Approaches to Enhancing the Gastrointestinal Health of Calves

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Abstract

The gastrointestinal tract (GIT), as the largest immunological organ of the body, plays a pivotal role in calf health, growth, and long-term productivity. Important contributors to optimal gastrointestinal function of calves include colostrum status, a balanced intestinal flora, nutrition, intestinal immune factors, motility, and transport of nutrients. The promotion of GIT health of young calves through dietary manipulations, nutritional supplements, addition of immune components, oral antibiotics, and vaccinations are discussed. Antibiotic alternatives to improve growth and reduce enteric disease are plasma proteins, immunoglobulins, probiotic bacteria, yeast cultures, and oligosaccharides. To ascertain health, growth, and profitability from measures taken to improve intestinal immune function, outcome measurements, intestinal health parameters, and dietary composition should be monitored closely.

Résumé

Le tractus gastro-intestinal, en tant que plus grand organe immunologique du corps, joue chez les veaux un rôle clé au niveau de la santé, de la croissance et de la productivité à long terme. Le statut du colostrum, une flore intestinale équilibrée, la nutrition, les facteurs immunitaires intestinaux, la motilité et le transport des aliments sont autant de facteurs qui contribuent à l'optimisation de la fonction gastro-intestinale chez les veaux. On discute ici de la promotion de la santé du système gastro-intestinal chez les jeunes veaux par la manipulation du régime alimentaire, les suppléments alimentaires, l'ajout de composantes immunitaires, les antibiotiques oraux et la vaccination. Pour améliorer la croissance et réduire les maladies entériques, les protéines plasmiques, les immunoglobulines, les bactéries probiotiques, les cultures de levures et les oligosaccharides sont des alternatives aux antibiotiques. Afin d'évaluer la santé, la croissance et la profitabilité qui découlent des mesures prises pour améliorer la fonction immunitaire intestinale, il faut surveiller attentivement les résultats médicaux, les paramètres de santé intestinale et la composition du régime.

Introduction

The gastrointestinal tract (GIT), as the largest immunological organ of the body, plays a pivotal role in calf health, growth, and long-term productivity. While delivering, transporting and absorbing nutrients, secreting ions and immunoglobulins, and discriminating amongst enteropathogens, harmless intestinal flora, and food antigens, the GIT also maintains an epithelial barrier that is the first line of defense against the infectious diseases common to calves. Synergism between the mucosal surface of the GIT and the intestinal lumen is required for optimal function. The intestinal epithelial cells (IEC) separate the lumen from the gut-associated lymphoid tissue (GALT), creating both an intrinsic physical and extrinsic secretory barrier. GALT has functional inductive and effector compartments that deliver innate and adaptive immune responses. The induction of an immune response in Peyer's patches with production of IgA by B-lymphocytes in the lamina propria is characteristic of GALT immunity. There is good evidence to support the presence of an immunologic communication between the GIT and mucosal surfaces throughout the body via a common mucosal immunity,[30] thus validating the clinical perception that the calf with diarrhea is at much higher risk for development of respiratory disease. The importance of intestinal health in the young calf cannot be understated. Chronic inflammation, diarrhea, ill thrift, and decreased growth are some of the consequences of digestive tract dysfunction.

Components of Gastrointestinal Health

Important contributors to optimal gastrointestinal function of calves include colostrum status, a balanced intestinal flora, nutrition, intestinal immune factors, motility, and transport of nutrients. The formation, delivery, and absorption of adequate colostrum continue to be a major challenge. Variability in the IgG concentration of colostrum, the potential for pathogenic bacterial contamination, and a paucity of accurate cow-side tests for colostrum quality and calf immune status are just a few of the obstacles. At birth, the gastrointestinal tract of calves is relatively mature but still requires morphologic and functional changes. Colostrum, with its nutrient and non-nutrient components, has a profound effect on the functional development of the GIT. Immunoglobulins are usually the focus of colostrum's immunologic importance to calves, but the short and long-term benefits of the non-nutrient components of colostrum are often overlooked. The non-nutrient factors modulate the microbial population and the functional capacity of the GIT, including epithelial cell proliferation, migration, differentiation, and apoptosis; protein synthesis and degradation; digestion, absorption, and motility; and immune system development and function.[11] Outside of the GIT, colostral components affect metabolism, endocrine system development, vascular tone and hemostasis, systemic growth, activity, and behavior.[11]

At the time of birth, the gastrointestinal tract (GIT) of the calf is sterile but microbes are introduced from the fecal and vaginal flora during delivery, from the environment immediately after delivery, and from ingestion of colostrum. Once colonized, the GIT flora remains relatively stable and a balanced flora of as many as 400 species of bacteria and 10^{14} microbes serves an important protective function against infection. Temporary modifications in the GIT flora that can occur with stress or antibiotic administration is thought to put animals at risk for enteric infection.

Nutrition is a critical component of calf health, growth, immunity, and future milk production. After feeding colostrum, the calf must rely on dietary intake to supply calories from protein, carbohydrates, and fat that are required for maintenance, growth, generation of body heat, and immune system function. Key aspects of dairy calf nutrition are the composition and amount of liquid feeds, the starter feed offered, and availability of water. Current concepts relative to feeding dairy calves have changed and are appropriately focused on targeted growth with feed components and delivery systems that promote welfare, performance, and future production. For a more complete discussion of dairy calf nutrition, readers are referred to a recent review.[16] Feeding dairy calves liquid feed in an amount and composition that more closely mimics natural conditions is termed accelerated growth, intensified nutrition or biologically appropriate growth. Using this approach, milk feeding rates are almost double the traditional feeding rates, giving calves 1.5% of body weight as milk solids during the first week of life, followed by 2% of body weight from week 2 until the week before weaning, when one liquid feeding per day is dropped. Compared to conventional milk replacer feeding programs, accelerated milk replacer feeding programs can deliver improved expected growth rates of 1.3 to 1.8 lb (0.59 to 0.82 kg)/day, compared to 1.1 to 1.3 lb (0.5 to 0.59 kg)/day for conventionally fed calves from day 0 to 42.[16]

The protein and energy requirements of young calves must be met for optimal immune function. In the first two weeks of life, conventional milk replacer diets of young dairy calves are very likely to be protein and energy limited, particularly in cold weather. Add the caloric demand of an inflammatory response from disease or vaccination, and the energy and protein deficits of young calves are potentially life threatening. Feed refusal due to illness may have a profoundly negative impact on the intestinal barrier designed to protect the host from invasion by intraluminal bacteria and toxic products.[30] Increasing the volume of milk fed, increasing the milk solids provided at each milk feeding, increasing the crude protein level of the milk replacer or providing additional fat to milk replacer may improve feed efficiency, growth, and health of young calves.[6,10,14,22,38]

Abomasal emptying rate and intestinal motility have an important effect on nutrient delivery and subsequent absorption. Abomasal emptying is influenced by the volume and caloric content of an ingested meal, type of protein or fat, osmolarity, and duodenal pH.[4,45] The optimal abomasal emptying rate for calves is not known, but hypertonic solutions from carbohydrates or electrolytes may delay emptying when osmolality is above 500 mOsm/L.[39,45] Delayed emptying may be beneficial for slower, more sustained delivery of larger nutrient load to absorptive sites in the small intestine. Cow's milk is isotonic when secreted, but increases with digestion of milk protein and lactose in the small intestine. Mucosal and intestinal luminal contents are hyperosmotic compared to body fluids, and hyperosmolar gradients appear to be a normal and beneficial part of absorption. Increased dry matter in the calf diet decreased diarrhea, a mechanism attributed to increased osmolality and decreased gastric emptying.[48]

Promotion and Manipulation of Intestinal Health

The promotion of GIT health through dietary manipulations, nutritional supplements, addition of immune components, antibiotics, and vaccinations has been studied in calves.

Supplementation with prebiotics, probiotics or a combination known as synbiotics may offer an alternative to antibiotic use in calves as their proliferative effect on beneficial intestinal bacteria may result in improved weight gain, enhanced immune function, and a reduced population of pathogenic bacteria. Prebiotics are naturally occurring and readily available, non-digestible carbohydrates. They are not hydrolyzed by acidic pH nor are they absorbed in the upper GIT. Prebiotic supplementation has been associated with increased immunoglobulin levels in serum and the intestinal lumen in some animal and human studies[24,53] but consistency in calf studies has not been present.[21] Probiotics are live microorganisms that exert health benefits beyond general nutrition when administered orally. Viability of the probiotic organisms is essential for efficacy and requires that they be resistant to acid and bile, have strong adhesive properties to mucosal cells, suppress bacterial enzyme activity, and/or produce antimicrobial substances. While cross species colonization has been demonstrated for some probiotic organisms, it is generally considered most beneficial when a probiotic has been isolated from the target species. In calves, *Lactobacillus*, *Bifidobacterium*, and *Enterococcus* spp bacteria appear to be most effective, with proliferation of beneficial intestinal bacteria, improved weight gain, feed efficiency, immune function, decreased intestinal pathogen shedding, and improved fecal score as the potential benefits.[1,15,20,37,50,56] Not all probiotic trials have demonstrated significant growth or health benefits,[19,35] but no harmful results are reported. Probiotic organisms like *Lactobacillus* spp may produce L-lactate but formation of D-lactate, which is poorly metabolized, may have detrimental effects on calves with diarrhea.[17] Prebiotic, probiotic or synbiotic products are generally low cost, pose minimal potential for doing harm and, when used in calves exposed to enteropathogens but not yet affected or receiving antibiotics, fed to calves that have completed a course of antibiotic therapy or given to calves recovering from diarrhea, there is potential to improve intestinal health.

Yeast and yeast cell wall products are also given strong consideration as alternatives to antibiotics in calf milk replacer and other calf feeds. Potential benefits to calves are improved growth of beneficial intestinal bacterial flora, increased volatile fatty acid concentration, energy balance, intestinal structure and function changes, agglutination of gram-negative intestinal pathogens, and stimulation of antibody production. When yeast cells are lysed and centrifuged to isolate cell wall components, mannans on the cell surface of yeast cells are the primary antigenic components. Mannan oligosaccharides (MOS) contain cell wall fragments obtained from *Saccharomyces cerevisiae.* Because many gram-negative bacteria attach to the intestinal epithelium using mannose-specific fimbriae, MOS can competitively bind selective pathogens like *Escherichia coli* and *Salmonella*.[41,47] Without being digested or absorbed, MOS-bound pathogens are excreted. In calf studies, fructooligosaccharide (FOS) or MOS inclusion in the diet has improved fecal scores, starter intake, intestinal morphology, immune function, and disease incidence.[20,36,40,41,49] Beta-glucans are major structural components of yeast cell wall, fungi and some cereals such as barley and oats and, when added to the diet of calves, may improve health or growth.[12,18,31,32] Effectiveness may vary with the delivery formulation, feed type for delivery, immune status of the calf, and the enteric challenge model tested.

Oral neomycin and tetracycline, widely used for feed efficiency and prevention of bacterial enteritis in calves fed milk replacer, are also linked to malabsorption syndromes in people and other animals and do not stimulate or support GIT immune function. The presumed mechanism for antibiotic diarrhea by alteration of intestinal flora is not substantiated, though the eaffect is proportional to the systemic and local (intestinal luminal) antibiotic concentration. In addition to the effect on bacterial cells, antibiotics affect enterocyte mitotic activity. Impaired enterocyte turnover and maturation alters morphology and absorptive surface, thereby being a potential mechanism for diarrhea.[33] The continuous feeding of a 2:1 neomycin-oxytetracycline ratio (mg/gallon or gm/ton) in calf milk replacers to aid in the prevention or treatment of bacterial enteritis is no longer permissible. A 1:1 neomycin-oxytetracycline ratio (mg/lb of body weight) can be used for two different indications: 1) 0.05-0.10 mg/lb (0.11-0.22 mg/kg) body weight for increased weight gain and improved feed efficiency fed continuously or; 2) 10 mg/lb (22 mg/kg) body weight for treatment of scours caused by *E. coli* and bacterial pneumonia fed for seven to 14 continuous days.

Optimal nutrition is a pivotal component of intestinal health and the performance of calves. Some amino acids are considered essential and studies indicate that their inclusion in the diet of calves is beneficial, while others like arginine may only be useful under conditions of deficiency. Dietary components with purported beneficial immunonodulatory effects are vitamins, minerals, fatty acids, proteins, and individual amino acids.[5] The addition of lysine, methionine, and glutamine to the diet of calves has been beneficial,[23,44] but other *in vitro* and *in vivo* studies that show activation of lymphocytes, macrophages, cytokines, and γ-interferon require more comprehensive field trials before supplementation is widely endorsed. Medium-chain triglycerides added to the milk of calves at two different levels reduced coccidial oocyst shedding. Lactoferrin and essential oils have also been fed in milk replacer to reduce growth of bacteria and viruses, but need more calf studies before commercial use is recommended.

Acidification of milk or milk replacers to a pH < 5.5 was originally introduced as a means of preserving cold milk in an ad libitum milk feeding program. Citric, formic, and proprionic acids are most commonly used for this purpose, and a systematic set up has recently been described.[2] Other benefits attributed to the feeding of acidified milk are a bacteriostatic effect of a lowered abomasal pH, control of *E. coli* proliferation, promotion of lactobacilli growth, enhanced digestion in the lowered pH environment of the intestinal tract, scours control, and improved fecal consistency.[28] More field studies that demonstrate consistent improvement in appetite, growth, and health are needed.

Vaccination is one tool to promote enteric health and prevent diarrhea of young calves, but it is not without challenges. Timely ingestion of good quality colostrum from a cow vaccinated against the most common enteric pathogens is a standard practice on many farms. Proportionate to the amount of colostral antibody absorbed, the passively acquired colostral IgG_1 in circulation is transferred into the GIT as a mechanism for clearance. To the degree that there is retention of antigen binding capacity against specific enteric pathogens, intestinal immunity may be enhanced.[9] Potential limitations are the magnitude of the vaccine response in the cow, the colostral IgG_1 concentration, efficiency of immunoglobulin absorption by the calf, and the type of immunity that is most effective against the enteric pathogen of importance to the calf.

Live or modified-live vaccination of the newborn calf prior to ingestion of colostrum or in the absence of passively acquired specific antibodies is another approach to enhancing intestinal immunity by eliciting a protective mucosal immune response.[51] Oral modified-live rotavirus and live salmonella vaccination have been used to elicit IgM, followed by IgA antibody production within five to 10 days of vaccination, effectively addressing the susceptibility to enteric disease at a very young age. In the face of passively acquired circulating maternal immunity, the conventional view that calves cannot be vaccinated effectively has changed.[13,54] New vaccine approaches that circumvent maternal antibody interference have been developed for many of the respiratory pathogens of calves but not against enteric pathogens, many of which infect calves at or within three days of birth.

Increasing concerns over the use of antibiotics in feed of cattle, antibiotic resistant bacteria, viral and parasitic enteric pathogens have resulted in growing interest in the oral administration of blood, serum, colostrum, and antibodies as alternatives to antibiotics to prevent and treat enteric disease of calves. Immunoglobulins provided after cessation of colostrum immunoglobulin absorption can be a source of local intestinal immunity. Whether it is continued feeding of colostrum or addition of colostrum supplement, blood, plasma, serum, IgG or IgY to milk or milk replacer fed to young calves, markers of enteric disease, days of treatment, protection from pathogen challenge, feed intake and weight gain have been improved in several studies.[3,8,25,43,46] Trial design, incoming IgG status and health of the enrolled calves, type or severity of the enteric challenge, source, specificity, and intestinal degradation of the IgG can affect study results.

Immunization or hyperimmunization of chickens results in the production of specific IgY antibodies that are transported to the egg yolk where they can be harvested and separated without sacrificing chickens. Oral administration of IgY has proved successful for treatment of a variety of GI infections, such as rotaviruses, coronavirus, enterotoxigenic *Escherichia coli*, *Salmonella* spp, and many others in human beings.[27,29,34] There is still controversy regarding the stability of IgG and IgY through the GIT. Finding an effective way to protect antibodies from enteric degradation would open the door for significant advances in IgY technology and nutraceutical applications. Monoclonal antibodies may be somewhat resistant to intestinal degradation and therefore have better enteritis protection when fed to calves.

Monitoring and Assessment of Intestinal Health

To ascertain health, growth, and profitability from measures taken to improve intestinal immune function, outcome measurements should be compared. For calves until weaning, growth parameters that may be measured are weaning weight, weight gain since birth, height at the withers or hipometer measured distance between the hips. Parameters of intestinal health are improved fecal consistency, days with scours, days with respiratory disease, number of treatment days, lowered morbidity, mortality, and cost of medication. Some measures of profitability in young calves are the number of days on milk, age at weaning, average daily gain to weaning, and calf starter and milk/milk replacer consumption.

Laboratory testing of intestinal immune function is limited except for diagnostic tests and fecal cultures for enteric pathogens. Fecal pH has not been thoroughly investigated in calves but may be a useful tool for measuring the effect of nutritional additives. Quantitation of fecal immunoglobulin elimination[21,55] has limited field application.

Proper use of feed additives and oral medications is essential to the health of young calves. It should be clear that there is no substitute for good colostrum management, placing young calves on a high plane of nutrition or providing clean, comfortable housing. Health screening parameters that are not solely appetite-based should be clearly established and twice-weekly monitoring is needed for early detection and timely intervention. Additives to milk or milk replacer may affect the total solids, sodium concentration or the osmolarity of the liquid feed. Adaptation and feeding consistency will avoid sudden changes in abomasal emptying rate, intestinal transport time, milk digestibility, the balance of normal flora, and sodium concentration. Monitoring tools (digital refractometers) on the farm and periodic sodium and osmolarity testing at the local diagnostic laboratory can prevent the serious consequences of inadvertent feeding errors.

Conclusions

Enhancing the intestinal health of calves begins with colostrum, follows with optimal nutrition, and is complemented by the provision of a clean, comfortable housing environment. Disease exposure will occur, but enhanced resistance and reduced fecal shedding may prevent or shorten the course of disease episodes, morbidity and mortality while maintaining growth in young calves. Alternatives to antibiotics to improve growth and reduce enteric disease include plasma proteins, immunoglobulins, probiotic bacteria, yeast cultures, and oligosaccharides.

Strategies for the maintenance of a balanced intestinal flora, feeding of nutritional supplements, vaccination, and provision of oral immunoglobulins are discussed. Monitored outcomes, diagnostic tools, and calf health screening will determine efficacy, safety, and the consistency of implementation strategies.

References

1. Abe F, Ishibashi N, Shimamura S: Effect of administration of bifidobacteria and lactic acid bacteria to newborn calves and piglets. *J Dairy Sci* 78:2838-2846, 1995.
2. Anderson NG: Experiences with free-access acidified-milk feeding in Ontario. *Proc Am Assoc Bov Pract Conf* 41:12-24, 2008.
3. Arthington JD, Kost CJ, Tyler HD, Kapil S, Quigley JD III: The use of bovine serum protein as an oral support therapy following coronavirus challenge in calves. *J Dairy Sci* 85:1249-1254, 2002.
4. Ash RW: Abomasal secretion and emptying in suckled calves. *J Physiol* 172:425-438, 1964.
5. Athanasiadou S, Huntley JF: Emerging technologies and their applications in interactions between nutrition and immunity to gastrointestinal parasites in sheep. *Parasite Immunol* 30:101-111, 2008.
6. Bartlett KS, McKeith FK, VandeHaar MJ, Dahl GE, Drackley JK: Growth and body composition of dairy calves fed milk replacers containing different amounts of protein at two feeding rates. *J Anim Sci* 84:1454-1467, 2006.
7. Bell FR, Razig SAD: Gastric emptying and secretion in the milk-fed calf. *J Physiol* 228:499-511, 1973.
8. Berge ACB, Besser TE, Moore DA, Sischo WM: Evaluation of the effects of oral colostrum supplementation during the first fourteen days on the health and performance of preweaned calves. *J Dairy Sci* 92:286-295, 2009.
9. Besser TE, McGuire TC, Gay CC: The transfer of serum IgG_1 antibody into the gastrointestinal tract in newborn calves. *Vet Immunol Immunopathol* 17:51-56, 1987.
10. Blome RM, Drackley JK, McKeith FK, Hutjens MF, McCoy GC: Growth, nutrient utilization, and body composition of dairy calves fed milk replacers containing different amounts of protein. *J Anim Sci* 81:1641-1655, 2003.
11. Blum JW: Nutritional physiology of neonatal calves. *J Anim Physiol Anim Nutr* 90:1-11, 2006.
12. Cary DC, Eicher SD, Patterson JA, Johnson TA: A yeast cell-wall derivative and ascorbic acid fed to neonatal dairy calves is protective against enteric challenge with *Salmonella Dublin*. *J Dairy Sci* 87:406 (abstract), 2004.
13. Chase CL, Hurley DJ, Reber AJ: Neonatal immune development in the calf and its impact of vaccine response. *Vet Clin North Am Food Anim Pract* 24:87-104, 2008.
14. Diaz MC, Van Amburgh ME, Smith JM, Kelsey JM, Hutten EL: Composition of growth of Holstein calves fed milk replacer from birth to 105-kilogram BW. *J Dairy Sci* 84:830-842, 2001.
15. Donovan DC, Franklin ST, Chase CCL, Hippen AR: Growth and health of Holstein calves fed milk replacers supplemented with antibiotics or Enteroguard. *J Dairy Sci* 85:947-950, 2002.
16. Drackley JK: Calf nutrition from birth to breeding. *Vet Clin North Am Food Anim Pract* 24:55-86, 2008.
17. Ewaschuk JB, Naylor JM, Cirino-Trejo M, Zello GA: *Lactobacillus rhamnosus* strain GG is a potential probiotic for calves. *Can J Vet Res* 68:249-253, 2004.
18. Galvão KN, Santos JEP, Coscioni A, Villasenor M, Sischo WM, Berge AC: Effect of feeding live yeast products to calves with failure of passive transfer on performance and patterns of antibiotic resistance in fecal *Escherichia coli*. *Reprod Nutr Dev* 45:427-440, 2005.
19. Harp JA, Jardon P, Atwill ER, Zylstra M, Checel S, Goff JP, De Simone C: Field testing of prophylactic measures against *Cryptosporidium parvum* infection in calves in a California dairy herd. *Am J Vet Res* 57:1586-1588, 1996.
20. Heinrichs AJ, Jones CM, Heinrichs BS: Effects of mannan oligosaccharides or antibiotics in neonatal diets on health and growth of dairy calves. *J Dairy Sci* 86:4064-4069, 2003.
21. Heinrichs AJ, Jones CM, Elizondo-Salazar JA, Terrill SJ: Effects of a prebiotic supplement on health of neonatal dairy calves. *Livestock Sci* 125:149-154, 2009.
22. Hill TM, Aldrich JM, Schlotterbeck RL, Bateman HG II: Effects of feeding calves different rates and protein concentrations of twenty percent fat milk replacers on growth during the neonatal period. *Prof Anim Sci* 22:252-260, 2006.
23. Hill TM, Bateman HG, Aldrich JM, Schlotterbeck RL, Tanan KG: Optimal concentrations of lysine, methionine and threonine in milk replacers for calves less than five weeks of age. *J Dairy Sci* 91:2433-2442, 2008.
24. Hosono A, Ozawa A, Kato R, Ohnishi Y, Nakanishi Y, Kimura T, Nakamura R: Dietary fructooligosaccharides induce immunotregulation of intestinal IgA secretion by murine Peyer's patch cells. *Biosci Biotechnol Biochem* 67:758-764, 2003.
25. Hunt E, Fu Q, Armstrong MU, Rennix DK, Webster DW, Galanko JA, Chen W, Weaver EM, Argenzio RA, Rhoads JM: Oral bovine serum concentrate improves cryptosporidial enteritis in calves. *Pediatr Res* 51:370-376, 2002.
26. Kuroki M, Ohta M, Ikemori Y, Icatlo FC Jr, Kobayashi C, Yokoyama H, Kodama Y: Field evaluation of chicken egg yolk immunoglobulins specific for bovine rotavirus in neonatal calves. *Arch Virol* 142:843-851, 1997.
27. Ikemori Y, Ohta M, Umeda K, Icatlo FC, Kuroki M, Yokoyama H, Kodama Y: Passive protection of neonatal calves against bovine coronavirus-induced diarrhea by administration of egg yolk or colostrum antibody powder. *Vet Microbiol* 58:105-111, 1997.
28. Jaster EH, McCoy GC, Tomkins T, Davis CL: Feeding acidified or sweet milk replacer to dairy calves. *J Dairy Sci* 73:3563-3566, 1990.
29. Kovacs-Nolan J, Mine Y: Passive immunization through avian egg antibodies. *Food Biotechnol* 18:39-62, 2005.
30. Kudsk KA: Current aspects of mucosal immunology and its influence by nutrition. *Am J Surg* 183:390-398, 2002.
31. Lesmeister KE, Heinrichs AJ, Gabler MT: Effects of supplemental yeast (*Saccharomyces cerevisiae*) culture on rumen development, growth characteristics and blood parameters in neonatal dairy calves. *J Dairy Sci* 87:1832-1839, 2004.
32. Magalhães VJA, Susca F, Lima FS, Branco AF, Yoon I, Santos JEP: Effect of feeding yeast culture on performance, health and immunocompetence of dairy calves. *J Dairy Sci* 91:1497-1509, 2008.
33. Mero KN, Rollin RE, Phillips RW: Malabsorption due to selected oral antibiotics. *Vet Clin North Am Food Anim Pract* 1:581-588, 1985.
34. Mine Y, Kovacs-Nolan J: Chicken egg yolk antibodies as therapeutics in enteric infectious disease: a review. *J Medicinal Food* 5:159-169, 2002.
35. Morrill JL, Morrill JM, Feyerherm AM, Laster JF: Plasma proteins and a probiotic as ingredients in milk replacer. *J Dairy Sci* 78:902-907, 1995.
36. Newman K, Jacques K, Buede R: Effect of mannanoligosaccharide on performance of calves fed acidified and non-acidified milk replacers. *J Anim Sci* 71 (Suppl 1):271(abstract), 1993.
37. Ohya T, Marubashi T, Ito H: Significance of fecal volatile fatty acids in shedding of *Escherichia coli* O147 from calves: experimental infection and preliminary use of a probiotic product. *J Am Vet Med Sci* 62:1151-1155, 2000.

38. Ollivett TL, Nydam DV, Linden TC, Bowman DD, Van Amburgh M: Effect of nutritional plane on health and performance in dairy calves after experimental infection with *Cryptosporidium parvum*. *Proc Am Assoc Bov Pract Conf* 42:172, 2009.
39. Phillips RW: Fluid therapy for diarrheic calves: what, how and how much. *Vet Clin North Am Food Anim Pract* 1:541-562, 1985.
40. Quigley JD: Intake, growth, and health of dairy calves in response to mannanoligosaccharide and oral challenge with *Escherichia coli*. *J Dairy Sci* 79 (Suppl 1):230(abstract), 1996.
41. Quigley JD, Drewry JJ, Murray LM, Ivey SJ: Body weight gain, feed efficiency, and fecal scores of dairy calves in response to galactosyl-lactose or antibiotics in milk replacers. *J Dairy Sci* 80:1751-1754, 1997.
42. Quigley JD, Jaynes CA, Miller ML, Schanus E, Chester-Jones H, Marx GD, Allen DM: Effects of hydrolyzed spray dried red blood cells in milk replacer on calf intake, body weight gain and efficiency. *J Dairy Sci* 83:788-794, 2000.
43. Quigley JD, Drew MD: Effects of oral antibiotics or IgG on survival, health and growth in dairy calves challenged with *Escherichia coli*. *Food Ag Immunol* 12:311-318, 2000.
44. Reeds OJ, Burrin DG: Glutamine and the bowel. *J Nutr* 131:2505S-2508S, 2001.
45. Sen I, Constable PD, Marshall TS: Effect of suckling isotonic or hypertonic solutions of sodium bicarbonate or glucose on abomasal emptying rate in calves. *Am J Vet Res* 67:1377-1384, 2006.
46. Snodgrass DR, Stewart J, Taylor J, Krautil FL, Smith ML: Diarrhoea in dairy calves reduced by feeding colostrum from cows vaccinated with rotavirus. *Res Vet Sci* 32:70-73, 1982.
47. Spring P, Wenk C, Dawson KA, Newman KE: The effects of dietary mannanoligosaccharides on cecal parameters and the concentrations of enteric bacteria in the ceca of *salmonella*-challenged broiler chicks. *Poult Sci* 79:205-211, 2000.
48. Stiles RP, Grieve DG, Butler DG, Willoughby RA: Effects of fluid intake level and dry matter concentration on the incidence of scours in milk replacer-fed calves. *Can J Anim Sci* 54:73-78, 1974.
49. Terre M, Calvo MA, Adelantado C, Kocher A, Bach A: Effects of mannan-oligosaccharides on performance and microorganism fecal counts of calves following an enhanced-growth feeding program. *Anim Feed Sci Technol* 137:115-125, 2006.
50. Timmerman HM, Mulder L, Everts H, van Espen DC, van der Wal E, Klaassen G, Rouwers SMG, Hartemink R, Rombouts FM, Beynen AC: Health and growth of veal calves fed milk replacers with or without probiotics. *J Dairy Sci* 88:2154-2165, 2005.
51. Van Immerseel, F, Methner U, Rychlik I, Nagy B, Velge P, Martin G, Foster N, Ducatelle R, Barrow PA: Vaccination and early protection against non-host specific *Salmonella* serotypes in poultry: exploitation of innate immunity and microbial activity. *Epidemiol Infect* 133:959-978, 2005.
52. Van Zaane D, Ijzerman J, De Leeuw, PW: Intestinal antibody response after vaccination and infection with rotavirus of calves fed colostrum with or without rotavirus antibody. *Vet Immunol Immunopathol* 11:45-63, 1986.
53. White LA, Newman MC, Cromwell GL, Lindemann MD: Brewers dried yeast as a source of mannan oligosaccharides for weanling pigs. *J Anim Sci* 80:2619-2628, 2002.
54. Woolums AR: Vaccinating calves: new information on the effects of maternal immunity. *Proc Am Assoc Bov Pract Conf* 40:10-17, 2007.
55. Wyatt CR, Brackett EJ, Mason PH, Savidge J, Perryman LE: Excretion patterns of mucosally delivered antibodies to p23 in *Cryptosporidium parvum* infected calves. *Vet Immunol Immunopathol* 76:309-317, 2000.
56. Zhao T, Doyle MP, Harmon BG, Brown CA, Mueller POE, Parks AH: Reduction of carriage of enterohemorrhagic *Escherihcia coli* O157:H7 in cattle by inoculation with probiotic bacteria. *J Clin Microbiol* 36:641-647, 1998.