, T.J. Earleywine, J.D. Olson, and F.B. Garry. 2018. Preweaned heifer management on US dairy operations: Part V. Factors associated with morbidity and mortality in preweaned dairy heifer calves. J. Dairy Sci. 101(10):9229-9244. http://doi.org/10.3168/jds.2017-14019

Van Soest, B., F. Cullens, M.J. VandeHaar, and M.W. Nielsen. 2020. Short communication: Effects of transition milk and milk replacer supplemented with colostrum replacer on growth and health of dairy calves. J. Dairy Sci. 103(12):12104-12108. http://doi.org/10.3168/jds.2020-18361

Van Soest, B., M. Weber Nielsen, A.J. Moeser, A. Abuelo, and M.J. VandeHaar. 2022. Transition milk stimulates intestinal development of neonatal Holstein calves. J. Dairy Sci. 105(8):7011-7022. http://doi.org/10.3168/jds.2021-21723

Windeyer, M.C., K.E. Leslie, S.M. Godden, D.C. Hodgins, K.D. Lissemore, and S.J. LeBlanc. 2014. Factors associated with morbidity, mortality, and growth of dairy heifer calves up to 3 months of age. Prev. Vet. Med. 113(2):231-240. http://doi.org/10.1016/j.prevetmed.2013.10.019

Yoon, I.K. and M.D. Stern. 1995. Influence of direct-fed microbials on ruminal microbial fermentation and performance of ruminants - A review. Asian-Australasian Journal of Animal Sciences 8(6):533-555. http://doi.org/10.5713/ajas.1995.553

Zolova, A., D. Keidāne, and M. Zolovs. 2022. Prevalence of susceptibility to Cryptosporidium spp. among dairy calves with different feeding regimens with an emphasis on the feeding of transition milk. Vet. World 15(5):1256-1260. http://doi.org/10.14202/vetworld.2022.1256-1260