Indonesian Journal of Veterinary Sciences
Vol. 4. No. 1. March 2023, Page. 7-21
DOI:10.22146/ijvs.v4i1.93809, ISSN 2722-421X (Online)
Available online di https://journal.ugm.ac.id/ijvs

Benefits of Vitamin B Complex Supplements to Ruminants

Yanuartono[1]*, Alsi Dara Paryuni, Indarjulianto Soedarmanto[1], Hary Purnamaningsih[1]

[1]Department of Internal Medicine, Faculty of Veterinary Medicine,
Universitas Gadjah Mada, Yogyakarta, Indonesia
*Email: yanuartono@ugm.ac.id

Received: February 1, 2023, Accepted: February 22, 2023, Published: March 1, 2023

Abstract

Vitamins are nutritional components found in feed that perform specific vital functions in various body systems and are essential for maintaining optimal livestock health. The vitamin B-complex refers to essential water-soluble vitamins such as vitamin B1 (thiamine), vitamin B2 (riboflavin), vitamin B3 (niacin), vitamin B4 (choline), pantothenic acid (vitamin B5), vitamin B6 (pyridoxine), and vitamin B12 (cyanocobalamin). Vitamin B-complex plays a crucial role in the metabolism of carbohydrates, proteins, and fats. The primary source of vitamins in ruminants is green roughage. It is generally recognized that mature ruminants do not require B-vitamin supplements because the vitamins provided by the diet and synthesized by the ruminal microflora are sufficient to prevent deficiency symptoms. However, studies indicate that the synthesis of vitamin B-complex by ruminal microflora is not sufficient for optimal health maintenance and production, necessitating supplementation to meet their needs. Finally, vitamin B-complex supplementation is still necessary for high-production livestock because their requirements far exceed the amounts that can be produced by ruminal microorganisms. This paper aims to briefly review the benefits of vitamin B-complex supplementation in ruminants.

Keywords: ruminal microflora; ruminants; supplements; vitamin B-complex

Introduction

Vitamins are essential organic compounds involved in the metabolic processes of ruminants. Based on their solubility, vitamins are classified as either water-soluble or fat-soluble. Water-soluble vitamins include the B-complex and vitamin C, while fat-soluble vitamins include vitamins A, D, and E. The body does not store vitamin K. Excess water-soluble vitamins are excreted in the urine; therefore, it is essential to consume foods containing adequate amounts of these vitamins.

One important water-soluble vitamin required by livestock is vitamin B-complex (Fattal-Valevski, 2011). The vitamin B-complex consists of several vitamins, including vitamin B1 (thiamine), vitamin B2 (riboflavin), vitamin B3 (niacin), vitamin B4 (choline), vitamin B5 (pantothenic acid), vitamin B6 (pyridoxine), and vitamin B12 (cyanocobalamin) (Niehoff et al., 2013; Elitok & Akgun, 2018). Each vitamin has synergistic functions and plays a vital role in carbohydrate, protein, and fat metabolism (Demeyer, 1981; Jenkins, 1993; McGrath et al., 2016). In ruminants, rumen microflora produces vitamin B-complex, which serves biological functions such as acting as an enzyme cofactor, supporting enzyme activity, and facilitating oxidation-reduction reactions (Hellmann & Mooney, 2010; Girard, 2017).

The supplementation of vitamin B-complex in ruminants remains a topic of debate among researchers and practitioners. This is due to the general understanding that ruminal microbes produce sufficient quantities of vitamin B-complex to meet nutritional needs (Naga et al., 1975). However, recent research suggests that vitamin B-complex synthesis by ruminal microbes may be insufficient for maintaining optimal health and production, particularly in dairy cattle (Santschi, 2004; Duplessis et al., 2015; Safarkhanlou et al., 2016).

McDowell (2013) also states that vitamin B-complex supplementation is necessary under certain conditions, particularly for niacin, thiamine, choline, and cyanocobalamin. This claim is supported by Santschi et al. (2005), who suggest that high-producing livestock may have greater vitamin B-complex requirements than can be produced by ruminal microorganisms. Research indicates that vitamin B-complex supplements can enhance milk production, composition, and metabolic efficiency in high-producing dairy cows (Girard & Matte, 1998; Shaver & Bal, 2000; Graulet et al., 2007).

In contrast to non-ruminants, whose diet is their only source of vitamin B, the minimum vitamin B requirements are relatively easy to calculate. However, in ruminants—especially dairy cattle—the amount of vitamin B synthesized or degraded by ruminal microorganisms must also be considered, making the calculation of vitamin B-complex supplementation more complex. Ballet et al. (2000) added that very young ruminants cannot synthesize vitamin B-complex because their rumen is not yet fully developed, making them susceptible to deficiency. To date, numerous studies have been conducted on vitamin B-complex supplementation in beef cattle (Elitok & Akgun, 2018), dairy cattle (Graulet et al., 2007), sheep (Lobley et al., 1996), and goats (Ramadhan et al., 2017). This article provides a brief review of the benefits of vitamin B-complex supplementation in ruminants.

Feed Sources of Vitamin B-Complex for Ruminants

Bechdel conducted studies on the vitamin B-complex requirements of ruminant livestock more than 90 years ago. The study concluded that adult ruminants do not require vitamin B supplements because rumen microflora can synthesize enough to meet their nutritional needs (Combs, 2012). Apart from being synthesized by rumen microorganisms, vitamin B-complex intake also comes from forage, grain, vegetable waste, fruit, and concentrates (Ewan, 1993; Cruyvagen & Bunge, 2004; Schwab et al., 2006; Karapinar et al., 2010; Khattak & Rahman, 2017). However, with advancements in animal feed technology, many feed supplement products, including vitamin B-complex, are now widely available.

According to Braunlich et al. (1976) and McDowell (1989), ruminants with a healthy rumen function are generally considered not to require vitamin B1 (thiamine) supplementation due to its synthesis by rumen microbes—especially when the feed contains a high proportion of grains. Miller et al. (1986) added that the type of grain influences thiamine synthesis in the rumen, although this effect is not yet fully understood.

The primary source of thiamine in ruminants is its synthesis in the reticulo-rumen, with approximately 90% of thiamine found in rumen fluid in the form of thiamine pyrophosphate (TPP), which is readily accessible to extracellular microbial thiaminase (Holler & Breves, 1980; Edwin & Jackman, 1982).

Riboflavin (Vitamin B2) Sources for Ruminants

All plant and animal cells contain riboflavin, but only a few are rich in it, namely yeast and liver. Other sources of vitamin B2 (riboflavin) include milk, egg whites, fish eggs, kidneys, and plant leaves (EFSA, 2006). Farmer et al. (2011) added that broccoli, collard greens, and radishes are also sources of riboflavin. However, grains generally contain little riboflavin.

In ruminants, riboflavin is primarily synthesized by rumen microorganisms, eliminating the need for dietary intake (Zinn, 1992; NRC, 2000). Currently, riboflavin can be mass-produced through fermentation using various microorganisms. Initially, riboflavin products were used for human food supplements and deficiency therapy. However, they are now increasingly used as supplements for ruminants (Kutsal & Özbas, 1989; Lim et al., 2001).

Niacin (Vitamin B3) Sources for Ruminants

Vitamin B3 (niacin) is found in both plant and animal sources. In plants, niacin exists as nicotinic acid, whereas in animals, it is present as nicotinamide (Jaster & Ward, 1990). According to Panda et al. (2017), ruminants obtain niacin from various feed ingredients. Niacin intake for ruminants comes from three primary sources: (1) plant- and animal-based feed, (2) the conversion of tryptophan to niacin (Scott et al., 1982;

Fukuwatari & Shibata, 2013), and (3) synthesis by rumen microflora (Tienken et al., 2015).

Common plant and animal feed sources of niacin include corn, wheat, rice, soybean meal, animal by-products, and fish (Harmeyer & Kollenkirchen, 1989; Erickson et al., 1991; Shah et al., 2016; Çatak, 2019). Hankes (1984) further noted that niacin in feed grains is likely bound to polysaccharides, polypeptides, and glycopeptides in the form of ester bonds.

Choline (Vitamin B4) Sources for Ruminants

Animal feed sources relatively rich in vitamin B4 (choline) include soybeans, soybean meal, fish meal, and yeast (Pinotti et al., 2002). According to Zeisel et al. (2000), choline is an essential vitamin in mammals, particularly when methionine and folic acid are insufficient in the diet.

However, ruminants differ from non-ruminants in choline metabolism, as choline is extensively degraded in the rumen of adult ruminants (Neill et al., 1979). As a result, the exact choline requirements of ruminants, particularly dairy cattle, remain uncertain, and external supplementation may still be necessary (NRC, 2001). The beneficial effects of choline supplementation on livestock performance are likely influenced by protein intake and the availability of other feed components, such as carbohydrates and fats (Hartwell et al., 2000; Scheer et al., 2002; Pinotti et al., 2003; Zeisel & Da Costa, 2009).

Pantothenic Acid (Vitamin B5) Sources for Ruminants

Ruminants obtain vitamin B5 (pantothenic acid) from two sources: feed and synthesis by microorganisms in the rumen (Ragaller et al., 2011). Animal feed grains that serve as sources of pantothenic acid include barley, soybean meal, wheat, corn kernels, alfalfa, peanut meal, sugar cane, yeast, rice bran, and forage (Roth-Maier & Kirchgessner, 1979; Souci et al., 2000; Shah et al., 2016; Sinbad et al., 2019). Since many feed ingredients contain pantothenic acid, ruminant deficiencies are rare and typically occur only if the vitamin is degraded in the rumen before it can be absorbed in the small intestine (Finlayson & Seeley, 1983; Volker et al., 2011).

Pyridoxine (Vitamin B6) Sources for Ruminants

Sources of pyridoxine in ruminants include grain concentrates such as barley, sorghum, oats, corn, and soybean meal (Gregory & Kirk, 1981; McDowell & Ward, 2008; Shah et al., 2016). Pyridoxine is also present in meat, liver, and legume by-products (McDowell & Ward, 2008). Although little is known about the digestion and absorption of pyridoxine in ruminants, Zinn (1992) stated that deficiency rarely occurs because pyridoxine is not readily degraded in the rumen and is synthesized in large amounts by rumen microflora.

Cyanocobalamin (Vitamin B12) Sources for Ruminants

Animal-based feed ingredients, particularly liver and kidney, are rich sources of cyanocobalamin (Driskell et al., 2001). Meanwhile, the primary source of cyanocobalamin for ruminants comes from bacterial synthesis in the rumen, as fungi and yeast do not play a role in this process (Stemme et al., 2008; Girard et al., 2009).

Although minimal amounts of cyanocobalamin are present in plant tissue, these levels are insufficient to meet ruminant needs (Watanabe & Bito, 2017). Brito et al. (2015) further noted that bacteria are almost entirely responsible for synthesizing cyanocobalamin, which is why it is found in large quantities in fermented feed ingredients. Currently, cyanocobalamin is commercially produced through fermentation. According to Gadient (1986), commercial cyanocobalamin has low sensitivity to heat, oxygen, humidity, and pH.

The Role of Vitamin B Complex in Ruminants

Most research on the relationship between ruminants and the vitamin B complex has been conducted over the past 90 years (Girard, 2017). This research concludes that adult ruminants do not require a dietary supply of vitamin B complex because rumen microflora synthesize sufficient amounts to prevent deficiency. The vitamin B complex produced by rumen microflora plays a vital role in carbohydrate, protein, and fat metabolism (Coleman, 1980;

Demeyer, 1981). Additionally, ruminants need vitamin B complex to maintain normal bodily functions and support immunity (Yoshii et al., 2019). According to Leklem (1991) and Girard (1998), ruminants obtain vitamin B by digesting bacteria in the rumen or absorbing it from body fluids. Vitamin B can only be synthesized by plants, yeast, and bacteria. In contrast, mammals cannot synthesize it, so they must obtain it from food sources or microbes in the digestive tract.

Thiamine (Vitamin B1) in Ruminants

Thiamine plays a crucial role in metabolism, particularly in energy production through carbohydrate metabolism. Its primary function in cells is as a coenzyme in thiamine pyrophosphate (TPP) or cocarboxylase (Bender & Mayes, 2003; Pan et al., 2018). Thiamine pyrophosphate serves as a coenzyme for three important enzyme complexes: pyruvate dehydrogenase, α-ketoglutarate dehydrogenase, and keto-acid dehydrogenase (Karapinar et al., 2010).

Although thiamine can be synthesized by rumen microflora, in high-producing cows, this synthesis may not meet overall requirements (Santschi et al., 2005). If the rumen does not function normally due to various disorders, the synthetic ability decreases, potentially leading to a deficiency (NRC, 2000; Casals & Calsamiglia, 2012). Thiamine deficiency in ruminants can result in clinical disorders such as anorexia (Liu et al., 2014) and cerebrocortical necrosis (Randhawa et al., 1988; Nocek, 1997; Vetreno et al., 2012).

Riboflavin (Vitamin B2) in Ruminants

There is ongoing uncertainty regarding the optimal amount of riboflavin supplementation for adult ruminants because riboflavin is synthesized in the rumen. According to Radostits et al. (2007), riboflavin plays a vital role in the synthesis of carbohydrates, amino acids, and fatty acids. Rivlin (2006) further noted that riboflavin functions in the flavoprotein enzyme system, helping regulate cell metabolism, particularly in carbohydrate metabolism.

Symptoms of riboflavin deficiency are usually non-specific, including anorexia, chronic diarrhea, and stunted growth. However, deficiency symptoms are more pronounced in young ruminants whose rumen is not yet fully developed (Fletcher, 1956; Hurley & Doane, 1989). Roy (1980) estimated that young ruminants require 1 to 1.6 mg/kg (0.45 to 0.73 mg/lb) of dry matter to prevent riboflavin deficiency.

Niacin (Vitamin B3) in Ruminants

According to Girard (1998), niacin is essential for protein and energy metabolism in ruminants and can enhance rumen microbial protein synthesis. Research by Rammell and Hill (1986) indicates that rumen microflora synthesis can meet ruminants' niacin requirements. Cervantes et al. (1996) reported that niacin supplementation can increase milk production, reduce the incidence of ketosis, and enhance microbial protein synthesis. Schwab et al. (2005) and Panda et al. (2017) further stated that niacin, derived from both rumen microflora and feed, plays a role in energy production and the synthesis of amino acids and fats essential for milk production.

Niacin deficiency in young ruminants, whose rumen is not yet fully developed, manifests as symptoms such as anorexia, diarrhea, ataxia, and dehydration (NRC, 2001). According to Campbell et al. (1994), commercial niacin is available in two forms: nicotinamide and nicotinic acid, both of which have the same biological activity. Commercial niacin supplementation has been proven to increase milk production in dairy cows.

Choline (Vitamin B4) in Ruminants

Choline, or vitamin B4, is an integral component of tissue structure and plays a role in all normal cellular functions. It acts as an acetylcholine precursor (Kuksis & Mookerjea, 1978) and indirectly contributes to fat metabolism by promoting carnitine synthesis (Zeisel & Holmes-McNary, 1991; McGuffey, 2017). Grummer (1993) added that choline aids in fatty acid transport, helping maintain normal fat concentrations in the liver.

However, choline metabolism in adult ruminants differs from that of most mammals, as it is extensively degraded in the rumen (Sharma & Erdman, 1988). Zeisel and Holmes-McNary

(1991) stated that choline deficiency can lead to fatty liver degeneration and lipid metabolism disorders. Therefore, choline supplementation can help prevent fatty degeneration and reduce fat accumulation in the liver (Zom et al., 2001).

Pantothenic Acid in Ruminants

The ability of microorganisms in the rumen to synthesize pantothenic acid has long been known. However, determining the total amount synthesized is challenging due to the dynamic nature of the rumen, where synthesis, degradation, passage along the digestive tract, and possibly absorption occur simultaneously (Ragaller et al., 2011; Yoshii et al., 2019). The primary role of pantothenic acid is in the production of coenzyme A and as a catalyst in the conversion of carbohydrates, fats, and proteins into energy (Leonardi & Jackowski, 2007; Acevedo-Rocha et al., 2019). Sheppard and Johnson (1957) discovered that pantothenic acid deficiency in ruminants results in coarse hair, visual impairment, dermatitis, excessive nasal discharge, decreased appetite, impaired growth, and weight loss, which may ultimately lead to death.

Pyridoxine (Vitamin B6) in Ruminants

Pyridoxine plays an essential role in maintaining the function of the nervous, immune, and endocrine systems. It also serves as a cofactor for more than 60 enzymatic reactions involved in the metabolism of proteins, lipids, and carbohydrates (McCormick & Chen, 1999; Ahmad et al., 2013). The pyridoxine needs of ruminants are met through both dietary intake and microbial synthesis in the rumen. However, the precise requirement for ruminants remains uncertain (Johnson et al., 1950). Driskell (1984) noted that pyridoxine requirements depend on factors such as species, age, physiological function, feed composition, intestinal microflora, and other variables that are not yet fully understood. According to the NRC (2001), the amount of pyridoxine synthesized by rumen bacteria is sufficient to prevent deficiency symptoms. However, pyridoxine deficiency can result in stunted growth and anemia (Ladipo, 2000).

Folic Acid (Vitamin B9) in Ruminants

Rumen microflora can synthesize sufficient folic acid to meet ruminants' needs (NRC, 2001). Wolin and Miller (1988) identified several bacterial species in the rumen capable of folic acid synthesis. However, the amount produced depends on the type of feed.With technological advancements and the increasing demand for milk, dairy cows now require more folic acid to support higher milk production (Schwab et al., 2006). Consequently, folic acid synthesis by rumen microflora may be insufficient to meet the needs of high-producing dairy cows (Girard & Matte, 1999). Research by Gabory et al. (2011) indicates that clinical folic acid deficiency can lead to placental deformation, premature birth, and low birth weight in calves.

Until now, there has been no definitive recommendation for the vitamin B12 (cyanocobalamin) requirement in ruminants, as it can be produced by rumen microflora (NRC, 2001). According to Combs Jr. (1998), rumen microorganisms can synthesize cyanocobalamin in sufficient quantities, provided that cobalt is adequately supplied through the feed.However, research by Girard et al. (2005) shows that 90% of orally supplemented cyanocobalamin is degraded in the rumen. Cyanocobalamin plays several essential roles in ruminants, including facilitating the utilization of cobalt by rumen microflora, aiding in feed protein digestion, and contributing to trypsin secretion by the pancreas for protein digestion (Underwood & Suttle, 1999). Additionally, cyanocobalamin is crucial for purine and pyrimidine synthesis, protein formation from amino acids, and carbohydrate and fat metabolism (Laquale, 2006). Another primary function of cyanocobalamin is red blood cell synthesis and maintaining nervous system integrity. Consequently, the most apparent sign of cyanocobalamin deficiency is anemia (Yoshii et al., 2019).

The B-complex vitamins are generally produced by microflora in the rumen of ruminants. However, with the increasing global demand for milk and meat, the natural production of B-complex vitamins by rumen microflora is often insufficient. To address this, various efforts have been made to enhance production, one of which is supplementing with external B-complex vitamins. Currently, numerous commercial B-complex vitamin products are available on the market, making access to supplementation increasingly convenient.

Benefits of B-Complex Vitamin Supplements for Ruminants

B-complex vitamins play a vital role in the growth and overall health of ruminants. Although rumen microorganisms can synthesize these vitamins, the rapid expansion of the ruminant farming industry necessitates supplementation to optimize growth and physical condition. B vitamins are essential for energy metabolism (Elmadfa et al., 2001), normal bodily functions, immunity (Hosomi et al., 2017), energy production, muscle and nerve maintenance, and protein synthesis (Girard, 1998). Under certain conditions where growth and production decline, B-complex vitamin supplementation is necessary to restore and enhance ruminants' physical condition.

Currently, a wide range of B-complex vitamin supplements is available on the market to improve the performance of both large and small ruminants. Commercial B-complex vitamin supplements used to enhance livestock performance include thiamine (Shaver & Bal, 2000; Neville et al., 2010), riboflavin (Santschi et al., 2005), niacin (Riddell et al., 1981), choline (Morrison et al., 2018), pantothenic acid (Ragaller et al., 2011), pyridoxine (Robinson, 2019), and cyanocobalamin (Judson et al., 2002). These supplements can be administered through feed additives (Shaver & Bal, 2000; Pan et al., 2016), injections (Grace, 1999; Duplessis et al., 2014), intra-ruminal boluses (Judson et al., 1997), or fat-based encapsulation (Ashwin et al., 2018). The effects of B-complex vitamin supplementation on ruminants' physical condition and milk production are presented in Table 1.

Many factors influence the physical condition of ruminants, one of which is feed intake, which is directly related to their vitamin

Table 1. Vitamin B complex supplementation in ruminants

Ruminants	Vitamin B Supplementation	Effect	Library
Sheep	Thiamine, riboflavin, niacin Increase in Average Daily Gain (ADG) 0.13 kg	Increase in Average Daily Gain (ADG) 0.13 kg	Oltjen et al., 1962
Dairy Cows	Niacin	Increased ADG	Chang et al., 1995
Dairy Cows	Niacin10-20mg/hari	Increased milk production 1.0 kg/day	Midla et al., 1998
Dairy Cows	Thiamine 150 or 300 mg/day	Increase in total milk production 2.7 kg/day, milk protein 0.13 kg/day milk fat 0.10 kg/day	Shaver dan Bal, 2000
Dairy Cows	niacin 6 g/day	Increased conception rate	Kaur et al., 2003
Dairy Cows	20-30mg/day	Increased dry matter intake and milk production	Rosendo et al., 2004
Goat	2000 µg vitamin B12	Improved carcass quality	Kadim et al., 2004
Dairy Cows	Folic acid + cyanocobalamin 2.6 g/day	Increased milk production	Graulet et al., 2007
Dairy Cows	combination of biotin, folic acid, pantothenic acid and pyridoxine 3 g/day	Increased milk production, protein and fat content	Sacadura et al., 2008
Dairy Cows	Niacin 14 g/day	Increased milk production, protein, fat and blood glucose levels	Karkoodi and Tamizrad, 2009
Dairy Cows	Niacin 6 g/hari	prevent heat stress	Wrinkle et al., 2012
Sheep	Combination of cobalt acetate (10 mg/mL), cyanocobalamin (200 µg/mL), and sodium selenite (0.25 mg/mL).	Increased ADG	Keady et al., 2017
Goat	Vitamin B complex (100 mg thiamine HCl, 5 mg Riboflavin, 10 mg pyridoxine HCl, 100 mcg cyanocobalamin, 100 mg niacin and 10 mg pantothenic acid/1 ml)	Increased cellular immunity against parasitic infestation	Uslu et al., 2017
Beef cattle	vitamin B Complex 10-20 ml	Rumen tone becomes stronger	Elitok dan Akgun, 2018

B-complex requirements. Supplementing with B-complex vitamins can enhance growth, stimulate rumen microbial activity, and improve fermentation efficiency, ultimately serving as a protein source for livestock (Ashwin et al., 2018). Several studies have also shown that B-complex vitamin supplementation can increase milk production, improve milk composition, and enhance metabolic efficiency in high-producing dairy cows (Graulet et al., 2007; Matte et al., 2011; Zimbelman et al., 2013).

However, research on B-complex vitamin supplementation has produced highly variable results, as presented in Table 1. According to Girard (2017), this variation is likely due to differences in the dosage administered to research animals. Additionally, variations in the route of administration—whether by injection or oral supplementation—may contribute to these differences. According to the NRC (2001), in dairy cattle, choline and cyanocobalamin provided through feed are largely degraded in the rumen. Research findings indicate that B-complex vitamin supplementation via intramuscular injection is significantly more effective than oral administration (Lobley et al., 1996; Akins et al., 2013), as B vitamins can be destroyed or utilized as a nutrient source by rumen microorganisms (Elmadfa et al., 2001; Niehoff et al., 2013).

The main drawback of the vitamin B complex injection route is its short-term effects, requiring frequent administration. Grace et al. (1998) reported that a cyanocobalamin injection in young sheep lasted only three months. This short duration is likely due to the rapid mobilization from the injection site and elimination by the kidneys. To address this issue, researchers have developed long-acting cyanocobalamin injections that remain in the ruminant's system for an extended period. Chen (1999) found that long-acting cyanocobalamin injections could last 6–8 months. Similarly, Grace and Knowles (2011) used long-acting cyanocobalamin injections to prevent vitamin B12 deficiency, though they did not observe an increase in milk production in pasture-raised cows.

So far, research on long-acting injectable supplementation has primarily focused on cyanocobalamin, while other B vitamins have been studied mainly in oral administration. Jaster and Ward (1990) examined the effects of nicotinic acid and nicotinamide supplementation mixed with a premix containing wheat flour and dry molasses. Their study found that nicotinamide supplementation increased milk production in early lactation, likely due to its effects on fat and energy metabolism.These findings highlight the need for further research into alternative vitamin B supplementation routes, both enteral and parenteral, to improve cost efficiency and maximize effectiveness.

Conclusion

Rumen microorganisms can naturally synthesize B complex vitamins to meet ruminants' needs. However, in practice, this synthesis is often insufficient to maintain health and support optimal production, necessitating supplementation. The rapid expansion of the ruminant livestock industry has increased the demand for vitamin B complex supplements to enhance production and overall livestock performance. Fortunately, commercially available vitamin B complex supplements are now widely accessible, offering a practical solution for optimizing livestock health and productivity.

References

Acevedo-Rocha, C.G., Gronenberg, L.S., Mack, M., Commichau, F.M. and Genee, H.J. 2019. Microbial cell factories for the sustainable manufacturing of B vitamins. Current Opinion in Biotechnology. 56: 18-29. https://doi.org/10.1016/j.copbio.2018.07.006

Ahmad, I., Mirza, T., Qadeer, K., Nazim, U. and Vaid, F.H.M. 2013. Vitamin B6: Deficiency diseases and methods of analysis. Pak. J. Pharm. Sci. 26 (5): 1057-1069

Akins, M.S., Bertics, S., Socha, M. and Shaver, R.D. 2013. Effects of cobalt supplementation and vitamin B 12 injections on lactation performance and metabolism of Holstein dairy cows. J Dairy Sci. 96 (3):1755-1768.
doi: 10.3168/jds.2012-5979.

Ashwin, K., Paladan, V., Uniyal, S., Sahoo, J.K., Perween, S., Gupta, M. and Singh, A. 2018. An Update on B Vitamin Nutrition for Cattle. Int. J. Curr. Microbiol. App. Sci. 7(07): 188-192. doi: https://doi.org/10.20546/ijcmas.2018.707.023

Ballet, N., Robert, J.C. and Williams, P.E.V. 2000. Vitamins in Forages.in Forage Evaluation in Ruminant Nutrition (eds D.I. Givens, E. Owen, R.F.E. Axford and H.M. Omed. CAB International 2000

Bender, D.A., and Mayes, P.A. 2003. Vitamins & Minerals. In: Murray RK, Granner DK, Mayes PA, Rodwell VW, editors. Harper's Biochemistry. New York: Lange Medical Books. pp. 481–498.

Braunlich, K. and Zintzen, H. 1976. Vitamin B1 in animal nutrition. Basel, Hoffmann-La Roche. Number: 1593

Brito, A., Chiquette, J., Stabler, S.P., Allen, R.H. and Girard, C.L. 2015. Supplementing lactating dairy cows with a vitamin B12 precursor, 5,6-dimethylbenzimidazole, increases the apparent ruminal synthesis of vitamin B12. Animal. 9(1): 67-75. DOI:10.1017/S1751731114002201

Campbell, J.M., Murphy, M.R., Christensen, R.A. and Overton, T.R. 1994. Kinetics of niacin supplements in lactating Dairy cows. J. Dairy Sci., 77: 566-575.

Casals, R. and Calsamiglia, S. 2012. Optimum vitamin nutrition beef cattle, in Optimum vitamin nutrition; in the production of quality animal foods. 5M Publishing: United Kingdom. pp. 309-331.

Çatak, J. 2019. Determination of niacin profiles in some animal and plant based foods by high performance liquid chromatography: association with healthy nutrition. J Anim Sci Technol. 61(3):138–146. doi:10.5187/jast.2019.61.3.138

Cervantes, A., Smith, T.R. and Young, J.W. 1996. Effects of Nicotinamide on Milk Composition and Production of Dairy Cows fed Supplemental fat. J. Dairy Sci. 79 (1): 105-113. https://doi.org/10.3168/jds.S0022-0302(96)76340-3

Chang, X., Mowat, D.N. and Mallard, B.A. 1995. Supplementalchromium and niacin for stressed feeder calves. Can. J. Anim. Sci. 75:351-358. DOI:10.4141/cjas95-054

Chen, Z.H. 1999. Development of sustained release products suitable for the management of vitamin B12 deficiency in animals. Doctor of Philosophy thesis, University of South Australia, Adelaide, Australia

Coleman, G.S. 1980. Rumen Ciliate Protozoa, in Advances in Parasitology, W.H.R. Lumsden, R. Muller, and J.R. Baker, Editors, Academic Press.:121-173.

Combs, Jr., G.F. 2012. The vitamins. Fundamental aspects in nutrition and health. 4th ed. Academic Press, New York, NY, USA.

Combs, G.F. Jr . 1998. The Vitamins: Fundamental Aspects in Nutrition and Health, 2nd ed. San Diego, CA: Academic

Cruyvagen, C.W. and Bunge, G.A. 2004. The effect of supplemental biotin in dairy cow diets on fibre fermentation patterns as measured by in vitro gas production. South African Journal of Animal Science. 34 (Supplement 2): 68-70.

Demeyer D I. 1981. Rumen microbes and digestion of plant cell walls. Agriculture and Environment. 6 (2-3):295-337. https://doi.org/10.1016/0304-1131(81)90020-5

Driskell, J.A. 1984. Vitamin B6. In "Handbook of Vitamins," (L.J. Machlin, ed.). Marcel Dekker, Inc., New York.

Driskell, J.A., Kim, Y., Giraud, D.W., Hamouz, F.L., de Mello, A.S., Erickson, G.E. and Calkins, C.K. 2011. Vitamin and mineral content of value cuts from beef steers fed distiller's grains. J. Food Comp. Analy. 24 (3): 362-367. https://doi.org/10.1016/j.jfca.2010.08.013

Duplessis, M., Girard, C.L., Santschi, D.E., Laforest, J.P., Durocher, J. and Pellerin, D. 2014. Effects of folic acid and vitamin B12 supplementation on culling rate, di-seases, and reproduction in commercial dairy herds. J. Dairy Sci. 97(4) :2346–2354. http://dx.doi.org/ 10.3168/jds.2013-7369

Duplessis, M., Mann, S., Nydam, D.V., Girard, C.L., Pellerin, D. and Overton, T.R. 2015. Short communication: Folates and vitamin B12 in colostrum and milk from dairy cows fed different energy levels during the dry period. Journal of Dairy Science. 98 (8): 5454-5459. doi: 10.3168/jds.2015-9507.

Edwin, E.E. and Jackman, R. 1982. Ruminant thiamine requirement in perspective. Veterinary Research Communications 5: 237-250. https://doi.org/10.1007/BF02214990

EFSA, 2006. Tolerable upper intake levels for vitamins and minerals – EFSA. https://www.efsa.europa.eu › efsa_rep › blobserver_assets › ndatolerableuil

Elitok, B., and Akgun, S. 2018. Investigation on Effects of Parenterally Given Vitamin B Complex on Ruminal Protozoa in Cattle. Int. Biol. Biomed. J. Winter. 4 (1): 54-61.

Elmadfa, I., Majchrzak, D., Rust, P. and Genser, D. 2001. The thiamine status of adult humans depends on carbohydrate intake. Int J Vitam Nutr Res. 71(4): 217-21. DOI: 10.1024/0300-9831.71.4.217

Erickson, P.S., Murphy, M.R., Sweeny, M. and Trusk, A.M. 1991. Niacin absorption from the rumen. J. Dairy Sci. 74 (10): 3492-3495. DOI:10.3168/jds.S0022-0302(91)78540-8

Ewan, R.C. 1993. Vitamins. In: Swenson MJ, Reece WO, eds. Duke's Physiology of Domestic Animals. London: Cornell Univer Pr. 503–516.

Farmer, B., Larson, B.T., Fulgoni, V.L., Rainville, A.J. and Liepa, G.U. 2011. A vegetarian dietary pattern as a nutrient-dense approach to weight management: an analysis of the national health and nutrition examination survey 1999–2004. J Am Diet Assoc. 111(6): 819–827. DOI:10.1016/j.jada.2011.03.012

Fattal-Valevski, A. 2011. Thiamine (Vitamin B1). J Evidence-Based Complement Altern Med. 16 (1):12-20. https://doi.org/10.1177/1533210110392941

Finlayson, H.J. and Seeley, R.C. 1983. The synthesis and absorption of pantothenic acid in the gastrointestinal tract of adult sheep. J Sci Food Agric. 34 (5): 427–432. https://doi.org/10.1002/jsfa.2740340503

Fletcher, D.W. 1956. Studies on the growth requirements of a cellulolytic coccus from the bovine rumen. Ph.D. Thesis, State College of Washington, Pullman, Washington.

Fukuwatari, T. and Shibata, K. 2013. Nutritional aspect of tryptophan metabolism. Int J Tryptophan Res. 6(Suppl 1):3-8. doi:10.4137/IJTR.S11588

Gabory, A., Attig, L. and Junien, C. 2011. Developmental programming and epigenetics. Am J Clin Nutr 94 (6 suppl):1943S–1952S. DOI:10.3945/ajcn.110.000927

Gadient, M. 1986. Effect of pelleting on nutritional quality of feed. Proceedings of Maryland Nutrition Conference. 73–79.

Girard, C. L. 1998. B-complex vitamins for dairy cows: A new approach. Can J Anim Sci. 78 (Suppl):71-90

Girard, C.L., Santschi, D.E., Stabler, S.P. and Allen, R.H. 2009. Apparent ruminal synthesis and intestinal disappearance of vitamin B12 and its analogs in dairy cows. J. Dairy Sci. 92 (9) :4524–4529 doi: 10.3168/jds.2009-2049

Girard, C.L. 2017. Invited Review New approaches, development, and improvement of methodologies for the assessment of B-vitamin requirements in dairy cows. R. Bras. Zootec., 46(7): 614-620. DOI: 10.1590/s1806-92902017000700009

Girard, C.L., and Matte, J.J. 1999. Changes in serum concentrations of folates, pyridoxal, pyridoxal-5-phosphate and vitamin B12 during lactation of dairy cows fed dietary supplements of folic acid. Can. J.

Anim. Sci. 79(1): 107–113. https://doi.org/10.4141/A98-016

Girard, C.L. and Matte J.J. 1998. Dietary supplements of folic acid during lactation: Effects on the performance of dairy cows. J. Dairy Sci. 81(5): 1412-1419. http://dx.doi.org/10.3168/jds.S0022-0302(98)75705-4

Grace, N.D. 1999. An evaluation of a long acting injectable vitamin B12 to increase and maintain the vitamin B12 status of lambs and ewes. Proceedings from the 29th Seminar of the society of sheep and beef cattle veterinarians NZVA 189: 61-67

Grace, N.D., West, D.M. and Sargison, N.D. 1998. The efficacy of a subcutaneous injection of soluble vitamin B12 in lambs. New Zealand veterinary journal 46: 194-196

Grace, N.D. and Knowles, S.O. 2012. Lack of production response in grazing dairy cows supplemented withlong-acting injectable vitamin B12, New Zealand Veterinary Journal, 60 (2): 95-99,
DOI: 10.1080/00480169.2011.639932

Graulet, B., Matte, J.J., Desrochers, A., Doepel, L., Palin, M.F. and Girard, C. L. 2007. Effects of dietary supplements of folic acid and vitamin B12 on metabolism of dairy cows in early lactation. J. Dairy Sci. 90 (7):3442–3455. http://dx.doi.org/10.3168/jds.2006-718.

Gregory, J.F. and Kirk, J.R. 1981. The bioavailability of vitamin B6 in foods. Nutr Rev. 39 (1):1-8.
DOI:10.1111/j.1753-4887.1981.tb06700.x

Grummer, R.R. 1993. Etiology of lipid related metabolic disorders in periparturient dairy cattle. J. Dairy Sci. 76(12):3882-3896. https://doi.org/10.3168/jds.S0022-0302(93)77729-2

Hankes, L.V. 1984. Nicotinic acid and nicotinamide. In Handbook of Vitamins, Nurrional, Biochemical and Clinical Aspects, pp. 329-377 [L. J. Machlin, editor]. New York: rcel Dekker Inc

Harmeyer, J. and Kollenkirchen, U. 1989. Thiamin and Niacin in Ruminant Nutrition. Nutrition Research Reviews 2(1): 201-225.
DOI: 10.1079/NRR19890015

Hartwell, J.R., Cecavqa, M.J. and Donkin, S.S. 2000. Impact of dietary rumen undegradable protein and rumen-protected choline on intake, peripartum liver triacylglyceride, plasma metabolites and milk production in transition dairy cows. J. Dairy Sci. 83 (12): 2907 – 2917. https://doi.org/10.3168/jds.S0022-0302(00)75191-5

Hellmann, H., and Mooney, S. 2010. Vitamin B6: A Molecule for Human Health? Molecules. 15 (1):442- 459.
doi: 10.3390/molecules15010442

Holler, H.A. and Breves, G. 1980. Vitamin B, in the sheep rumen. Tanzanian Veterinary Bulletin 2: 31-37.

Hosomi, K. and Kunisawa, J. 2017. The specific roles of vitamins in the regulation of immunosurveillance and maintenance of immunologic homeostasis in the gut. Immune Netw. 17 (1):13–19.
doi: 10.4110/in.2017.17.1.13

Hurley, W.L. and Doane, R.M. 1989. Recent Developments in the Roles of Vitamins and Minerals in Reproduction. J Dairy Sci. 72 (3):784-804.
DOI:10.3168/jds.S0022 0302(89)79170-0

Jaster, E.H. and Ward, N.E. 1990. Supplemental Nicotinic acid or Nicotinamide for Lactating Dairy Cows. J. Dairy Sci. 73 (10): 2880-2889. https://doi.org/10.3168/jds.S0022-0302(90)78975-8

Jenkins, T.C. 1993. Symposium: Advances in Ruminant Lipid Metabolism Lipid Metabolism in The Rumen. J Dairy Sci. 76 (12):3851-3863. https://doi.org/10.3168/jds.S0022-0302(93)77727-9

Johnson, B.C., Pinkos, J.A., and Burke, K.A. 1950. Pyridoxine Deficiency in the Calf: Three Figures, The Journal of Nutrition. 40 (2): 309–322, https://doi.org/10.1093/jn/40.2.309

Judson, G.J., Babidge, P.J., Chen, Z.H. and Sansom, L.N. 2002. Recent developments in the detection and treatment of vitamin B12 deficiency in sheep and cattle at pastureProceedings of the New Zealand Society of Animal Production 62: 307-310

Judson, G.J., McFarlane, J.D., Mitsioulis, A. and Zviedrans, P. 1997. Vitamin B12 responses to cobalt pellets in beef cows. Australian veterinary journal 75 (9): 660-662. DOI:10.1111/j.1751-0813.1997.tb15365.x

Kadim, I.T., Mahgoub, O., Srikandakumar, A., Al-Ajmi, D.S., Al-Maqbaly, R.S., Al-Saqri, N.M. and Johnson, E.H. 2004. Comparative effect of low levels of dietary cobalt and parenteral injection of vitamin B12 on carcass and meat quality characteristics in Omani goats. Meat Science 66 (2004) 837–844. https://doi.org/10.1016/j.meatsci.2003.08.003

Kahraman, O., Citil, O.B., Alatas, M.S. and Ozbilgin. A. 2015. Folic Acid In Ruminant Nutrition. Scientific Papers. Series D. Animal Science. LVIII: 140-143

Karapinar, T., Dabak, M. and Kizil, O. 2010. Thiamine status of feedlot cattle fed a high-concentrate diet. Can Vet J. 51(11):1251–1253.

Karkoodi, K. and Tamizrad, K. 2009. Effect of niacin supplementation on performance and blood parameters of Holstein cows. South African Journal of Animal Science. 39(4):349-354. DOI: 10.4314/sajas.v39i4.51128

Kaur, H., Chawla, R. and Kewalramani, N. 2003. Need to review B vitamin requirement in ruminants. 55(10):68-70

Keady, T.W.J., Hanrahan, J.P. and Fagan, S.P. 2017. Cobalt supplementation, alone or in combination with vitamin B12 and selenium: Effects on lamb performance and mineral status, Journal of Animal Science. 95 (1) 379–386. https://doi.org/10.2527/jas.2016.0825

Khattak, K.F. and Rahman, T.U. 2017. Analysis of vegetable's peels as a natural source of vitamins and minerals. International Food Research Journal. 24(1): 292-297

Kuksis, A. and Mookerjea, S. 1978. Choline. Nutr. Rev. 36 (7): 201–207. DOI:10.1111/j.1753-4887.1978.tb07359.x

Kutsal, T. and Özbas M.T. 1989. Microbial Production of Vitamin B2 (Riboflavin). In: Vandamme E.J. (eds) Biotechnology of Vitamins, Pigments and Growth Factors. Elsevier Applied Biotechnology Series. Springer, Dordrecht

Ladipo, O.A. 2000. Nutrition in pregnancy: Mineral and vitamin supplements. Am. J. Clin. Nutr. 72(S1):280S–290S. DOI:10.1093/ajcn/72.1.280S

Laquale, K.M. 2006. B-complex vitamins' role in energy release. In Movement Arts, Health Promotion and Leisure Studies Faculty Publications. Paper 25. Available at: http://vc.bridgew.edu/mahpls_fac/25

Leklem, J.E. 1991. Vitamin B6. In: Handbook of Vitamins (Machlin LJ. ed, Marcel Dekker, Inc., New York. 341-65.

Leonardi, R. and Jackowski, S. 2007. Biosynthesis of Pantothenic Acid and Coenzyme A. EcoSal Plus. 2(2):10.1128/ecosalplus.3.6.3.4. doi:10.1128/ecosalplus.3.6.3.4

Lim, S.H., Choi, J.S. and Park, E.Y. 2001. Microbial Production of Riboflavin Using Riboflavin Overproducers, Ashbya gossypii, Bacillus subtilis, and Candida famate: An Overview. Biotechnol. Bioprocess Eng. 6(2): 75-88. DOI: 10.1007/BF02931951

Liu, M., Alimov, A.P., Wang, H., Frank, J.A., Katz, W., Xu, M., Ke, Z.J. and Luo, J. 2014. Thiamine deficiency induces anorexia by inhibiting hypothalamic AMPK. Neuroscience. 267:102–113. doi:10.1016/j.neuroscience.2014.02.033

Lobley, G., Connell, A., and Revell, D. 1996. The importance of transmethylation reactions to methionine metabolism in sheep: effects of supplementation with creatine and choline. Br J Nutr.75 (1):47-56. DOI:10.1079/bjn19960109

Lucock M., 2000. Folic acid: nutritional biochemistry, molecular biology, and role in disease processes. Mol. Genet. Metab. 71(1-2): 121-138. DOI: 10.1006/mgme.2000.3027

Matte, J.J., Guay, F., and Girard, C.L. 2011. Bioavailability of vitamin B12 in cows' milk. The British journal of nutrition 107(1):61-66. DOI: 10.1017/S0007114511002364

McCormick, D.B. and H. Chen. 1999. Update on interconversions of vitamin B6 with its coenzyme. J. Nutr. 129:325-327.

Mc Dowell, L. 2013. Vitamin History: the Early Years 1st Ed. University of Florida (US): Design Pub.

McDowell, L.R. 1989. Vitamins in Animal Nutrition. San Diego: Academic Pr, 1989:155–183.

McDowell, L.R. and Ward, N.E. 2008. Optimum vitamin nutrition for poultry. Inter. Poult. Prod. 16(4):27-34.

McGrath, B.A., Fox, P.F., McSweeney, P.L.H. and Kelly, A.L. 2016. Composition and properties of bovine colostrum: a review. Dairy Science and Technology. 96 (2):133-158. DOI: 10.1007/s13594-015-0258-x

McGuffey, R.K. 2017. A 100-Year Review: Metabolic modifiers in dairy cattle nutrition. J. Dairy Sci. 100 (12):10113–10142. doi: 10.3168/jds.2017-12987.

Midla, L.T., Hoblet, K.H., Weiss, W.P. and Oeschberger, M.L. 1998. Supplemental diet. biotin for prevention of lesions associated with aseptic subclinical laminitis (Pododermatitis aseptica diffusa) in primiparous cows. Am. J. Vet. Res. 59 (6): 733-738.

Miller, B.L., Meiske, J.C. and Goodrich, R.D. 1986. Effects of grain source and concentrate level on B-vitamin production and absorption in steers. Journal of Animal Science 62 (2): 473-483. https://doi.org/10.2527/jas1986.622473x

Morrison, E.I., Reinhardt, H., Leclerc, H., DeVries, T.J. and LeBlanc, S.J. 2018. Effect of rumen-protected B vitamins and choline supplementation on health, production, and reproduction in transition dairy cows. Journal of Dairy Science.101(10): 9016-9027. https://doi.org/10.3168/jds.2018-14663

Naga, M.A., Harmeyer, J.H., Holler, H. and Schaller, K. 1975. Suspected B-vitamin deficiency in sheep on protein-free urea-containing purified diet. Journal of Animal Science 40 (6): 1192-1198. DOI:10.2527/jas1975.4061192x

National Research Council (NRC) 2000. Nutrient requirements of small ruminants. National Academy of Sciences, Washington, DC.

Neill, A.R., Grime, D.W., Snoswell, A.M., Northrop, A.J., Lindsay, D.B. and Dawson, R.M. C. 1979. The low availability of dietary choline for the nutrition of the sheep. Biochemical Journal. 180 (3): 559-565. doi: 10.1042/bj1800559

Neville, B.W., Schauer, C.S., Karges, K., Gibson, M.L., Thompson, M.M., Kirschten, L.A., Dyer, N.W., Berg, P.T. and Lardy, G.P. 2010. Effect of thiamine concentration on animal health, feedlot performance, carcass characteristics, and ruminal hydrogen sulfide concentrations in lambs fed diets based on 60% distillers dried grains plus solubles, Journal of Animal Science. 88 (7): 2444–2455. https://doi.org/10.2527/jas.2009-2607

Niehoff, I.D., Huther, L., Lebzien, P., and Flachowsky, G. 2013. The effect of a Niacin supplementation to different diets on ruminal fermentation and flow of nutrients to the duodenum of dairy cows. Applied Agricultural and Forestry Research. 63 (2):143-154. DOI: 10.3220/LBF-2013-143-154

Nocek, J.E. 1997. Bovine acidosis: Implications on laminitis. J Dairy Sci. 80 (5):1005–1028. DOI:10.3168/jds.S0022-0302(97)76026-0

NRC, 2001. Nutrient Requirements for Dairy Cattle, (Seventh Revised Edition)National Academy Press, Washington, DC.

NRC, 2000. Nutrient Requirements of Beef Cattle. 7th ed., Washington DC: National

Academy of Science, National Research Council.

Oltjen, R.R., Sirny, R.J. and Tillman, A.D. 1962. Effects of B Vitamins and Mineral Mixtures upon Growth and Rumen Function of Ruminants Fed Purified Diets. The Journal of Nutrition. 77 (3):269–277. https://doi.org/10.1093/jn/77.3.269

Pan, X., Nan, X., Yang, L., Jiang, L. and Xiong, B. 2018. Thiamine status, metabolism and application in dairy cows: a review. Br J Nutr. 120 (5): 491-499. doi: 10.1017/S0007114518001666.

Pan, X.H., Yang, L., Xue, F.G., Xin, H.R., Jiang, L.S., Xiong, B.H. and Beckers, Y. 2016. Relationship between thiamine and subacute ruminal acidosis induced by a high-grain diet in dairy cows. Journal of Dairy Science. 99 (11): 8790-8801. https://doi.org/10.3168/jds.2016-10865

Panda, S., Panda, N., Panigrahy, K.K., Gupta S.K., Mishra, S.P. and Laishram, M. 2017. Role of niacin supplementation in dairy cattle: A review. Asian J. Dairy & Food Res. 36(2) : 93-99. DOI: 10.18805/ajdfr.v36i02.7949

Pinotti, L., Baldi, A., Politis, I., Rebucci, R., Sangalli, L. and Dell'Orto, V. 2003. Rumen protected choline administration to transition cows: effects on milk production and vitamin E status. J. Vet. Med. Ser. A 50(1): 18-21. DOI: 10.1046/j.1439-0442.2003.00502.x

Pinotti, L., Baldi, A. and Dell'Orto, V. 2002. Comparative mammalian choline metabolism with emphasis on role in ruminants, especially the high yielding dairy cow. Nutrition Research Review. 15(2): 315-332. DOI:10.1079/NRR200247

Radostits, O., Gay, C. and Hinchcliff, K. 2007. A textbook of the diseases of cattle, sheep, goats, pigs and horses. Veterinary Medicine 10th edition Bailliere, Tindall, London, UK.1576-80

Ragaller, V., Hüther, L. and Lebzien, P. 2008. Folic acid in ruminant nutrition: A reviewThe British journal of nutrition 101(2):153-164. DOI: 10.1017/S0007114508051556

Ragaller, V., Lebzien, P., Sudekum, K.H., Huther, L. and Flachowsky, G. 2011. Pantothenic acid in ruminant nutrition: a review. Journal of Animal Physiology and Animal Nutrition 95 (1) 6–16. DOI: 10.1111/j.1439-0396.2010.01004.x

Ramadhan, A.F., Dartosukarno, S., and Purnomoadi, A. 2017. Pengaruh Pemberian Vitamin B Komplek Terhadap Pemulihan Fisiologi, Konsumsi Pakan, Dan Bobot Badan Kambing Kacang Muda Dan Dewasa Pasca Transportasi. Mediagro. 13 (1): 23-33. DOI: http://dx.doi.org/10.31942/md.v13i1.2154

Rammell, C.G. and Hill, J.H. 1986. A review of thiamine deficiency and its diagnosis, especialy in ruminants. N. Z. Vet. J. 34(12): 202-204. DOI:10.1080/00480169.1986.35350

Randhawa, S.S., Ahuja, A.K., and Rathor, S.S. 1988. Effect of lactic acidosis on histamine and thiamine levels in buffalo calves. Indian J Anim Sci. 58:1019–1023.

Riddell, D.O., Bartley, E.E. and Dayton, A.D. 1981. Effect of nicotinic acid on microbial protein synthesis in vitro and on dairy cattle growth and milk production. J. Dairy Sci. 64(5): 782–791. DOI:10.3168/jds.S0022-0302(81)82648-3

Rivlin, R.S. 2006. Riboflavin. In Bowman, B.A. and Russell, R.M. (Editors) "Present Knowledge in Nutrition", ninth edition, International Life Sciences Institute, Washington, D.C. Pp. 250-259.

Robinson, P.H. 2019. Vitamin B requirements and duodenal deliveries in lactating dairy cows: Organization of a limited literature. Livestock Science. 226: 48-60. https://doi.org/10.1016/j.livsci.2019.06.004

Rosendo, O., Staples, C.R., McDowell, L.R., McMahon, R., Badinga, L., Martin, F.G., Shearer, J.F., Seymour, W.M. and Wilkinson, N.S. 2004. Effects of biotin supplementation on peripartum performance and metabolites of Holstein cows. J Dairy Sci. 87(8):2535-2545. DOI:10.3168/jds.S0022-0302(04)73378-0

Roth-Maier, D.A. and Kirchgessner, M. 1979. Pantothenic acid supply of market pigs and broilers by practical rations. Zeitschrift fu¨r Tierphysiologie, Tierernа¨hrung und Futtermittelkunde. 41(5): 275–279.

Roy, J.H.B. 1980. The Calf, 4th Ed. Butterworths, London.

Sacadura, F.C., Robinson, P.H., Evans, E. and Lordelo, M. 2008. Effects of a ruminally protected B-vitamins supplementation on milk yield and composition of lactating dairy cows. Animal Feed Science and Technology 144 (1): 111-124. DOI: 10.1016/j.anifeedsci.2007.10.005

Safarkhanlou, M., Maheri-Sis, N., Ebrahimnezhad, Y. 2016. The Effects of Intramuscular Injections of Vitamin B12 on Production Performance of Dairy Cows in Early Lactation Fed Dietary Supplements of Rumen-Protected Methionine. J Biol Environ Sci. 10:11-19

Santschi, D. 2004. Rate of B-complex vitamins in the gastrointestınal tract of dairy cows. Doctorate Thesis. McGill University Montreal, Quebec, Canada.

Santschi, D.E., Berthiaume, R., Matte, J.J., Mustafa, A.F. and Girard, C.L. 2005. Fate of supplementary B-vitamins in the gastrointestinal tract of dairy cows. J Dairy Sci. 88 (6): 2043–2054. DOI:10.3168/jds.S0022-0302(05)72881-2

Scheer, W.A., Lucy, M.C., Kerley, M.S. and Spain, J.N. 2002. Effects of feeding soybeans and rumen protected choline during late gestation and early lactation on performance of dairy cows. J. Dairy Sci. 85 (Suppl. 1): 276.

Schwab, E.C., Schwab, C.G., Shaver, R.D., Girard, C.L., Putnam, D.E. and Whitehouse, N.L. 2006. Dietary forage and nonfiber carbohydrate contents influence B-vitamin intake, duodenal flow, and apparent ruminal synthesis in lactating dairy cows. Journal of Dairy Science. 89(1): 174- 187. https://doi.org/10.3168/jds.S0022-0302(06)72082-3

Schwab, E.C., Caraviello, D.Z. and Shaver, R.D. 2005. Review: A meta-analysis of lactation responses to supplemental dietary niacin in dairy cows. Professional Animal Scientist 21:239-247.

Scott, M.L., Nesheim, M.C. and Young, R.J. 1982. Nutrition of the chicken 4th edition. M.L. Scott & Associates, Ithaca, New York.

Shah, T.R., Prasad, K. and Kumar, P. 2016. Maize—A potential source of human nutrition and health: A review. Cogent Food & Agriculture. 2(1):1-9. http://dx.doi.org/10.1080/23311932.2016.1166995

Sharma, B.K. and Erdman, R.A. 1988. Effects of high amounts of dietary choline supplementation on duodenal choline flow and production responses of dairy cows. J Dairy Sci. 71(10): 2670–6. doi: 10.3168/jds.S0022-0302(88)79860-4.

Shaver, R.D. and Bal, M.A. 2000. Effect of dietary thiamin supplementation on milk production by dairy cows. Journal of Dairy Sci. 83(10):2335- 2340. DOI:10.3168/jds.S0022-0302(00)75121-6

Sheppard, A.J. and Johnson, B.C. 1957. Pantothenic Acid Deficiency in the Growing CalfThe Journal of Nutrition. 61(2): 195–205, https://doi.org/10.1093/jn/61.2.195

Sinbad, O.O., Folorunsho, A.A., Olabisi, O.L., Ayoola, O.A. and Temitope, E.J. 2019. Vitamins as Antioxidants. J Food Sci Nutr Res. 2 (3): 214-235. DOI: 10.26502/jfsnr.2642-11000021

Souci, S., Fachmann, W. and Kraut, H. 2000. Food Composition and Nutrition Tables, 6th edn. Medpharm Scientific Publishers, Stuttgart, Germany.

Stemme, K., Lebzien, P., Flachowsky, G., and Scholz, H. 2008. The influence of an increased cobalt supply on ruminal parameters and microbial vitamin B12 synthesis in the rumen of dairy cows. Archives of Animal Nutrition. 62

(3): 207-218.
DOI: 10.1080/17450390802027460

Tienken, R., Kersten, S., Huther, L., Frahm, J., Meyer, U. and Danicke, S. 2015. Relative Bioavailability of Niacin Supplements for Dairy Cows: Effects of Rumen Protection and Feed Processing.Vet. Sci. 2 (4): 440-455.
doi: 10.3390/vetsci2040440

Underwood, E.J. and Suttle, N.F. 1999: The mineral nutrition of livestock. 3rd Edition. Wallingford, CABI Publishing

Uslu, U., Balevi, T., Uçan, U.S., Ceylan, O. And Uslu A. 2017. Effect of Parenteral Administration of Vitamin Bto Goats on Performance, Lice (Phthiraptera) Infestations and Cellular Immunity. Kafkas Univ Vet Fak Derg, 2017 (in Press).
DOI: 10.9775/kvfd.2017.17592

Vetreno, R.P., Ramos, R.L., Anzalone, S. and Savage, L.M. 2012. Brain and behavioral pathology in an animal model of Wernicke's encephalopathy and Wernicke-Korsakoff Syndrome. Brain Res. 1436:178–192.
doi: 10.1016/j.brainres.2011.11.038.

Volker, D., Huther, L., Daş, G. and Hansjorg Abel, H. 2011. Pantothenic acid supplementation to support rumen microbes?, Archives of Animal Nutrition, 65:2, 163-173,
DOI: 10.1080/1745039X.2011.552272

Watanabe, F. and Bito, T. 2017. Vitamin B12 sources and microbial interaction. Exp. Biol. Med. 243(2): 148-158.
DOI: 10.1177/1535370217746612

Wolin, M.J. and Miller, T.L. 1988. Microbe–microbe interactions. In The Rumen Microbial Ecosystem, pp. 343–359 [PN Hobson, editor]. London and New York: Elsevier Applied Science.

Wrinkle, S.R., Robinsona, P.H. and Garrett, J.E. 2012. Niacin delivery to the intestinal absorptive site impacts heat stress and productivity responses of high producing dairy cows during hot conditions. Animal Feed Science and Technology. 175 (1–2): 33-47. https://doi.org/10.1016/j.anifeedsci.2012.04.005

Yoshii, K., Hosomi, K., Sawane, K. and Kunisawa, J. 2019. Metabolism of Dietary and Microbial Vitamin B Family in the Regulation of Host Immunity. Front. Nutr. 6 (48):1-43. https://doi.org/10.3389/fnut.2019.00048

Zeisel, S.H. and Da Costa, K.A. 2009. Choline: An Essential Nutrient for Public Health. Nutrition Reviews. 67(11): 615–623.
doi: 10.1111/j.1753-4887.2009.00246.x.

Zeisel, S.H. and Holmes-McNary, M. 1991. Choline. In: Dekker M., editor. Handbook of Vitamins. Taylor & Francis; New York, NY, USA.513–528.

Zeisel, S.H., Da Costa, K.A., Franklin, P.D., Alexander, E.D., Lamont, J.T., Sheard, M.F. and Beiser, A. 2000. Choline: an essential nutrient for humans. The FASEB Journal. 5(7): 2093-2098. DOI: 10.1096/fasebj.5.7.2010061

Zimbelman, R.B., Collier, R.J. and Bilby, T.R. 2013. Effects of utilizing rumen protected niacin on core body temperature as well as milk production and composition in lactating dairy cows during heat stress. Animal Feed Science Technology. 180(1-4): 26-33.
DOI: 10.1016/j.anifeedsci.2013.01.005

Zinn, R.A. 1992. B-vitamin in Beef cattle Nutirition. In Takeda Technical symposium. 53rd Minnesota Nutrition Conference. September 21. 1992.

Zom, R. L. G., van Baal, J., Goselink, R.M.A., Bakker, J.A., de Veth, M. J. and van Vuuren, A.M. 2011. Effect of rumen-protected choline on performance, blood metabolites, and hepatic triacylglycerols of periparturient dairy cattle. J. Dairy Sci. 94:4016–4027.