

Recent Developments in Equine Nutrition with Farm and Clinic Applications

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1. Introduction

Significant changes have occurred in the last 5 yr in horse nutrition, leading to a greater understanding of several nutritionally related diseases and improved feeding practices. It is difficult if not impossible to keep up with research results, let alone incorporate them into a practitioner's daily farm call recommendations or health management at the clinic. Our intent is to update and refresh the equine practitioners' knowledge of nutritional research primarily from the last 5 yr (1998–2002). Because it is not feasible to cover every nutritional study conducted during this time frame, we took the liberty to select, in our opinion, the most important. In each study, we attempted to summarize and to give our interpretations of relevant applications for the farm or hospital scenario.

2. Water

Water's importance to good horsekeeping continues to elude many owners, resulting in dehydration, compromised performance, and poor health.

Drinking behavior and amounts were monitored by the New Bolton Center where they found horses drank more warm water in the winter than icy water when not given a choice.[1] When warm and cold water were offered together, horses invariably chose the cold water, but in less amounts. If you want to increase the volume of water the horse drinks in cold weather, provide warm water as the sole source of water. Confined horses do most of their drinking within a few minutes after eating grain and within an hour after given hay. The absence of water or limited amounts during these critical times could help explain poor performances or transient colics observed in otherwise well cared for, stalled horses.

Kentucky researchers used mature geldings in simulated endurance training to determine if high-intensity exercise influenced fluid uptake from the gastrointestinal tract and thus, rehydration rate.[2] The 1-h rest period in endurance rides and in this simulated race allowed some absorption of fluid and rehydration to occur; however, the study found that resuming exercise delayed further absorption. From previous studies we know that exercise reduces blood flow by 75% to the intestines; however, it is still unclear if moderate- to high-intensity exercise reduces gastric emptying or intestinal absorption of water. It would seem that hard working horses in any prolonged performance should be allowed periodic rests of at least 1 h with access to water to rehydrate. Humans are more efficient at

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rehydrating in the 2 h immediately after exercise and can drink large volumes of fluids during this time to take advantage of this phenomenon. It would seem that the horse is similar to humans. However, there is a risk of colic and founder when hot horses consume cold water during a rest and do not immediately continue with exercise. The horse should rehydrate safely if a cool-down period and incremental drinking are coupled over a 1- to 2-h rest period.

Adding fat to the diet of performance horses seems to have beneficial effects on water retention, water available for sweating, and therefore, heat dissipation during hot, humid weather.[3] Horses fed high hay diets supplemented with fat retained a higher percentage of absorbed water. There was a greater reserve of extracellular water because the packed cell volumes during exercise were lower and sweat losses higher on the fat-supplemented diets.

3. Energy

Close attention should be paid to the quality and quantity of pasture or hay, because forage is the most important source of energy and nutrients for breeding and growing horses on horse farms. Results of a series of studies reported by researchers at Virginia[4–6] serve to reemphasize the important role that pasture and hay play in equine nutrition. Forage intake can be as high as 2–3% of body weight depending on the quality and quantity of forage available. Good bluegrass white clover pastures can have an average protein content of more than 20% and a digestible energy content of 1–1.5 Mcal/lb depending on climatic conditions. However, to maintain high quality pasture, attention has to be paid to soil fertility, weed control, and grazing management. The hydrolyzable and rapidly fermentable carbohydrate content of early spring and fall pastures can be sufficiently high to cause laminitis and colic in horses. The Virginia researchers[6] found peak levels of the hydrolyzable and rapidly fermentable fractions in forage samples taken in October and March, respectively.

Research in humans and dogs has shown that ingestion of starches and sugars have varying effects on post-prandial blood glucose levels. This is known as the glycemic response. Glycemic response to different diets has been studied in horses with two areas of interest—its effect on performance and its effect on bone development. (Glycemic effect on bone development is covered in Section 8.)

Pagan et al.[7] determined the glycemic response in six Thoroughbred (TB) geldings to different feed types. They found the highest glycemic response was from sweet feed, followed by oats, corn, and a high-fiber feed. Adding fat to diets containing high levels of starch decreases the glycemic response to starch in horses. In the above study and in a later study[8], adding vegetable oil to a sweet feed reduced the glycemic response to the sweet feed to a level that was comparable with an alfalfa diet.

Feed processing methods can affect the glycemic response to corn fed to horses. Hoekstra et al.[9] measured glucose in blood samples taken at 30-min intervals after mature horses were fed either cracked, ground, or steam-flaked corn at a level of 2 g/kg body weight. The glycemic response was somewhat greater for ground corn than for cracked corn, whereas the glycemic response to steam-flaked corn was significantly greater than that for either cracked or ground corn. Bullimore et al.[10] studied the effects of glucose and fructose on plasma glucose and insulin. Mature Arabian geldings were given 300-g doses of glucose or fructose by stomach tube. Blood samples were taken at rest and during an endurance-type treadmill exercise test. No differences were found in the responses to the administration of glucose and fructose in horses, and it was concluded that fructose is well absorbed in horses and rapidly converted to glucose. Practically speaking, glucose and fructose sources such as molasses and honey are well used by horses. Based on this study, fructose does not result in a lower glycemic response in horses as it does in humans.

Studies were reported on various aspects of fat feeding and use in horses. Kronfeld et al.[11] presented a retrospective study on the digestibility of various fats fed to horses at levels of 5–20%. Evaluated fat sources included corn oil, peanut oil, soy oil, soy lecithin, tallow, and fat blends. They concluded that there was nearly 100% absorption of the fat in all the fat sources and there were no negative effects of added fat on fiber digestion in the horses. In general, selection of fat sources should be determined by availability and economics. Most researchers agree that vegetable sources have good palatability, whereas animal sources are less palatable.

Bush et al.[12] studied the effects of adding of 5%, 10%, and 15% corn oil to forage-grain diets of mature mares on feed intake and nutrient digestibility. The corn oil had little or no effect on feed intake or digestibility of other nutrients. However, work report from The Netherlands[13] showed that fiber digestion was reduced significantly in trotting horses when a test feed was formulated to contain 37% of the net energy in the form of soybean oil. They suggested that very-high fat intakes by horses might result in enough fat entering the large intestine to depress fiber fermentation by bacteria.

There are questions about possible effects of adding fat to diets of competition horses on glycogen repletion after intense exercise. Researchers in Finland[14] supplemented non–fat-adapted horses and horses adapted to fat feeding for 3 wk with either 1000 g of carbohydrate or 400 g of vegetable oil after an exercise test on a treadmill. They concluded that the fat supplement depressed glycogen repletion in non-fat adapted horses. After feeding fat for 3 wk, glycogen repletion was similar in control horses and fat- and carbohydrate-supplemented horses. Therefore, horses should be conditioned to fat feeding for a minimum of 3 wk before intense exercise.

Studies in humans and dogs have shown that omega-3 fatty acids, especially those derived from fish oil, have many health benefits. These benefits include improvements in lipid metabolism, coronary artery disease, red blood cell formation, and insulin sensitivity. O'Connor et al.[15] carried out studies to determine if dietary omega-3 fatty acid supplementation would be reflected in the serum fatty acid profile of horses. Corn oil that contains no significant amounts of omega-3 fatty acids or fish oil was top dressed on the feed of TB and Standardbred geldings at the rate of 324 mg/kg body weight for 63 days. Blood serum was analyzed for the omega-3 fatty acids found in fish oil, eicosapentaenoic acid and docohexaenoic acid. There was no increase in serum omega-3 fatty acids in horses receiving corn oil, whereas there was a fourfold increase in the omega-3 fatty acids in horses receiving fish oil. The fish oil–supplemented horses also had a lower concentration of omega-6 fatty acids and a significantly lower omega-6:omega-3 fatty acid ratio in blood serum.

4. Protein

Alfalfa is a good source of protein for growth in young horses. Wall et al.[16] conducted a study with yearling Quarter Horse fillies to determine the efficacy of alfalfa hay protein to support growth. Various growth parameters and nitrogen retention were compared when the fillies were fed a diet in which alfalfa hay was the source of supplemental protein versus fillies fed a diet in which soybean meal was the source of supplemental protein. The growth measurements were similar between the two diets. Fillies fed the soybean meal supplemented diet retained more nitrogen, and this suggests that muscle protein gain may have been greater in fillies fed the soybean meal–supplemented diet. Coleman et al.[17] also found that a diet containing 60% alfalfa cubes that was formulated to meet 100% of the NRC (National Research Council) requirements for protein and lysine supported satisfactory growth rates in stock horse-type weanling fillies. It should be pointed out that alfalfa made up 40% of the diet in the first study[16] and 60% of the diet in the second study,[17] and that it is important to supplement phosphorus and trace minerals that are deficient in alfalfa when young horses are fed diets containing large amounts of alfalfa.

Superior feed protein sources for horses have high levels of essential amino acids with high prececal digestibilities. Coleman et al.[18] used ponies with cannulas in the terminal ileum to determine the prececal digestibility of protein and lysine in alfalfa cubes and in mixed concentrates with graded levels of protein and lysine. He determined that the prececal digestibility of protein and lysine in high quality alfalfa was only 60% of that of the concentrate mixtures used in his studies. Results of studies by Almeida et al.[19] in Brazil also indicated that the prececal digestibilities of amino acids differed between feed protein sources. These results have primary application in young growing horses or in performance horses when attempts are made to minimize total dietary protein intake.

Protein levels can be reduced in the diets of mature performance horses if adequate levels of essential amino acids are maintained in the diet. Graham-Thiers et al.[20,21] fed mature Arabian horses diets containing 12% fat that were formulated to contain either 14.5% crude protein or 7.5% crude protein supplemented with lysine and threonine to match the levels of these amino acids in the higher protein diet. No signs of a protein deficiency were observed in the horses receiving the 7.5% protein diet with lysine and threonine added.

5. Minerals

Mineral metabolism is one of the top areas of horse research. In the last 5 yr, there has been abundant literature on bone mineral content, availability of organic versus inorganic sources, emerging significance of previously considered minor minerals, and effects of growth, exercise, or sedentary status on mineral metabolism.

Evaluating Bone Mineral Content

Bone composition and mineral deposition are not well understood in the horse, partially because of the difficulty in diagnosing nutritionally related bone disease. Earlier work described a biopsy procedure of the 12th rib in standing horses, but other researchers questioned if rib bone is representative of bone in the lower leg where many breakdowns occur. Texas researchers compared the bone mineral content of the third metacarpal and 12th rib in equine cadavers and live animals.[22] Results indicate the biopsy of the 12th rib is a useful diagnostic tool in evaluating the mineral status in the horse, especially for calcium.

Michigan workers used non-invasive, computed tomography (CT) to estimate bone mineral content and density of the third metacarpal bone.[23] In tomography, X-rays are passed through a subject and detectors record transmitted energy. The computer then constructs cross-sectional images representing the internal anatomy. The image recorded by the CT uses an imaging photodensitometer and a software package to estimate the area of each bone section. The authors concluded CT may be useful in calculating estimated bone mineral content and could detect differences in bone density.

Chromium

Chromium's (Cr) role in growth, immune function, and energy metabolism of horses is poorly understood but has generated a lot of interest. Ott and Kivipelto found Cr tripicolinate supplementation increased the rate at which glucose is metabolized, but it had no effect on the growth rate and development of yearling horses in a 112-day trial.[24] Gentry et al.[25] concluded that Cr tripicolinate supplementation (5 mg/head/day) in the adult sedentary mare on a Bermuda grass hay diet had marginal effects on metabolic, hormonal, and immune responses.

Cr supplementation has been reported to enhance insulin action in several species; because insulin resistance is a common problem in geriatric horses, Cr-L-methionine was tested as a solution.

Colleagues at Rutgers[26,27] supplemented geriatric mares (21–32 yr) with two levels of Cr-L-methionine for 4 wk. They did not alter immune parameters or glucose and insulin responses in a consistent manner. It appeared Cr had no effect on the glucose/insulin responses to either an intravenous dextrose challenge or a natural challenge of a meal of concentrates. Contrary to previous work with performance horses, these data in growing, sedentary, and geriatric horses found that supplementation with Cr tripicolinate or Cr-L-methionine were not justified by improved growth, immunity, or glucose/insulin responses.

Molybdenum and Copper

Research data from other species show that excess molybdenum (Mo) can cause a secondary copper (Cu) deficiency, but little is known of this relationship in horses. Oklahoma scientists found that mature geldings fed 0, 5, 10, and 20 ppm of supplemental Mo for 23 days had a similar Cu balance in all diets.[28] As Mo intake increased, fecal and urine excretion of Mo increased, resulting in no adverse effect on the absorption and retention of Cu. In contrast to rabbits, ruminants, swine, and chickens, horses seem to be immune to the detrimental effects of excess dietary Mo on Cu.

Aluminum

High levels of aluminum (Al) in ruminants have been reported to adversely affect the metabolism of calcium and phosphorus. Kentucky workers fed 931 ppm Al for 4 wk to mature TBs and found no effect on the nutrient digestibility or metabolism of calcium, phosphorus, magnesium, zinc, copper, and boron.[29] Urinary iron excretion was higher in the Al diets compared with the basal diet. It was concluded that short-term consumption of a diet with moderate amounts of Al (931 ppm) has negligible effect on nutrient digestibility and mineral metabolism.

Silicon

Previous work has shown silicon (Si) to have a role in bone metabolism by enhancing osteoblastic activity and decreasing osteoclastic activity. In addition, when zeolite A, a silicon-containing supplement was fed to young Quarter Horses in race training, there were less bone-related injuries compared with the controls. In a continuation of this theme, Si supplemented yearlings had increased plasma Si concentrations by day 15 and continued for the 45-day trial, plus they had decreased bone resorption.[30] Biochemical bone turnover markers gave no indication as to the quality of the bone that was formed, consequently, it is not known if bone strength was improved. This paper also pointed out the tedious collection, preparation, and analytical methods that must be employed because silicon is a component of glass and circulating dust particles. Minimizing environmental and laboratory silicon contamination is critical in these studies.

Iron

Pearson and Andreasen fed mature ponies excessive dietary iron at the rate of 50 mg of iron (as ferrous sulfate) per kilogram of body weight daily to observe the effects on blood and liver.[31] By the end of the 8-wk study, hepatic iron, serum iron, percentage saturation of transferrin, and serum ferritin concentrations were elevated compared with day 0 levels and the control ponies. Liver biopsies revealed no abnormalities, and no adverse clinical signs were documented. Liver iron concentrations returned to baseline when checked at 28 wk. Horses or ponies are unlikely to develop iron toxicosis caused by excessive consumption of Fe in the form of ferrous sulfate.

Manganese

In Florida, yearlings were fed either a diet deficient in manganese (Mn) or one meeting NRC recommendations for 112 days.[32] Those on adequate Mn gained more weight, had better feed efficiencies, higher serum Cu, and in general had higher serum hydroxyproline (an indicator of bone resorption) and higher total bone mineral content (estimated by photodensitometry) than those with the lower level of Mn. Authors confirmed that the horse requires NRC levels of 40 ppm Mn, and regions known to have low or marginal Mn in forages could benefit from supplementation.

Copper, Zinc, and Manganese

Scant research exists on the effect of exercise on trace minerals requirements; therefore, Kentucky workers fed mature TB geldings varying levels of copper (Cu), zinc (Zn), and manganese (Mn) for 16 wk.[33] One-half of the animals were kept in a sedentary situation and the other half were exercised on a high-speed treadmill. Results indicated that exercise causes an increase in zinc requirements, but does not affect the true digestibility or maintenance requirements of copper and manganese; furthermore, NRC recommendations for zinc in working horses may be underestimated.

Limited and contradictory research exists regarding the effect of organic trace minerals on the trace mineral status of horses. Colorado workers replaced 50% of the supplemental inorganic sources of Cu, Zn, and Mn with organic sources for 120 days in the diets of mature non-pregnant mares. The organic form did not effect liver concentrations of these minerals, did not improve cellular immune response, and did not influence hoof wall growth rates, hardness, tensile strength, or trace mineral content in the hoof.[34,35] In mature, non-pregnant mares, the use of 50% organic forms (also known as chelated-, proteinated-) of Cu, Zn, and Mn was not beneficial. Inorganic sources of copper sulfate, zinc sulfate, and manganese oxide were as effective as the organic forms of copper-lysine, zinc-methionine, and manganese-methionine.

Selenium

Vitamin E and Selenium (Se) have been reported to reduce exercise-induced oxidative stress, tissue damage, and possibly capture free radicals. Many antioxidants, such as glutathione peroxidase, are selenoproteins, making selenium an important mineral in the diets of hard working horses. Digestibility and retention of organic versus inorganic sources of Se were evaluated with mature exercising horses using sodium selenite or Se-enriched yeast. Horses were fed the Se-enriched diets for 5 wk and exercised 3 day/wk on a high-speed treadmill; the two diets contained approximately 0.4 ppm Se, with 75% of the total Se provided by either the selenite or yeast form.[36] Se from the yeast form was more digestible with greater retention than the selenite, leading to a greater positive Se balance in the exercising horse.

Calcium, Phosphorus, and Magnesium Involved in Bone Density

Confinement or deconditioning in mature horses for 12 wk with only minimal exercise on a mechanical walker resulted in a decrease in bone mineral content by approximately 0.45% per week (determined by radiographic photometry using an aluminum step wedge).[37] This strong drop was unaffected by twice the currently recommended level of Ca. After 12 wk of stall confinement, loss of bone mineral content may have weakened bones. Great care should be used in the reconditioning process to avoid skeletal injuries.

Biochemical and radiographic data on young, mature, and aged horses were recorded to find the effect of different Ca and P levels and of increasing aerobic exercise after confinement.[38] Horses received either control diets with 133% of NRC requirements for Ca and P or diets with 275% of NRC levels of Ca and P. Horses were confined for 63 days and then placed on an ascending aerobic exercise program for four 21-day periods. Higher levels of minerals allowed greater bone turnover in all ages, but the highest turnover was in the young animals. As horses age, they do not have the ability to respond to exercise after a period of idleness, and osteoblastic activity was lowest in the aged (over 16 yr) compared with young and mature horses. Inactivity results in lower bone density, and when exercise begins, there is an increased risk of injury in older horses.

6. Vitamins

Vitamin E resides in lipid membranes where it protects against exercise-induced muscle damage and improves immune response in horses. It is proposed that ascorbic acid spares tissue vitamin E by reducing the tocopheroxyl radical and restores the radical scavenging ability of vitamin E. Horses normally can synthesize sufficient blood ascorbate, but during stress of transportation and training, ascorbate demand may overwhelm the body's ability to manufacture the vitamin. Weanlings given supplemental vitamin C (10 g/day) and E (800 IU/day) after being transported 2400 miles showed a higher vaccine response, fewer upper respiratory infections including fever, and less days off feed compared with nonsupplemented animals.[39] While the numbers in this study were small (5/treatment), researchers at Rutgers found there was sufficient response to warrant a sequential study.

Using mature exercising polo ponies, researchers in Connecticut studied the influence of dietary vitamin E (240 IU vitamin E/kg intake) and vitamin C (10 g ascorbic acid/day) on nutritional oxidative status.[40] Serum ascorbate and tocopherol concentrations were higher in the vitamin E- and C-supplemented animals, especially in the late season. The authors concluded that the performance and welfare of the heavily worked animal such as the polo horse might be improved with vitamin E and C additions, especially late in the season when overtraining is an issue.

Practitioners are often at a loss to select the most effective form of vitamin E to increase the serum tocopherol concentrations. There are several synthetic and natural, oral and injectable forms on the market; all vary in their bioavailability and kinetic properties. Virginia researchers found the oral products gave the greater responses measured by areas under the concentration versus time curves.[41] Likewise, the natural forms exhibited higher bioavailabilities than synthetic sources. The most effective source of vitamin E is the oral and natural form, D-α-tocopherol.

Broodmares and foals benefited from vitamin A supplementation to mares in the form of retinyl palmitate, but they did not respond to water dispersible β-carotene. Forty-five mares were depleted of vitamin A for 8 mo and then repleted for 20 mo with retinyl palmitate, β-carotene, or a placebo. Foals from the depleted mares with no vitamin A had lower birth weights and slower growth rates than those on a vitamin A supplement or on pasture and hay. Supplementation with retinyl palmitate at twice the NRC recommended daily level resulted in a higher pregnancy rate and foaling rate.[42] Lack of vitamin A during pregnancy may increase the risks of retained placenta and congenital contracted tendons. In practice, mares kept in dry lot on medium- to poor-quality hay may benefit from vitamin A in the form of retinyl palmitate.

Folate, folic acid, and pteroylglutamic acid are synonyms for the water-soluble B vitamin that serves as a carbon donor in DNA, RNA, and protein synthesis. Folate requirements increase during growth and lactation and are especially important in early lactation when the mare and foal have high demands. Mares' milk folate declined during the first 3 mo of lactation, indicating less folate is mobilized into milk to maintain the dams' body stores.[43] The decline in milk folate coincided with a marked decline in foals' folate status. As foals start to consume forage, their folate status improved dramatically. Folate supplementation during early lactation and growth is warranted to sustain folate status in foals either by supplementation of the mares to increase milk folate or directly to foals until 3 mo of age.

Vitamin K is an overlooked nutrient involved in bone growth and development as well as blood coagulation. Historically, it was assumed that typical horse diets supplied adequate vitamin K because horses consuming these diets had normal blood coagulation; however, vitamin K required for normal blood clotting in other species is less than that required for carboxylation of osteocalcin. Therefore, horses may have enough K for clotting but lack enough for proper bone metabolism. Blood samples were analyzed for total serum osteocalcin; vitamin K status was expressed as the hydroxyapatite binding capacity of serum osteocalcin in 18- to 24-mo-old Quarter Horses before 194 days of training. When horses were exercised, there was a trend toward greater serum osteocalcin concentrations over time. While these studies are preliminary, they are the first reports of vitamin K status as it relates to its function in bone growth.[44,45]

7. Broodmare Nutrition

Much of our time and effort in the weaning process has been dedicated to foal nutrition with little focus on the mare. Holland et al.[46] monitored stress parameters in 18 mares during and after weaning on two diets: fat-supplemented versus starch-based. Serum cortisol and zinc levels, plasma ascorbate, and neutrophil:lymphocyte ratios supported the conclusions that mares on the fat and fiber diet handled weaning stress better than those on a carbohydrate-based diet. Another interesting sidelight to this study was that mares weaned later were stressed more than the early-weaned mares. Prepare mares for weaning by feeding a fat- and fiber-based diet, and problem mares should be weaned first.

Louisiana workers explored the relationship between body condition and reproductive and hormonal characteristics of mares during the traditional seasonal anestrous period into the transitional period before breeding.[47] Mares with very-low body condition scores (3–3.5 on Henneke scale) went in to a deep anestrous state, whereas very-high body conditioned mares (8–8.5) continued to cycle without going anestrous. From September to January, blood levels of LH (luteinizing hormone), FSH (follicle stimulating hormone), and prolactin clearly supported the findings. Mares kept in a fat condition during the fall and winter months are hormonally better prepared for breeding than thin mares.

Mares in a low body condition at foaling did not respond hormonally or reproductively to a fat-supplemented diet that allowed them to gain 15% of their post-foaling body weight in 90 days.[48] Mares foaling in a thin body condition (<5.0 on Henneke scale) and then fed a high-calorie diet for 3 mo did not recover sufficiently to positively impact LH concentrations or reproductive parameters. Mares should be in a moderate-to-fleshy body condition (>5) before foaling to reduce the risk of poor pregnancy rates.

German authors published an interesting list of dietary factors that they think influence mare reproduction.[49] We will share a few of the more relevant items: twin pregnancy may be favored by excessive energy before conception; energy restriction just before parturition can induce a premature birth; mares need an adequate intake of methionine (essential amino acid) to ensure the onset of estrus; fetal growth is retarded by the marginal intake of calcium; and selenium and iodine influence mare fertility and fetal development. This paper may be a good resource for practitioners with an unsolved farm or regional reproductive problem.

Concentrates of fat and fiber (beet pulp, soy hulls, straw, and corn oil) are superior to sugar and starch concentrates (corn and molasses) when fed to mares by influencing milk composition in ways that improved foal health.[50] Mares were maintained on bluegrass and clover pastures and fed one of the two concentrates pre-foaling to weaning (at 6 mo). The diets were isoenergetic and isonitrogenous with minerals balanced to complement the pastures and to meet NRC recommendations. Concentrates of fat and fiber fed to lactating mares caused elevated linoleic acid in milk. Furthermore, the authors postulated that the elevated linoleic acid may reduce the risk of foal gastric ulcers and the higher IgG (4.2-fold increase) in colostrum may enhance passive immunity.

Broodmares are often fed large meals of grain to increase body fat before breeding, to increase fetal size, or to stimulate milk production after foaling. This ingestion of large quantities of grain-based soluble carbohydrates has been implicated in certain digestive and metabolic disorders. A continuation of the fat and fiber versus sugar and starch work in Virginia shed light on the glucose and insulin response in barren mares and broodmares to the two diets. Differences between the barren and reproductive mares reveal that pregnancy has a profound effect on maternal fuel metabolism, presumably to meet the fetal demands. Glycemic effect in barren mares was less with fat and fiber than in sugar and starch diets during the spring and summer months.[51] More work is needed, but these findings indicate that the risk of certain digestive disorders may be reduced in broodmares with a fat and fiber feed in place of grain.

There is no benefit to overfeeding trace minerals Cu, Zn, and Fe to pregnant and lactating mares. Pregnant mares were fed either a concentrate that met NRC Cu, Zn, and Fe recommendations or a concentrate fortified with four times the trace minerals for 84 days pre-foaling and 112 days post-foaling.[52] In conclusion, the extra minerals had no influence on foal growth, mare and foal serum levels of Cu, Zn, and Fe, trace minerals in mares' milk, foal serum bone specific alkaline phosphatase (BALP, an indicator of bone deposition), or foal bone mineral content.

The effect of source and level of selenium (Se) on mare and foal Se status and antibody titers to influenza were examined by Kentucky workers.[53] Mares were assigned to one of three Se supplements: 1 mg Se/day as sodium selenite, 3 mg Se/day as sodium selenite, or 3 mg Se/day as Se-yeast for 55 days pre-foaling and 56 days post-foaling. Milk Se, foal serum Se, and foal glutathione peroxidase activity were higher on the yeast source. After 2 wk, antibody titers were greater in foals from mares receiving 3 mg Se/day. When selecting a bioavailable source for individual or regional selenium deficiency, selenium yeast is superior to sodium selenite.

Feeding a concentrate with 160 versus 80 IU of dietary vitamin E/kg for 4 wk before foaling and 4 wk after foaling enhanced colostrum and improved blood levels of E in mares and foals.[54] Concentrations of IgG, IgM, and IgA in colostrum were significantly enhanced by dietary vitamin E over control animals, presumably improving passive transfer and foal health.

8. Growth

A great deal of important research has been undertaken in recent years on bone development in young growing horses. Warren et al.[55] studied possible effects of weaning foals at 4.5 and 6 mo of age on bone density and growth. They concluded there were no significant effects from weaning at either 4.5 or 6 mo of age on wither height or bone density, as indicated by analysis of radiographs of the third metacarpals using an aluminum step wedge technique. A decline in weight gain at 1 and 3 wk post-weaning was observed in foals weaned at either age.

Many believe that bone development problems are more prevalent in larger, more rapidly growing horses. This seemed to be the case on a Kentucky TB farm where 271 foals were evaluated over a 4-yr period.[56] DOD was diagnosed in about 10% of the foals. Those that developed hock and stifle OCDs as yearlings tended to be large foals at birth and ones that grew rapidly as foals. It remains to be determined whether such possible effects of size and growth rate on bone development are the result of genetics or nutrition.

Petersen et al.[57,58] conducted a study of the effect of rations formulated for slow and rapid growth on bone mineral content and bone mineral density of appendicular skeleton. They used dual energy x-ray absorptiometry techniques to measure bone mineral content and quality. They concluded that horses fed for rapid gain tended to have greater increases in bone mineral content than foals fed for slow gain and there were no differences in bone mineral quality. Blood serum analyses showed that serum osteocalcin concentrations were higher in foals growing more rapidly at similar ages but there was no effect on serum bone specific alkaline phosphatase concentrations. They noted, however, that three of six foals fed for rapid gains developed clinical signs of physitis and joint pain. Clinical signs of physitis were not evident 60 days later at the end of the study.

Some have proposed that certain combinations of ingredients or nutrients in feeds coupled with growing horses' hormonal responses may predispose them to OCD problems. It has been suggested that glucose intolerance caused by insulin resistance may be associated with OCD in young horses. Ralston et al.[59] developed an oral dextrose challenge test for glucose intolerance in foals and found indications with limited numbers of animals that there may be an association of glucose intolerance with OCD.

Pagan et al.[60] studied the possible implication of hyperglycemia and hyperinsulinemia with OCD in a field study in which young horses were fed concentrate feeds with different glycemic indexes. They conducted a glycemic response test on 218 Thoroughbred weanlings on six central Kentucky farms. Blood plasma glucose and insulin levels were analyzed in samples taken 120 min after the foals were fed their normal concentrate feed at levels adjusted to equalize the intake of non-structural carbohydrates (primarily starch and sugar). The overall incidence of OCD was recorded until the horses were sold as yearlings. Twenty-five horses were treated surgically for OCD lesions. There was a strong positive correlation ($p < 0.01$) across all farms between the incidence of OCD and serum glucose and insulin levels 120 min after feeding. However, within a farm, there were no significant differences in the glycemic response between horses that had lesions and those that did not. They concluded that the high correlations between farms in the incidence of OCD with the glycemic response was probably caused by differences in the glycemic index of feeds fed on the farms. The results of this study suggest that it would be prudent to feed foals concentrates that produce low glycemic responses.

Juvenile racehorses entering training undergo a period of demineralization followed by a period of remineralization. Research by Nielsen et al.[61] with yearling Quarter Horses and Porr et al.[62] with yearling TBs showed a significant decrease in the density of metacarpal bone that was believed to be caused by remodeling of the bone in response to exercise. The onset of speed work often coincides with the time of greatest demineralization (50–60 days into training), which may account for the high incidence of skeletal injuries in 2-yr-old horses in training.[63] Training methods and protocols should be designed to reflect the findings that significant demineralization of metacarpal bone occurs in the first 60 days of training.

Studies on the mineral requirements of young horses in training found NRC levels of P adequate, but recommended higher Ca levels (35 versus 28 g/day) for young horses in training.[64] Biochemical markers in blood and radiographic bone aluminum equivalence were used to track bone turnover and density in horses fed four different levels of Ca, P, and Mg.[65,66] Horses on the two highest intakes of minerals showed higher rates of bone mineralization.

Researchers in Oklahoma found evidence that NRC recommendations for Ca for long yearlings (18 mo) not in training need to be increased. There were increased absorption, retention, and digestibility of Ca during periods of growth, indicating a level of 115% of NRC may more correctly meet the needs of the idle long yearlings.[67]

With the onset of training, young horses experience a significant management change in that they become primarily confined to stalls. This practice of moving growing horses from pasture to stalls before yearling sales or training may predispose them to injury, delay, or even terminate a competitive career. Michigan authors found that housing long yearling/2-yr-old horses in stalls is associated with a loss of bone mineral content in comparison with horses maintained on pasture.[68] The mineral content of the third metacarpus, using lateral and medial radiographic bone aluminum equivalency (RBAE), was determined on 16 Arabian yearlings. By day 28, the confined yearlings had a lower RBAE, which continued for the remainder of the 140-day experiment. The authors suggested that allowing young horses free access to exercise on pasture might supply the loading necessary to strengthen the skeletal system. If free exercise is not an option, training must be modified to account for the possible bone loss experienced as a result of confinement to stalls.

Thomson et al.[69] studied the response in bone density to the administration of exogenous somatopropin (eST). The study was conducted with 30 Quarter Horse yearlings in race training. Geldings and fillies were used in the study with a mean age at entry into the study of 629 days (21 mo). Analysis of radiographs of the left third metacarpal using the RBAE technique indicated that bone density was greater in horses receiving eST. They proposed that eST might be a potential management tool to help prevent bone mineral loss that often occurs in the training of young racehorses.

9. Performance

Electrolytes and Water

The equine gastrointestinal tract provides a water and electrolyte reservoir that can be used to replace fluid and ions lost in sweat. The size of this ion bath can be influenced by diet composition and type of dietary fiber.[70,71] Eight conditioned Thoroughbred geldings were fed two diets in a cross-over design. Diets contained similar energy, protein, and electrolyte content but differed in the dietary fiber level. The high-fiber (HF) diet contained 54% NDF and 31% ADF, and the low-fiber (LF) diet contained 31% NDF and 19% ADF. Animals were dehydrated with furosemide for 4 h and then exercised on a high-speed treadmill for 45 min. The HF diet increased the size of the fluid reservoir in the GIT, making fluid in the GIT more available to replace fluid and electrolyte losses. The HF diet did not stop the plasma volume decline that accompanies dehydration and exercise. Endurance horses and others used in prolonged exercise bouts should be fed HF diets to help maintain fluid and electrolyte levels resulting in fewer cardiovascular and thermoregulation problems.

Researchers at Michigan were able to hyperhydrate horses with an 8-l glycerol-saline solution.[72] Normal, resting horses were given one of four nasogastric treatments: water only, saline solution, glycerol solution, or glycerol-saline solution. The glycerol-saline solution resulted in a tendency toward increased renal water conservation and increased water consumption in the 5 h after administration. While preliminary in nature, it seems that a glycerol-saline solution stimulated voluntary drinking and reduced renal water output, achieving a short-term hyperhydration.

Hypertonic electrolyte supplementation just before and during exercise provides greater health benefits to horses than no supplementation during 60 km (38 miles) of treadmill work.[73] Horses were given either water or an electrolyte paste 90 min before exercise and at 15-km intervals. Electrolyte-supplemented horses drank twice as much water, lost less weight, and maintained higher blood electrolyte levels (sodium and chloride) than non-supplemented horses. Horses should have frequent access to water when given these pastes. The paste consisted of 38–75 g of a 2:1 NaCl:KCl mixture.

Spanish workers reported that an isotonic sweat-like electrolyte solution was preferred because it rapidly restored the fluid and plasma electrolyte imbalances. In contrast, isotonic glucose-glycine-electrolyte solutions impaired the plasma electrolyte imbalances. Horses were dehydrated using furosemide and given an equal volume of solution by nasogastric tube as the weight they lost through dehydration. Plasma values of chloride, potassium, and creatinine recovered to premedication levels significantly faster with the isotonic sweat-like solution.[74] In summary, an isotonic electrolyte solution with composition similar to equine sweat is the best solution to rapidly and efficiently restore fluid loss and plasma electrolytes in exercise-dehydrated horses.

Work in Germany concluded that glycerol was not a hyperhydrating substance for horses during a simulated 60-km endurance ride on a treadmill and should not be administered.[75] Results showed electrolyte supplementation in the form of hypertonic oral pastes improved water intake during endurance exercise, but glycerol administrations provided no benefits over the electrolytes alone. Furthermore, the sweet taste of glycerol was not well tolerated and temporarily stopped the horses from eating hay during the rest break.

Coenen et al.[76] studied the effects of post-exercise supplementation of water, glucose, or electrolyte solutions on fluid and electrolyte balance in Standardbred horses during a 2-h recovery period and during subsequent exercise. The solutions were administered through a nasogastric tube after exercise. They concluded that electrolyte supplementation was the most effective treatment for increasing plasma volume and maintaining plasma electrolytes during rest after exercise and during subsequent exercise. The administration of water and glucose solutions seemed to have no benefit on electrolyte and fluid balance.

Exercise and Digestion

Some have suggested that exercise may have a detrimental effect on the digestion of feed in horses. Pagan et al.[77] compared the digestibility and rate of passage of forage and forage-grain mixed diets in horses exercised on a treadmill and non-exercised horses. They found that there was a small but significant decrease in dry matter digestibility caused by exercise, and rate of passage was also increased. However, the authors noted that the differences were small and concluded that the decrease in digestibility caused by exercise probably had little or no practical significance.

Protein Effects on Exercise

Protein must be provided in the diets of exercised horses to provide nitrogen and amino acids needed for muscle development and repair and to replace sweat losses. Graham-Thiers et al.[20,21,78] proposed that feeding low-protein diets supplemented with essential amino acids might be an effective way to supply the required nitrogen and amino acids while reducing some of the possible adverse metabolic effects of dietary protein. They suggested that excess dietary protein could depress exercise performance because of possible thermogenic, acidogenic, and ureogenic effects. In one study, two groups of five mature Arabian horse were fed two diets containing 12% fat as added corn oil and either 14.5% crude protein or 7.5% crude protein supplemented with 0.5% lysine and 0.3% threonine to provide similar levels of lysine and threonine in both diets.[21] After a 9-wk conditioning period, the horses performed a repeated sprint-type exercise test on a treadmill. Analyses of blood samples showed that blood pH declined in all animals during the exercise test, but blood pH remained higher in horses fed the 7.5% protein diet than in the 14.5% protein diet. They concluded that dietary protein restriction for 9 wk moderated sprint-induced acidosis in fat-adapted horses.

Blood Gas Testing

Blood gas testing is common in Standardbred racehorses to control pre-race administration of alkalizing agents. Kauffman et al.[79] carried out studies to determine whether feeding different types of forages and forage-grain mixes might result in different plasma T_{CO_2} values that could affect the interpretation of blood gas tests. Ten mares were fed five diets composed of 100% alfalfa, 60% alfalfa, 40% alfalfa, predominately coarse roughage, and pasture for 2 wk in a 5×5 Latin square design study. Blood samples were drawn throughout the study for analysis. They found that plasma T_{CO_2} values tended to be higher in horses consuming the alfalfa diets than in horses consuming the coarse roughage and pasture diets with the greatest differences between diets occurring within 2 days of changing diets. They concluded that racehorses consuming predominately alfalfa diets may be at higher risk for testing above allowable limits for plasma T_{CO_2} and suggested that racing jurisdictions should consider local feeding and management practices when determining allowable limits for plasma T_{CO_2}.

Feeding Time and Feed Restriction

A number of studies have been reported on the effects of time of feeding, feed restriction, and dietary composition on various blood hormones and metabolites in exercised horses. Kentucky researchers noted the increasing concern about the effects of thyroid hormone concentrations on exercise performance and have studied possible nutritional effects on thyroid hormones and other blood constituents. Powell et al.[80] investigated the effects of feed restriction and different forage-grain ratios on blood concentrations of thyroxine (T_4), triiodothyronine (T_3), lactate, glucose, and free fatty acids (FFA). They concluded that short-term diet restriction may affect peripheral conversion of T_4 to T_3 in exercising horses and that either diet composition or short-term feed restriction may affect the ability of horses to maintain blood glucose concentrations during exercise.

In studies[81,82] of longer-term feed restriction, the Kentucky researchers concluded that restricting feed to horses might elicit metabolic changes that are dependent on the composition of the diet. Their work suggested that during feed restriction, FFA mobilization and use may be greater in horses adapted to high forage diets and glucose uptake may be greater in horses adapted to high-grain diets.

Their work also indicates that exercised and sedentary horses do not have the same adaptive responses to long-term caloric restriction. Their data supports the proposal that glucose may play a regulatory role in the conversion of T_4 to T_3.

Duren et al.[83] conducted studies on the effects that time of feeding and fat supplementation had on concentrations of plasma insulin and metabolites in exercised TB horses. A standardized exercise test (SET) was conducted with horses fed a textured feed or a textured feed supplemented with fat at three different times, 12, 8, and 3 h before the SET. Blood samples were taken several times before, during, and after the SET and analyzed for glucose, lactate, insulin, and nonesterified fatty acids (NEFA). Plasma glucose and insulin were elevated at rest in horses fed 3 h before the SET. The elevated insulin levels before the SET seemed to decrease plasma glucose during exercise. Levels of plasma NEFA indicated that fat oxidation was depressed during exercise in horses fed 3 h before the SET. Fat supplementation seemed to increase the ability to use fat at rest and during exercise. They concluded that these and other studies show that pre-exercise feeding time does have an influence on circulating blood metabolites available for use during exercise. They also stated the view that the potential for hyperinsulinemia to negatively influence plasma concentrations of nutrient and hormones outweighed any potential benefits of feeding horses 3 h before exercise.

Pagan and Harris[84] reported on a series of studies on the effects of timing and amount of forage and grain feeding on the exercise response in horses. The exercise tests were designed to simulate the physiological and metabolic stresses of a 3-day event. The objectives of these studies were to evaluate how feeding forage along with grain influences plasma hormones and metabolites and water intake and then to determine whether these changes had an effect on exercise performance. They found that feeding hay either before or with grain reduced the glycemic response from the grain and plasma insulin levels were also reduced. Feeding only forage before exercise did not seem to have an adverse effect on performance. They concluded that grain should be withheld from horses before exercise and recommended that small amounts of hay be fed to ensure proper gastrointestinal tract function.

Rice et al.[85] studied the effects of *ad libitum* and restricted hay intake (1% of body weight) on body weight and metabolic responses of TB horses to high-intensity exercise. Restricting hay for 3 days reduced body weight by 2% and improved the efficiency of energy use. The authors pointed out that it is normal practice to limit hay intake of racehorses to a level that is similar to the restricted hay intake level used in this study. They concluded that more severe or longer-term restrictions of hay intake could not be recommended on the basis of this study, but further studies were warranted on the effects of different feed fiber types on body weight and exercise performance.

10. Nutritionally Related Diseases

Muscle Disorders: Equine Rhabdomyolysis Syndrome and Polysaccharide Storage Myopathy

Equine rhabdomyolysis syndrome affects the muscles of horses of nearly any age, breed, or gender. Horses afflicted with the syndrome have partial or complete inability to move, profuse sweating, and elevated respiratory rates during or after exercise. Two subgroups, with specific and different causes, have been observed. One involves a dysfunction of the muscle excitation-contraction process (sporadic tying up) in a previously normal horse; the other, chronic/recurrent form, involves a defect in the carbohydrate storage-use process.[86]

Minnesota workers in a valuable series of studies found the recurrent form has two separate breed-specific targets identifiable by muscle biopsies. Polysaccharide storage myopathy (PSSM) is a form of chronic rhabdomyolysis in heavily muscled horses such as Quarter Horse-related breeds, warmbloods, and drafts with abnormal polysaccharide accumulation in the muscle fibers. In TB, Standardbreds, and Arabians, recurrent exertional rhabdomyolysis (RER) is seen without the polysaccharide accumulation in the muscle fibers.[86–88] RER is most often seen at the track in fit young fillies with a nervous temperament but has been identified in older males. Typically these animals are well conditioned, have trouble maintaining body weight, and are fed 12 or more pounds of grain per day. It seems the susceptibility is inherited as a dominant trait, which can be influenced, by diet, rest, lameness, and training regimen.[89,90]

A biochemical basis for RER in TBs has been identified by Lentz et al.[91] The altered contraction/relaxation muscle state in RER suggests abnormal intracellular calcium that is completely independent of dietary calcium concentrations.

There is no single diet change that stops RER; however, several nutritional and management procedures are recommended, which reduce the frequency and severity of attacks. In the past, many caregivers suggested that reducing grain levels would alleviate the episodes. Because racehorse required the starchy grains to meet energy needs, reducing grain usually negatively affected performance. Recent research suggests that replacing most of the grain in the diet with a high-fat, high-fiber, low-starch diet kept the post-exercise serum CK values low and provided sufficient calories to meet performance expectations.[86,90,92,93] Susceptible horses should also have standardized daily exercise and an environment that minimizes excitement.

PSSM is identified by an accumulation of phosphorylated glucose, glycogen, and an abnormal polysaccharides in the skeletal muscles. Horses will often show signs of PSSM at a young age, and it can reoccur at one episode per year or at every exercise session. Often a few days rest before exercise is a common triggering factor. When PSSM horses are fed a starch meal, they store a higher proportion of the absorbed glucose in their muscle compared with normal horses. It seems that affected PSSM horses are able to clear glucose from the blood faster than normal horses as a result of an increased insulin sensitivity.[87,94]

Horses with PSSM are often easy keepers and do not need large quantities of grain. A diet of good quality hay will often supply the needed calories; however, the addition of small amounts of fat has proven beneficial and is advised. The inclusion of 2 lbs of rice bran per day or one cup of vegetable oil over alfalfa pellets, plus 600-1000 IU/day of vitamin E has been found to reduce muscle glycogen.[95] Dietary changes alone will not curtail the PSSM episodes. A modification of the training schedule to include gradual increases in time and intensity of work and daily turnout are critical to maintain fitness.

Fescue Toxicosis

Tall fescue is the most abundant and economically important cool season perennial grass in the United States. Fescue is very tolerant to adverse environmental conditions while maintaining above average forage yields. Approximately 75% of the tall fescue in Southeastern United States is infected with the endophyte, *Acremonium coenophialum*. The endophyte increases the plant's hardiness but causes a toxicosis that is detrimental to livestock, especially to the late pregnant mare. Deciding how to use the forage but minimize the side effects has interested several laboratories.

Most of the negative effects of endophyte-infected fescue have been documented in late gestating mares with no data on the early or mid-gestational mare. Hill et al. found that mares in early to mid-pregnancy grazing in endophyte-infected pastures were unaffected by the endophyte and did not have suppressed progesterone, T_3, or T_4 concentrations.[96] North Carolina investigators found adult exercising horses suffered vasoregulatory and thermoregulation side effects to the endophyte.[97] Horses grazing in endophyte-infected fescue pastures had a decreased ability to dissipate heat and a prolonged recovery from exercise during hot weather. It seemed that blood flow to the skin and core tissues is decreased, limiting the animals ability to dissipate heat from the body surface by inducing vasoconstriction.

Laminitis

Fresh grass contains large amounts of water-soluble carbohydrates, such as sucrose, fructose, glucose, and fructan. With the exception of fructan, plant sugars are digested in the small intestine. When large amounts of undigested carbohydrates, such as fructan, are pushed into the hindgut, there can be a rapid and major change in the hindgut microbial population. As bacteria die, they release toxins, which may trigger the onset of laminitis. Welsh researchers concluded that the fructan accumulated in fresh grasses change dramatically during the day, by the season, and according to daily climatic conditions (cool and wet versus hot and bright).[98] While preliminary in nature, these results show horses predisposed to laminitis should not be allowed to graze grasses free choice during the growing season, and if grazing is allowed, it should be for short periods, avoiding the hours around midday. Grass fructans levels were lowest in early morning hours.

Gastric Ulcers

Volatile fatty acids (VFA), byproducts of carbohydrate fermentation, have been implicated in acid insult and gastric ulceration in horses. Tennessee researchers fitted six mares with chronic gastric cannulas and studied the effects of two diets on pH, VFA concentration, and lesion number and severity.[99] The diets consisted of an alfalfa hay and grain diet or a brome grass hay diet. In summary, the high concentrate diet (alfalfa hay and grain) produced greater VFA concentrations in gastric contents. The high calcium and protein concentrations in alfalfa acted as a buffering antacid resulting in less severe ulcerations even when higher VFA concentrations were present. Alfalfa hay had a protective effect on the nonglandular squamous mucosa for 6 h after feeding. Authors suggest alfalfa hay should be given at 5- to 6-h intervals.

Intermittent feed deprivation produced low pH and moderate-to-high bile salt concentrations; both of these conditions are known to be conducive to the development of equine gastric ulcers. Three adult horses fitted with gastric cannulas were rotated through three feeding protocols: twice daily feeding of hay and grain mix; hay with grain mix dispensed every 90 min; and fasting for 12–24 h.[100] Fasting periods greater than 14 h produced bile salt concentrations and pH values considered damaging to tissue. Horses should be fed every 12 h, at a minimum, to avoid these pathological situations.

If ulcers cannot be prevented, knowing how to heal them can be just as valuable. Pronutrin, a commercial lecithin-pectin mixture, when administered in a dose of 300 g/day over 10 days, had a positive influence on gastric mucosal lesions; however, the 10-day treatment period was too short because the lesions did not completely heal.[101] Authors suggest giving the lecithin mixture for a minimum of 14 days.

Sand Colic

Ingestion of sand is an unfortunate occurrence in many regions of the United States; however, the exact cause of sand ingestion is not known. Underfeeding, as well as other management practices, has been implicated as a cause for sand eating in horses. Eight mature horses were used to determine whether protein- and/or energy-deficient diets would induce sand consumption.[102] The four diets consisted of a maintenance diet, low-protein diet (approximately 70% of basal protein requirements), low-energy diet (75% of the basal energy requirements;), and a low-protein and energy diet. Horses were fed Bermuda grass and oats, with free choice water and salt-mineral blocks; horses were housed on concrete with rubber mats and offered a bucket of sand for 5 days of the feeding trial. Diets deficient in energy, protein, or both did not influence sand intake in confined horses; in addition, mineral consumption was unrelated to sand intake.

Sand removal strategies have produced varied and conflicting results. Florida workers compared three sand removal treatments. Using a nasogastric tube, 0.5 kg of sand was gravity fed into each horse using 5 l of water. Each horse was given a single dose of one of four treatments: 0.5 g psyllium/kg body weight; 1 g wheat bran/kg body weight in the feed, 8 g/kg body weight of a 0.5 mineral oil/0.5 water mixture through a nasogastric tube, or one untreated control horse.[103] All horses received a normal ration of hay, sweet feed to maintain body weight, and free choice trace mineral salt. Total fecal collection found no treatment advantage for the three common sand removal treatments. Psyllium produced the greatest amount of sand in the first 24 h; however, over the entire collection period, there was no difference in treatments. Other studies have found psyllium or psyllium combined with magnesium sulfate and/or mineral oil produced large variations in response and were not correlated with the initial appearance of sand accumulations. Other authors reported that radiography of the abdomen was a useful means for monitoring sand accumulations.[104]

Foal Diarrhea

Foal diarrhea is most common during the first 2 wk of life, when foal immune systems are weak and foals are susceptible to dehydration caused by the diarrhea. Treatment is frequently expensive, so a dietary supplement that could significantly reduce the occurrence or severity of foal diarrhea would be highly practical. Werner et al.[105] fed arabinogalactan, a fiber derived from the larch tree to mares and foals. Mares were given 75 g of the supplement once per day in their grain for 2 wk before expected foaling date. Foals were treated with 10 g of the larch fiber mixed with 40 ml of water in an oral dosing syringe once per day of the first 14 days of life. While this is the first evidence of its kind, arabinogalactan seems to be an effective way to prevent diarrhea and associated medical expenses in neonatal foals. Commercial production of this product is handled by Larex; for more information on “larch for equine” contact www.larex.com or call 1–800-386–5300.

Thumps

Historically, thumps in the endurance horse have been attributed to hypocalcemia with typical treatments of calcium-containing oral supplements and fluids. Recent work shows that total calcium concentration seems to be unchanged in thumps, although there is a decrease in ionized calcium. This change in ionized calcium is now believed to be the result of increasing blood pH (alkalosis) that occurs secondarily to the large losses of chloride and potassium in sweat. Prevention strategies for thumps now include the replacement of sodium, chloride, and water, rather than calcium.[106,107]

11. New Products, Ingredients, and Processing Methods

New products and ingredients are constantly entering the market, tempting horse owners. New or improved processing methods can turn the digestibility and palatability of an inferior product into a gold mine. Researchers around the world are testing these new arrivals and finding some surprising results.

Lecithins or phospholipids are naturally occurring components of plants and animals and a source of choline. Lecithins are reported to aid in improving hair coat, treating and healing ulcers, enhancing memory, and learning and making animals less reactive to external sensory stimuli. Soybeans are the most recognized source of lecithins—they are found in the crude gums and filtrates produced in the de-oiling process. In early work in Virginia, lecithins were proven palatable, digestible, and metabolizable as an energy source, plus they reduced the excitability of horses. Harless[108] found that dogs fed lecithins were less aggressive. Furthermore, lecithin may be a new brain food, triggering improved memory and learning in young and reduced short-termed memory loss and brain cell shrinkage associated with aging in dogs and humans.[109–111] Lecithin molecules contain a hydrophobic portion with an affinity for fats and oils and a hydrophilic portion with an attraction for water. These properties prompted researchers to feed lecithins to horses with ulcers and concluded that they were useful in the healing/prevention strategy of gastric ulcers.[112,113] Because there is no NRC recommendation, a collective interpretation by these authors suggests 50 g of de-oiled lecithin/day for a l000-lb horse is reasonable.

Hulless or naked oats hold promise as an improved variety of an old favorite. These are not GMOs, but hand selected by oat breeders for their ability to drop their hulls or husks during the harvesting process, eliminating the storage and transportation of the nearly indigestible hulls. Hulless oats contain similar energy as corn or about 25% more calories than an equal weight of traditional hulled oats. They are higher in fat, phosphorous, crude protein, and antioxidants than conventional oats. Oats have been an equine favorite for their nearly universal acceptance by horses and because oat starch has higher digestibility than other grains.[114,115] Hulless oats, now available in the United States, are alternatives to conventional oats and are valuable in the diets of performance, geriatric, and growing horses.

Italian researchers[116] found supplementation with 12 g/head/day of L-carnitine reduced plasma lactic acid and had a favorable effect on long yearlings in trotter race training. Carnitine seems to improve the availability of lipids to aerobic muscle fibers in intense exercise like endurance and flat races.

Creatine supplement manufacturers claim it builds muscle mass, strengthens muscles, provides extra energy, and shortens recovery time after exercise. In Sweden, creatine supplementation (25 g of creatine monohydrate twice daily) did not show a metabolic or muscle response in trotters.[117] In humans, creatine's side effects include muscle cramps, dehydration, and stomach upset. At this time there seems no reason to supplement horses with creatine.

Racing TB supplemented with 10 g β-hydroxy-β-methylbutyrate (HMB)/day tended to show improvements in blood parameters and percentage of race wins, but the differences were not significant.[118] Endogenous HMB is derived both from the metabolism of the amino acid leucine and through dietary sources. Common equine feeds are low in HMB; therefore, researchers postulated HMB supplementation might reduce muscle damage and hasten the recovery period after intense exercise. This study showed trends but no significance; HMB supplementation is not recommended at this time.

How do you get an anorexic horse to eat? Whether the horse is a fussy Olympic athlete or a family pet recovering from surgery, we have all pondered what flavor or additive would make the picky eater ravenous. In a series of carefully controlled palatability tests with fruit flavors added to plain oats, cherry-flavored oats were consumed at a higher rate than apple, citrus, teaberry, or plain oats (control).[119,120] Of the fruit flavors, cherry flavoring seems to have the greatest influence on palatability.

Steam flaking of corn alters the gylcemic response, presumably making it more digestible, than grinding or cracking corn. Glycemic response was used as an indirect measure of prececal starch digestibility. Higher peak concentration of plasma glucose was observed in the steam-flaked corn (at 90–150 min post-feeding) indicating that the steam-flaked corn was digested in the small intestine, avoiding excessive microbial fermentation in the hindgut.[9] Steam-flaked corn is better used by the horse and is recommended when large proportions of corn are used in the concentrate.

Beet pulp is the fibrous byproduct after sugar is extracted from sugar beets and has become a flexible and valuable new feedstuff to horses. It is a good source of digestible fiber with fairly low crude protein, high calcium, low phosphorus, and low vitamin content. Contrary to popular opinion, you can feed dry beet pulp to horses and they do not explode, choke, or colic any more frequently than with wet beet pulp. While most horses prefer the moistened beet pulp, it can be fed dry. To avoid mold, wet beet pulp should be fed or discarded within 24 h.

Welsh researchers, using in vitro and in vivo techniques, found the addition of 30% beet pulp increased the digestibility of the hay portion of the diet.[121,122] Furthermore, they tested various ratios of beet pulp and high temperature–dried alfalfa, finding the mixture produced a palatable, consistently high-quality feed throughout the year and it was superior to alfalfa fed alone.

When Kentucky scientists compared sweet feed, vegetable oil, and beet pulp as energy sources, they found that substituting 15% of the total dietary energy as fat or fiber did not adversely affect performance of the horses.[123] Beet pulp, when fed at 15% of the total energy, provided adequate energy to maintain weight and to perform as well as horses on the high-starch diet. Groff et al.[124] found that soaking and rinsing beet pulp (removing the sugars) resulted in a negligible glycemic response. This preparation method may be useful for animals that require diets low in hydrolyzable carbohydrates such as recurrent exertional rhabdomyolysis and polysaccharide storage myopathy.

Fat has become the darling of the performance horse feed industry and is available in many different sources. Kentucky researchers compared corn oil, rice bran (20% fat), and refined dry fat (animal origin) as energy sources in exercising TBs.[125] They found that all three fat sources were highly digestible (near 90%) with few or no palatability problems. Rice bran–supplemented diets resulted in lower lactate levels and lower heart rates during exercise compared with corn oil, giving it a slight edge over corn oil and refined dry fat.

Lactic acid accumulation after exercise can limit performance, and any factor that can lower lactate production may enhance performance. Betaine is a supplement touted to reduce plasma lactate in the athletic horse. Kentucky workers used conditioned and unconditioned TBs and fed them 80 mg of betaine/kg of body weight for 14 days before exercise testing.[126] Results showed betaine was beneficial in the unconditioned horse and resulted in lowered lactate metabolism after exercise; however, it was not beneficial in the well-conditioned horse.

12. Miscellaneous Topics

Naylor[127] and Geor[128] published literature reviews judiciously complemented by their personal interpretations and experiences for hospital diets, pre- and post-surgery, esophageal problems, metabolic effects of and rehabilitation after starvation and malnutrition, respiratory disease, GIT disorders, laminitis, hepatic disease, renal failure, and anorectic solutions.

Food allergy with resulting urticaria in the horse was deemed rare by Littlewood,[129] and often misdiagnosed by the clinician or incorrectly assumed by the owner. Diagnoses of food allergy should include feeding an elimination diet, restricted to a single bulk food for a minimum of 4 wk, and then add oats or any other single ingredient whole grain one at a time for another 4 wk, etc. Dietary challenge and provocation episodes are required for confirmation.

Group feeding of horses with feed tubs on the ground, spaced five horse-lengths apart in a straight line is a common management practice on horse farms, with dominant, aggressive horses eating more feed. When the effect of tub placement and spacing on behavior was observed in geldings and mares, spacing feed tubs at a minimum of 3.6 m apart and in an equilateral triangle rather than a straight line allowed submissive horses more time to eat.[130]

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