Kentucky Equine Research®
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Advances in Equine Nutrition
Volume II

Edited by
J.D. Pagan

VITAMIN REQUIREMENTS IN THE HORSE

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Vitamins may be required in minute amounts by the body, but they are undeniably necessary for normal metabolic and physiological processes. The discovery of vitamins and an improved understanding of their functions are among the most important achievements of this century. Most vitamin deficiency diseases are rarely seen today except in developing countries. What exactly are vitamins? The nature of vitamins is as varied as any group of nutrients. In general, vitamins are organic compounds which cannot be produced in adequate quantities in the body and must be obtained from food or the environment. More specifically, vitamins serve the similar purpose of maintaining normal body function.

Vitamins are necessary for optimal growth, health, feed conversion and reproduction. To further complicate this, vitamins are also necessary for proper physical performance in horses. The target tissues of the fat-soluble vitamins A, D, E, and K are skin, bones, muscles and blood. B vitamins serve as catalysts in the conversion of nutrients to tissues and the metabolism of fats, carbohydrates and protein to the final oxidation end products of CO_2 and H_2O (via the citrate cycle).

Table 1. Functions and deficiency signs of vitamins (BASF 2000).

Nutrient	Major Function	Signs of Major Deficiency
Vitamin A	Vision, mucous tissue integrity, immunity	Xerophthalmia, tissue keratinization, polyneuritis, hind leg paralysis, elevated cerebrospinal fluid pressure, ataxia, depressed immune system, reduced fertility
Vitamin D	Calcium and phosphorus balance	Rickets, osteomalacia, metabolism, bone calcification, immunity
Vitamin E	Intracellular respiration, antioxidant, membrane integrity	Encephalomalacia, depressed immune status, skin edema, steatitis, jaundice, liver necrosis, anemia, erythrocyte hemolysis, muscular dystrophy, fetal death, reduced fertility
Vitamin K	Blood coagulation	Prolonged blood clotting, low prothrombin, intramuscular bleeding, anemia, hemorrhage
Thiamine (B_1)	Metabolism of carbohydrates and proteins, nervous system	Loss of appetite, polyneuritis, skin edema, fatty liver, fatty heart, convulsions, cyanosis, gastrointestinal hemorrhage, diarrhea
Riboflavin (B_2)	Antioxidant, H-transfer, ligament integrity	Poor growth, shortened bones, curled toe paralysis, fused ribs, dermatitis, poor hair coat, seborrhea, photophobia, cataracts, anemia, stiff crooked legs, fetal death, reduced fertility, collapsed ovarian follicles, diarrhea, anal mucosa inflammation, ulcerative colitis
Pantothenic Acid	Conversion of amino acid groups as coenzyme A, skin integrity	Dermatitis in feet and mouth, blindness, goose stepping, demyelinization of spinal cord, depressed immune system, decreased milk production, embryo detachment, diarrhea, GI ulceration, fatty liver

Niacin	Metabolism of carbohydrates, protein and fats, H carrying enzymes NAD and NADP, skin integrity	Bowed legs, diarrhea, general dermatitis of feet and mouth, anorexia, hind leg paralysis, GI ulceration
Vitamin B_6	Metabolism of proteins	Dermatitis around the eyes, fatty liver, ataxia, convulsions, diarrhea
Choline	Methyl donor group, phospholipids	Poor growth, fatty liver, enlarged spleen, abnormal gait, demyelinization of peripheral nerves, depressed immune system, reduced fertility, kidney damage
Vitamin B_{12}	Protein metabolism, transport of methyl groups	Anemia, poor growth, poor hair coat, fatty kidney, kidney damage, ataxia, uncoordinated hind legs, impaired thyroid, diarrhea
Folacin	Transfer of single carbon units in activated form for methylation reactions involving methyl donors such as methionine and choline, immunity	Poor growth, anemia, poor skin condition, reduced fertility
Biotin	Metabolism of fats, carbohydrates and proteins as coenzyme for CO_2 fixation and transcarboxylation	General dermatitis, dermatitis on feet, mouth and eyes, poor hair coat, weak-walled brittle hooves, spasms in hind legs, stiff gait, reduced fertility
Vitamin C	Antioxidant, hormone synthesis, conversion of vitamin D_3 to calcitriol, essential for bone calcification	Poor hair coat, depressed immune system, hemorrhage, delayed wound healing, degenerated enlarged adrenal, scoliosis, lordosis

Vitamin Requirements

Vitamin requirements, like those of other nutrients, are affected by age, reproductive status, amount of exercise and a variety of stresses such as gastrointestinal infections and intense muscular exercise. The need for vitamin supplementation also depends on the type and quality of the diet, the length of exposure to sunlight, the amount of microbial vitamin synthesis in the digestive tract, and the extent of vitamin absorption from the site of synthesis. Nonworking horses grazing high quality pastures are likely to need little or no vitamin supplementation because forages are a rich source of most fat- and water-soluble vitamins. Because many horses do not have the advantage of lush green pasture year-round, supplementation of vitamins becomes the responsibility of the care provider. Today, nearly all commercial horse feeds are fortified with vitamins (primarily fat-soluble vitamins) to supplement the low natural vitamin content of the grains.

Unlike research conducted on humans and food animals, actual vitamin requirements for horses have not undergone intensive scrutiny. Research into requirements is time consuming due to the lengthy period it takes to initiate obvious outward signs of vitamin depletion. Further, research may involve considerable suffering of the animal before death occurs, and many researchers are reluctant to put the animals through this suffering. Currently, function tests are used most frequently in vitamin studies in an attempt to detect the onset of vitamin depletion before it causes irreversible damage and suffering. With the use of function tests, it is becoming apparent that there is a clear distinction between the minimal requirement of a vitamin and an optimal requirement.

The minimum vitamin requirement is that quantity which has to be supplied daily to the animal to prevent or correct deficiency symptoms. These values were determined earlier in the twentieth century under experimental laboratory conditions; however, these values have only a theoretical value as far as practical animal feeding is concerned. Many times the research animals were maintained in a rigidly controlled environment, not in a natural situation. Animals were also not subjected to any form of physical exercise or reproductive effort, physiological states which may alter minimal vitamin requirements.

The optimum requirement is the quantity that promotes maximal growth rate, performance, health, feed utilization and body reserves. Experience indicates that the optimum supply is probably several times higher than the minimum vitamin requirement. Researchers are attempting to define the optimum requirement for many vitamins in the horse. For production animals, inadequate growth is the common measure of vitamin deficiency. Slowed growth can have adverse effects on the health and productivity of the animal. However, growth alone may be a misleading measure in the horse. Supplementation may be adequate for normal growth but not for optimal performance.

Symptoms of vitamin deficiency are not always visible. Suboptimal intake can occur frequently in practice and result in a nonspecific depression of performance, increased susceptibility to disease, reduced fertility, and shorter productive life. For these reasons, the objective in designing the ideal diet is to meet optimum requirements through vitamin supplementation.

Table 2. Levels of vitamin supplementation (BASF 2000).

Minimum supplementation	The vitamin quantity required for prevention and/or correction of deficiency symptoms (only of little practical value).
Optimum supplementation	The vitamin quantity required for achieving best performances (growth rate, feed conversion, health) can only be determined by using sensitive biological and physiological criteria.
Suboptimal supplementation	Supply of vitamins somewhere between minimum and optimum level (occurs frequently in practice without knowledge, resulting in nonspecific depression of production).

The National Research Council (NRC) last published Nutrient Requirements of Horses in 1989. The recommendations presented in this edition are restricted to the research that had been done for each nutrient before 1989. In compiling the requirements, many different recommendations had to be considered and a consensus was decided upon to establish requirements. The NRC vitamin requirements should be considered the minimum vitamin requirement under ideal circumstances to prevent clinical symptoms of vitamin deficiency. Since these requirements often differ drastically from the optimal vitamin requirements under true field conditions, the NRC recommendations should be considered only a part of the total vitamin requirement.

The most recent Nutrient Requirements of Horses (NRC, 1989) provides estimated requirements for vitamins A, D, E, thiamin and riboflavin, but not for the other vitamins. Deficiencies of other vitamins in the horse were not researched extensively prior to 1989. However, in designing diets for optimum health and well-being of horses, the gray zone between minimal and optimum requirement needs to be taken into consideration. For example, McMeniman et al. (1995) reported that exercising horses had lower peak plasma lactate concentrations and lower maximum heart rates when they received a diet containing a multi-vitamin supplement (A, D, E, K, thiamin, riboflavin nicotinamide, pyridoxine, pantothenic acid, biotin, choline, folic acid and cyanocobalamine), but the indices of performance were not improved. The fact that performance was not improved may be justification to not change the minimal requirement, but the changes in heart rate and lactate are sufficient to suggest that there can still be improvement with optimal levels.

Table 3. BASF recommendations for vitamin supplementation per 100 kg live weight/day.

Vitamin	**Foals**	**Leisure Horses**	**Race & Breeding Horses**
Vitamin A, IU	10,000-12,000	6,000-8,000	12,000-15,000
Vitamin D, IU	1000-1200	600-800	1200-1500
Vitamin E, mg	100-120	60-80	200-300
Vitamin K, mg (menadione)	3	2	3
Thiamin, mg	8-10	6-8	8-12
Riboflavin, mg	8-12	6-8	8-12
Vitamin B_6, mg	6	4	6
Vitamin B_{12}, ug	60-80	50-70	60-80
Biotin, ug	200-300	200*	200-300*
Folacin, mg	6	4	8
Niacin, mg	10-20	10-15	15-25
Pantothenic Acid, mg	8-10	6-8	10-12
Choline, mg	150-250	150-250	300-400
Vitamin C, mg	200	100	200-300
B-carotene, mg			400-500+

* for improvement of hoof health and integrity 15 - 20 mg/day for at least 6 months
+ for reproduction per horse per day, 4 weeks before birth to 10 weeks after

Aside from the basic and optimal vitamin requirements in the horse, there is increasing interest in using vitamins as healing foods. This is drastically changing the manner in which vitamin supplementation of horses is being viewed. Vitamin supplementation has evolved from meeting the basic physiological requirements of the animal to providing a food that will improve the quality of life. This is essentially the same development that occurred in human nutrition over the last ten years. Human supplementation with antioxidant vitamins (vitamins E and C, beta-carotene) and omega 3-fatty acids has become commonplace. The main justification for this supplementation is to improve the quality of life and to reduce risks associated with aging such as cancer, low immune competence, cardiovascular diseases, cataracts and renal failure. Such supplementation may improve the quality of life for horses as well. Supplement products found on the market frequently contain nutrients such as vitamins E and C, beta-carotene and omega 3-fatty acids.

Table 4. Factors that influence vitamin supplementation (BASF 2000).

Effect of feed	Level of other nutrients in the feed (protein, energy, minerals, drugs, etc.) Bioavailability of vitamins in feed ingredients Destruction of vitamins in feed due to high temperature/ pelleting, oxidation and the catalytic effects of trace minerals or the peroxiding effects of rancidifying polyunsaturated fats Binding of vitamins in feed Growth of fungi, bacteria and yeast
Effect of animal and metabolism	Race, breed and genetic variation Variation in carry through of vitamins from breeding stock to progeny Variation in the absorption of vitamins in the gut: Parasitic damage to intestine walls Low dietary fat levels to support optimum fat-soluble vitamin absorption Lack of bile salts to form micelles and other mechanisms involved in vitamin absorption Inadequate level of lipoproteins essential in vitamin transport Competition between vitamins that use similar absorption mechanisms (vitamins A and E) Influence of gut enzymes (lipase, thiaminase)
Effect of animal health and environment	Level of disease and other stress factors Malabsorption due to destruction of microvilli Endoparasites and ectoparasites Mycotoxins and peroxides are often responsible for malabsorption

Survey of Vitamin Research

Vitamin A

Because of the narrow range between deficiency and toxicity of vitamin A, recommendations for supplementation are very conservative in the 1989 NRC despite research indicating that the requirement should be two to five times the recommended level (Donoghue et al., 1981). Research done by Maenpaa and coworkers (1988b) also suggested that the recommended levels were insufficient when green forage was not available. In current research, vitamin A status was assessed by use of the function test. Relative dose response was found to be a more sensitive measure of vitamin A status than serum vitamin A (Greiwe-Crandell et al., 1995). Depletion of vitamin A reserves was found within two months of a diet of hay and vitamin A free concentrate. Subsequent supplementation of vitamin A palmitate at two times the NRC recommended level was not adequate to completely replete stores of vitamin A in mares with no access to pasture (Greiwe-Crandell et al., 1997a). Mares with access to green pastures had adequate liver stores of vitamin A regardless of vitamin A supplementation. Additional vitamin A palmitate supplementation did not induce any excesses of vitamin A in liver or serum (Greiwe-Crandell et al., 1997a). Further investigation on ß-carotene found carotenes in grass readily available as a source of vitamin A, but synthetic ß-carotene was not readily absorbed. Use of synthetic ß-carotene as a sole source of vitamin A could not meet vitamin A requirements of horses and is not recommended (Greiwe-Crandell et al., 1997b).

Vitamin D

Focus in current vitamin D research has been in exercise effects on requirement. Horses with adequate access to sunshine each day may always be able to meet their vitamin D requirement, but many of the horses in intensive work are confined indoors for the majority of the day. Extensive bone remodeling was found in young horses undergoing race training; this resulted in changes in calcium, phosphorus and vitamin D levels in serum and bone (Nielsen et al., 1995). Logically, anything that stresses the bone structure of the animal (such as carrying the weight of the rider, jumping or intensive training) will increase the amount of bone remodeling, and therefore, may increase the need for vitamin D. An increase in vitamin D intake has been found to increase efficiency of calcium and phosphorus absorption in the intestinal tract (Cromwell, 1996), which would increase the supply of these nutrients as needed in times of stress due to exercise.

Vitamin E

The vitamin most closely focused upon in both equine and production animals during the last decade has been vitamin E. Continuing previous research investigating the best form to supplement vitamin E, Wooden and Papas (1991) studied absorption of four forms of tocopherol in long yearling Thoroughbreds (dl-alpha-tocopheryl acetate, d-alpha-tocopheryl acetate, d-alpha-tocopheryl polyethelene glycol (TPGS) and TPGS + d-alpha-tocopherol acetate). Researchers found d-forms resulted in higher plasma concentrations than equivalent amounts of dl-forms. Gansen et al. (1995) reported on the ability of the horse to absorb synthetic and natural sources of vitamin E. Natural vitamin E elicited serum vitamin E increases equal to that of three times the amount of synthetic E. A function test of vitamin E absorption, the OVETT (oral vitamin E absorption test), found that maximal absorption occurred when vitamin E was naturally consumed in one liter of grain as compared to an oral paste or stomach tube (Craig et al., 1991).

Horses receiving a diet containing about 3000 IU of vitamin E/day had higher serum alpha-tocopherol concentrations than horses receiving less than 800 IU vitamin E/day (Siciliano et al., 1997). However, there was no difference in the susceptibility to exercise-induced muscle damage as measured by increase in serum creatine kinase or aspartate aminotransferase activities after a strenuous exercise bout. Low vitamin E levels were reported in exercising horses kept in confinement and fed hay (Hall et al., 1991). Additional vitamin E supplementation is warranted for horses when pasture is not available. In the same study, no differences in serum alpha-tocopherol levels were found between yearlings and mature horses in training; both were low compared to horses not in training. The vitamin E requirement in exercising horses and its effect on performance and cellular peroxidation were investigated (McMenniman and Hintz, 1992). The suggested intake of vitamin E was adequate for the exercising horse at 42 IU/kg DM. This is well below the currently recommended level of 80 IU/kg DM. However, it can be safely assumed that as the workload or the duration increases, so may the requirement.

The increasing popularity of high fat diets for horses has brought forth concern for an increased requirement for vitamin E because of its cellular antioxidant properties, quenching free radicals produced by fat oxidation for energy. Horses consuming a diet consisting of 6% added soybean oil did not show any indication of interference with vitamin E status in non-exercising horses (Siciliano and Wood, 1993). Exercising ponies fed a diet providing 10% of dietary energy in the form of corn oil caused a challenge to the cellular antioxidant systems in the muscle, but no reduction in plasma or muscle vitamin E (McMeniman and Hintz, 1992).

Vitamin E status in reproductive horses has been investigated. Hoffman et al. (1999) reported an increase in serum IgG concentrations in foaling mares from 160 IU vitamin E/kg daily intake as compared to 80 IU. After foaling, suckling foals of mares supplemented with the 160 IU vitamin E had higher serum IgG concentrations, even though there was no difference at birth.

A deficiency of vitamin E may cause a variety of symptoms and pathological changes, which may include nutritional muscular dystrophy (weak and poorly oxygenated muscles) and poor immunity to diseases (recurrent colds and coughing) (Moore and Kohn, 1991). Low serum vitamin E and blood glutathione peroxidase values were found in horses with degenerative myeloencephalopathy (Dill et al., 1989; Blythe et al., 1991). Treatment of this disease and equine motor neuron disease with 6,000 to 10,000 IU of vitamin E per day has been successful in numerous cases (Marcella, 1997).

Vitamin K

There is currently no requirement for vitamin K in the horse because of microbial production in the intestinal tract and amounts present in forage. Recent research is focusing on the role of vitamin K in bone growth and the possible link to developmental orthopedic diseases. Siciliano et al. (1999b) reported an increase in vitamin K status with age because of increased forage consumption and consequent increase in microbial synthesis as foals are weaned from milk. Vitamin K status affects bone metabolism as well as blood coagulation. However, there was a decline in serum osteocalcin during the same period which reflects the slowing of bone growth. In further investigations on vitamin K in the young growing horse in training, Siciliano et al. (1999a) reported no effect of exercise training on vitamin K status as measured by hydroxyapatite binding capacity. During times of increased bone metabolism (onset of exercise training), the vitamin K requirement may increase due to an increase in osteocalcin production. Lower vitamin K status was related to an increased incidence of hip stress fractures in humans (Szulc et al., 1994).

Vitamin C

There is no NRC requirement for vitamin C in horses because of adequate hepatic production from glucose under normal circumstances. However, the requirement has been seen to increase in times of stress and disease when body production may not be able to meet the need. Foals exhibiting high levels of stress during weaning by confinement in stalls had lower than normal plasma ascorbate levels (Hoffman et al., 1995). Vitamin C supplementation (20 g per day) increased antibody response to vaccines in aged horses, especially those with pituitary dysfunction or Cushing's syndrome (Ralston, 1999). Lieb et al. (1995) investigated the effectiveness of a nutrient supplement which included vitamin C and niacin (as well as tyrosine) in alleviating the clinical signs of anhidrosis (inability to sweat). The supplement appeared to improve heat dissipation in non-exercised anhidrotic horses by increasing the amount of body sweat area.

B vitamins

The NRC suggests that B vitamins are usually supplied in adequate amounts for the mature horse with ingestion of quality forages and that there is utilization of B vitamins produced by the microflora of the cecum and colon. However, bacterial products can not supply all the requirements at all times because B vitamin deficiencies can be produced by feeding diets containing low concentrations of certain B vitamins. The two B vitamins that have minimal requirements according to Nutrient Requirements of Horses (NRC, 1989) are thiamin and riboflavin. Little work has been done to investigate requirements of these vitamins since the last publication.

The most significant research on B vitamins has been on biotin. Even when the minimal requirement to maintain normal body function is met in the horse, there have been anecdotal accounts of feeding additional biotin improving hoof quality. In 1995, Josseck et al. demonstrated significant improvement in hoof horn quality with daily supplementation of 20 mg of biotin. Supplementation only affected new hoof growth. Improvements were observed after nine months of supplementation but a measurable improvement in tensile strength took 19 months. Lindner et al. (1994) reported that biotin supplementation alone was not found to affect lactate concentrations during exercise.

Parker et al. (1997) investigated the use of supplemental niacin in exercising horses to increase lipolysis, thus allowing for improved utilization of FFA during submaximal and maximal exercise. Just as small amounts of niacin are vital to energy metabolism (component of NAD and NADP), excess amounts have been found to inhibit lipolysis and thereby affecting mobilization of FFA from adipose tissue. In this study 3 g of nicotinic acid were fed for six weeks which resulted in neither improvement of exercise parameters or in niacin status over control exercised horses.

Conclusion

Continued investigation into vitamin requirements in horses will broaden the understanding of the vital importance of these delicate organic compounds and to highlight the significance of optimal, not just minimal, nutrition in the equine.

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