Nutritional Management of Metabolic Disorders

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INTRODUCTION

Several metabolic disorders are common in modern breeds of horses. Many of these disorders such as equine Cushing's disease (ECD), equine metabolic syndrome (EMS), osteochondritis dissecans (OCD), recurrent equine rhabdomyolysis (RER), and polysaccharide storage myopathy (PSSM) can be managed nutritionally by careful regulation of caloric intake with particular attention paid to the source of energy provided. Although these disorders have very different etiologies, they are all either triggered or aggravated by excessive starch and sugar intake. As in humans, excess consumption of calories from carbohydrates is one of the major problems in today's equine population. This paper will review the role various carbohydrates play in equine disease and will describe feeding programs for managing affected horses.

Carbohydrates in Horse Feed

The carbohydrates in equine feeds can be categorized by either their function in the plant or from the way they are digested and utilized by the horse. From a plant perspective, carbohydrates fall into three categories: (1) simple sugars active in plant intermediary metabolism; (2) storage compounds such as sucrose, starch, and fructans; and (3) structural carbohydrates such as pectin, cellulose, and hemicellulose. For the horse, it is more appropriate to classify carbohydrates by where and how quickly they are digested and absorbed. Carbohydrates can either be digested and/or absorbed as monosaccharides (primarily glucose and fructose) in the small intestine, or they can be fermented in the large intestine to produce volatile fatty acids or lactic acid. The rate of fermentation and types of end products produced are quite variable and can have significant effects on the health and well-being of the horse.

A physiologically relevant system to categorize carbohydrates in equine diets would be composed of three groups. (1) A hydrolyzable group (CHO-H) measured by direct analysis that yields sugars (mainly glucose) for metabolism. This includes simple sugars, sucrose, and some starches that are readily digested in the small intestine and produce fluctuations in blood glucose after feeding. (2) A rapidly fermentable group (CHO-FR) that yields primarily lactate and propionate. This group includes starches that escape digestion in the small intestine as well as galactans, fructans, gums, mucilages, and pectin. (3) A slowly fermentable group (CHO-FS) that yields mostly acetate and butyrate. This group includes the compounds captured in neutral detergent fiber (NDF) such as cellulose, hemicellulose, and lignocellulose.

Hydrolyzable carbohydrates (CHO-H) are an important component of equine diets, particularly for the performance horse, where blood glucose serves as a major substrate for muscle glycogen synthesis. Too much blood glucose, however, may contribute to or aggravate certain problems in horses such as RER, PSSM, ECD, and developmental orthopedic disease (DOD). It may also adversely affect behavior in certain individuals.

The quantity of blood glucose produced in response to a meal is a useful measure of a feed's CHO-H content. Table 1 contains the glycemic index of several equine feeds measured at Kentucky Equine Research (KER). Glycemic index characterizes the rate of carbohydrate absorption after a meal and is defined as the area under the glucose response curve after consumption of a measured amount of a test feed divided by the area under the curve after consumption of a reference meal, in this case oats.

Table 1. Glycemic index (GI) of equine feeds and forages.

Feed	**Glycemic index**
Sweet feed	129
Whole oats	100
Equine Senior®	100
Beet pulp + molasses	94
Cracked corn	90
Re·Leve®	81
Beet pulp (unrinsed)	72
Orchard grass hay	49
Rice bran	47
Ryegrass hay	47
Alfalfa hay	46
I.R. Pellet and orchard grass hay	34
Rinsed beet pulp	34
Bluestem hay	23

Rapidly fermentable carbohydrates (CHO-FR) such as pectin can yield propionate, which is an important gluconeogenic substrate for the horse. However, rapid fermentation can also produce latic acid, which may lead to a cascade of events culminating in laminitis. Undigested starch from cereals and fructans from pasture are the most likely compounds contributing to lactic acidosis in the hindgut.

Slowly fermentable carbohydrates (CHO-FS) from the plant cell wall are absolutely essential to maintain a healthy microbial environment in the horse. These carbohydrates alone, however, may not be able to supply enough energy to fuel a high-performance athlete. Carbohydrates in horse feeds have traditionally been estimated by measuring cell wall components as NDF and calculating the remaining carbohydrate by difference as nonfiber carbohydrate (NFC), where NFC = 100 - water - protein - fat - ash - NDF. More recently, laboratories have provided a direct analysis of additional carbohydrates in equine feeds.

Table 2 contains the chemical composition of several common equine feedstuffs as analyzed by Equi-analytical Laboratories in Ithaca, NY. In addition to NDF and the calculated values of NFC, Table 2 contains measured levels of water-soluble sugars (WSS) and starch. The sum of WSS and starch is considered the nonstructural carbohydrate (NSC). WSS in cereal grains and by-products such as beet pulp are composed of simple sugars that produce a pronounced glycemic response and fit into the CHO-H category. By contrast, much of the WSS in temperate grasses are actually fructans, which should be included in the CHO-FR fraction.

Table 2. Carbohydrate content of some common equine feeds.

	Oats	Corn	Beet pulp	Soy hulls	Legume hay	Grass hay
WSS (%)	3.9	3.5	10.6	3.6	9.0	10.7
Starch (%)	44.3	70.5	1.3	1.7	2.4	2.8
NSC (%)	50.7	73.1	12.1	5.3	11.4	13.3
NFC (%)	50.9	76.4	44.4	19.8	30.8	19.5
NDF (%)	27.9	9.8	41.9	61.7	38.5	63.8

Therefore, they would have little effect on glycemic response but may contribute to the development of hindgut acidosis and laminitis.

Starch is the predominant carbohydrate fraction in cereal grains. Although all starch is made up of glucose chains, how the starch molecule is constructed varies in different types of grain. These differences in the architecture of individual starches have a large impact on how well they are digested in the horse's small intestine.

Of the grains most commonly fed to horses, oats contain the most digestible form of starch, followed by sorghum, corn, and barley. Processing can have a huge effect on prececal digestibility, particularly in corn. In a KER study, steam flaking corn caused a 48% increase in glycemic response compared to coarse cracking. NSC is a mixture of CHO-H and CHO-FR fractions. NSC tends to be higher in CHO-H in processed cereal grains and mixes but may be high in CHO-FR in certain unprocessed cereals or high-fructan forages. NFC represents an even more mixed group of carbohydrates because in addition to the compounds found in NSC, they may also contain significant quantities of pectin and other fermentable compounds not captured in NDF. For instance, beet pulp contains only 12.1% NSC but 44.4% NFC. At present, there is no satisfactory, commercially available analytical method to segment carbohydrates into categories that are physiologically meaningful for the horse.

Metabolic Disorders

Equine Cushing's disease (ECD) or pituitary pars intermedia dysfunction (PPID) results from a tumor in the pituitary gland and is frequently recognized in older horses (Frank et al., 2006). For a review of ECD, see Dr. Frank Andrews's paper in these proceedings (Andrews, 2008). The pituitary glands of horses with ECD secrete excessive amounts of adrenocorticotropic hormone (ACTH), which results in an increased secretion of cortisol from the adrenal glands. Horses with ECD are prone to laminitis and may develop cortisol-induced insulin insensitivity, which leads to elevated blood insulin (hyperinsulinemia) and elevated blood glucose (hyperglycemia).

The best dietary strategy for horses with ECD will depend on several factors. First, since these horses tend to be insulin insensitive, a ration that produces a low glycemic response is essential. Rations containing CHO-FR such as lush pasture and high grain meals should be avoided to reduce the likelihood of laminitis. Additionally, the ration must also supply the correct amount of required nutrients for the horse, and it must supply the correct caloric intake to maintain or achieve a desired body condition. For additional information about assessing and manipulating energy balance, see Dr. Laurie Lawrence's paper in these proceedings (Lawrence, 2008).

ECD horses that are overweight should be fed a ration composed primarily of hay. Most hays have low glycemic indexes compared to cereals and sweet feeds (Table 1). Hay rations should be supplemented with a low-inclusion fortified balancer to provide nutrients that may be deficient in the forage. KER recently developed this type of product (I.R. Pellet; KERx, Versailles, KY) to balance the rations of horses requiring low-glycemic rations. In trials with Thoroughbreds, glycemic response was lower when hay was supplemented with I.R. Pellet than when only hay was given (Table 1).

If an older ECD horse has trouble maintaining weight, its ration can be supplemented with additional calories from a high-fat, low-starch product. In addition to providing a concentrated source of energy, vegetable oil has been shown to greatly reduce glycemic response to a grain meal, possibly by delaying gastric emptying (Geor et al., 2001). If beet pulp is added to the ration, it should be rinsed to reduce its glycemic index (Table 1) (Groff et al., 2001). Rice bran also has a low glycemic index (47%). Feeds that are designed for senior horses may not be desirable for ECD horses because they may contain ingredients such as molasses, which produce a high glycemic response. For example, in a recent study by Kentucky Equine Research, Purina Equine Senior had a glycemic index that was similar to oats (Table 1).

Equine metabolic syndrome (EMS) is an endocrine and metabolic disorder that results in insulin resistance (IR) and an increased risk of pasture-associated laminitis (Andrews, 2008). Horses and ponies with EMS tend to be obese with cresty necks. These animals have often had prior bouts of laminitis and are easy keepers. A feeding program for EMS horses should be focused on reducing body weight while providing adequate protein, vitamin, and mineral intake. It should be a forage-based program, but pasture intake should either be restricted with a grazing muzzle and limited turn-out, or completely avoided during times of lush growth. Since caloric restriction is important, a concentrated balancer such as I.R. Pellet should be used for supplementation.

Recurrent exertional rhabdomyolysis (RER) is a specific form of tying-up seen in Thoroughbreds, Standardbreds, and Arabians (Valberg et al., 2005). It is an inherited trait caused by abnormal intracellular calcium regulation during muscle contraction. Although the genetic predisposition for RER is evenly divided between males and females, clinical signs of the disease are more often seen in young fillies. Excitement and stress seem to be trigger factors. High grain intakes are associated with tying-up in racehorses. Research conducted at the University of Minnesota in conjunction with KER suggests that replacing much of the grain in the diet with a low-starch, high-fat feed will significantly decrease the amount of muscle damage in RER horses. In a feeding trial, five Thoroughbred horses with RER were exercised on a treadmill for five days a week while they consumed hay and a variety of energy supplements for three weeks at a time. When the daily caloric intake of a high-starch ration was kept low (21 Mcal DE/day), the horses had lower post-exercise serum creatine kinase (CK) than when this feed was increased to provide 28 MCal DE/day (MacLeay et al., 2000). In contrast, if extra calories were provided from a low-starch, high-fat feed (Re-Leve; KERx, Versailles, KY) rather than a grain supplement at 28 MCal/day, no increase in post-exercise serum CK activity occurred. No significant differences in muscle glycogen or lactate concentrations were apparent in these studies (MacLeay et al., 1999).

Most horses with RER have medium to high energy requirements and need significant calories supplied above those found in the forage portion of the ration. An appropriate feed should be fortified to be fed at fairly high levels of intake (4-6 kg/day). It should be low in NSC (<10%), high in fat (>10%), and supply a significant portion of its energy as fermentable fiber.

Polysaccharide storage myopathy (PSSM) is another muscle disorder that is more common in Quarter Horses, warmbloods, and draft breeds (Valberg et al., 2005). It is characterized by an abnormal accumulation of glycogen in muscle resulting from a hypersensitivity of the muscle to insulin. The same type of energy sources used for RER horses is effective for PSSM horses. Research at the University of Minnesota has shown that serum CK levels, which are indicative of tying-up, were reduced when Quarter Horses suffering from PSSM were fed Re-Leve (Ribeiro et al., 2004). Since these horses have lower energy requirements than RER horses, the concentration of other nutrients needs to be greater than in feeds designed for RER. Therefore, KER has developed a more nutrient-dense feed (Re-Leve Concentrate) for managing PSSM.

Osteochondrosis can be a problem among young horses. The source of calories for young horses may also be important, as hyperglycemia or hyperinsulinemia have been implicated in the pathogenesis of osteochondrosis (Glade et al., 1984; Ralston, 1995). Foals that experience an exaggerated and sustained increase in circulating glucose or insulin in response to a carbohydrate (grain) meal may be predisposed to development of osteochondrosis. In vitro studies with fetal and foal chondrocytes suggest that the role of insulin in growth cartilage may be to promote chondrocyte survival or to suppress differentiation and that hyperinsulinemia may be a contributory factor to equine osteochondrosis (Henson et al., 1997).

Research from KER (Pagan et al., 2001) suggests that hyperinsulinemia may influence the incidence of osteochondritis dissecans (OCD) in Thoroughbred weanlings. In a large field trial, 218 Thoroughbred weanlings (average age 300 $\pm$ 40 days, average body weight 300 kg $\pm$ 43 kg) were studied. A glycemic response test was conducted by feeding a meal that consisted of the weanling's normal concentrate at a level of intake equal to 1.4 g nonstructural carbohydrate (NSC) per kilogram body weight. A single blood sample was taken 120 minutes post-feeding for the determination of glucose and insulin.

In this study, a high glucose and insulin response to a concentrate meal was associated with an increased incidence of OCD. Glycemic responses measured in the weanlings were highly correlated with each feed's glycemic index (GI), suggesting that the GI of a farm's feed may play a role in the pathogenesis of OCD. In rats, prolonged feeding of a high-GI feed results in basal hyperinsulinemia and an elevated insulin response to an intravenous glucose tolerance test (Pawlak et al., 2001). Hyperinsulinemia may affect chondrocyte maturation, leading to altered matrix metabolism and faulty mineralization or altered cartilage growth by influencing other hormones such as thyroxine (Pagan et al., 1996; Jeffcott and Henson, 1998). Based on the results of this study, it would be prudent to feed foals concentrates that produce low to moderate glycemic responses.

Summary

The five metabolic disorders discussed in this paper have very different etiologies yet are all either triggered or aggravated by excessive starch and sugar intake. Table 3 summarizes important factors to consider for each disorder. While all of these horses require rations with a low glycemic index, the most appropriate form of energy supplementation depends on the disorder and the individual's energy requirement (Table 3). Horses with ECD are insulin insensitive and need a low-GI ration, but their energy requirement may vary. Some may be relatively easy keepers and benefit from mostly forage rations while others may need extra calories in the form of fat and fermentable fiber. EMS horses and ponies tend to be obese and easy keepers and should be fed mostly forage rations with an appropriate low inclusion balancer. Both ECD and EMS sufferers are prone to laminitis that can be triggered by access to lush pasture, so pasture intake should be carefully controlled. Horses with RER and PSSM are not insulin insensitive, but both groups benefit from low-starch feeds. Fat is an important supplement for both

Table 3. Variables related to feeding horses with different metabolic disorders.

Metabolic condition	Energy requirement	Insulin insensitive	Fat in feed	High laminitis risk
ECD	Low to high	Yes	Low to high	Yes
EMS	Low	Yes	Low	Yes
RER	Moderate to high	No	High	No
PSSM	Low to moderate	No	High	No
OCD	Low to moderate	No	Moderate	No

groups, but their energy requirements are different. RER horses tend to need moderate to high energy intakes while PSSM horses typically require fewer calories. Osteochondrosis may be triggered by high-glycemic feeds, but there is no evidence that young growing horses need extremely low-GI feeds. In fact, a certain amount of starch in the ration is desirable for young horses, particularly during sales preparation. Diets for young horses should have moderate glycemic indexes and be fortified to promote optimal muscular and skeletal development.

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