

## **CARBOHYDRATES IN EQUINE NUTRITION**

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Carbohydrates are an extremely important part of a horse's diet since about 75% of all plant matter is comprised of carbohydrates. There are a number of different types of carbohydrates in horse feed and they vary considerably in how well horses digest and utilize each one. In nutritional terms, carbohydrates can be divided into two broad categories:

### **Non-structural carbohydrates (NSC)**

Non-structural carbohydrates are those that occur either as simple sugars in the horse's feed or that can be broken down by enzymes produced by the horse. Included in this category are glucose and fructose, lactose, sucrose and starch. They range from being almost non-existent in a grass hay diet to comprising a high percentage of the total diet in a high grain-low fiber ration.

### **Structural carbohydrates (cell wall)**

Structural carbohydrates are those that are resistant to the horse's digestive enzymes. These carbohydrates occur in the cell wall portion of the plant and they must be fermented by bacteria living in the horse's gut before they can be utilized by the horse. As a group, these carbohydrates are called plant fiber and they consist primarily of cellulose and hemicellulose.

The various types of non-structural carbohydrates that appear in horse feed are summarized in table 1. Only these types of carbohydrates will be considered in depth in this paper.

### **Carbohydrate chemistry**

Carbohydrates got their name from the fact that they contain carbon combined with hydrogen and oxygen which are usually in the same ratio as in water. The basic repeating unit of a carbohydrate is called a monosaccharide and these usually have

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either 5 carbons (pentoses) or six carbons (hexoses). Hexoses have the empirical formula  $C_6H_{12}O_6$  and are the most important types of carbohydrates for horses. Hexoses that appear naturally as single sugars (monosaccharides) are fairly rare. Glucose and fructose are the only ones that appear free in nature. When glucose appears as a single sugar, it is called dextrose. Small amounts of dextrose are found in fruits and fruit juices and also in honey. It is obtained commercially by the hydrolysis of cornstarch. Glucose is of special interest in horse nutrition because the digestion of many more complex carbohydrates yields glucose as the end product of digestion and it is the form of carbohydrate which circulates in the blood. Glucose has a sweet taste, but it is not as sweet as cane sugar.

**Table 1.** NON-STRUCTURAL CARBOHYDRATES IN HORSE FEEDS

<i>Substance</i>	<i>Type of sugar</i>	<i>Digestive enzyme</i>	<i>Approximate digestibility</i>	<i>Digestive products</i>
Dextrose	monosaccharide	–	complete	glucose
Fructose	monosaccharide	–	complete	fructose <sup>a</sup>
Maltose	disaccharide	maltase	complete	glucose
Sucrose	disaccharide	sucrase	complete	glucose, fructose
Lactose	disaccharide	lactase	complete <sup>b</sup>	glucose, galactose
Starch	polysaccharide	amylase	complete <sup>c</sup>	glucose

<sup>a</sup>fructose is converted to glucose in the liver

<sup>b</sup>lactase activity diminishes after weaning

<sup>c</sup>total tract starch digestibility is complete, but prececal digestibility varies

Fructose occurs freely along with glucose in fruits and honey and in combined forms in higher carbohydrates. It is sweeter than sucrose which is a two sugar molecule (disaccharide) composed of one glucose and one fructose. Sucrose is the sugar obtained from sugar cane or sugar beets and it is the type used on the table and in cooking. It also occurs in ripe fruits and in tree sap (maple syrup). On hydrolysis with the enzyme sucrase or dilute acids, sucrose is split into mixtures of glucose and fructose which are called invert sugars. Cane molasses also contains sucrose, glucose and fructose. After sugar cane juice is boiled down and as much sugar as possible has been crystallized from it, the remainder is known as cane molasses. It contains about 55% invert sugar.

Lactose is another disaccharide, composed of one glucose molecule and one molecule of galactose, another hexose monosaccharide. Lactose is the sugar of milk and it is only about one-sixth as sweet as sucrose. It is broken down by the enzyme lactase and it is less likely than glucose or sucrose to undergo acid fermentation in the stomach, a process which may result in irritation. It also promotes the development of acidophilic organisms in the intestine and opposes the growth of undesirable putrefactive bacteria in foals. Lactose also has been shown to favor calcium and

phosphorus assimilation, so it is the sugar of choice for the suckling foal. As horses age, their ability to digest lactose decreases, so large intakes of lactose in the adult horse may lead to diarrhea.

Polysaccharides are complex carbohydrates that are long strings of simple sugars of varying lengths. They are of high molecular weight and are usually insoluble in water. Upon hydrolysis by enzymes and acids, they are broken down into various intermediate products and finally to their constituent monosaccharides. The most important form of polysaccharide for horses is starch. Starches are long strings of glucose molecules in both straight chains (amylose) and branched chain structures (amylopectin).

### **Carbohydrate digestibility**

Since monosaccharides are the only form of carbohydrates that can be absorbed from the intestine, more complex carbohydrates must be broken down into simple sugars before they can be utilized by the animal. Starches are broken down into the disaccharide maltose (two glucoses) by the enzyme amylase. Maltose, sucrose and lactose are split into their two monosaccharide units by the disaccharide enzymes maltase, sucrase and lactase which are produced in the intestinal brush border. These disaccharides are completely digested in the small intestine of the healthy horse. This is not the case, however, for starch. The horse's ability to produce amylase is limited. Horses only produce about 8-10% as much amylase as the pig. Therefore, a great deal of the starch in a horse's diet escapes digestion in the small intestine.

Meyer *et al* (1993) summarized five factors which affect prececal starch digestibility in horses:

1. Source of starch
2. Processing of starch
3. Amount of starch intake
4. Source and timing of forage feeding
5. Individual differences between horses

Each of these factors will be discussed below.

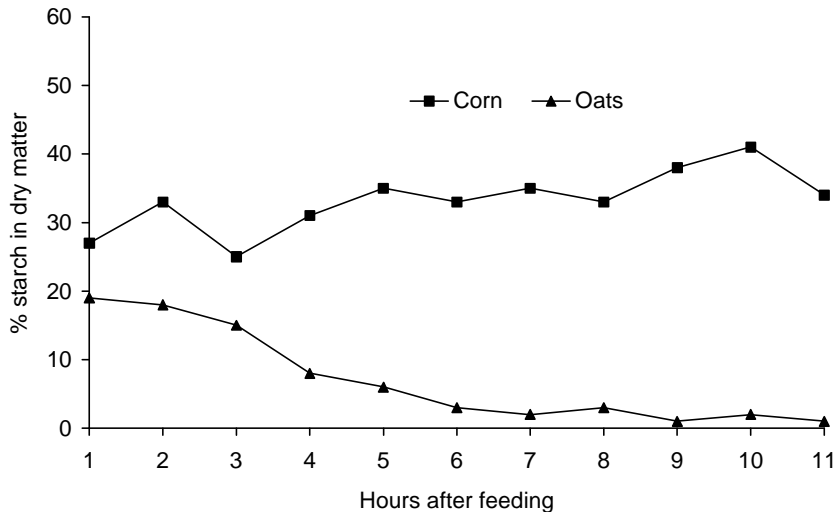
#### **SOURCE OF STARCH**

Although all starch is made up of chains of glucoses, how the starch molecule is constructed is very different in different types of grain. This difference in the architecture of different starches has 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.

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Dr. Meyer in Germany has conducted a large number of experiments evaluating the digestibility of different starch sources. In one study (Meyer *et al.*, 1993) either corn or oats was fed to horses and the concentration of starch was measured in the jejunal chyme. Jejunal chyme is a mixture of digestive juices and undigested feed material at the end of the small intestine. The concentration of corn starch remained high for 11 hours after feeding while oat starch concentration dropped rapidly and was very low after five hours (figure 1). Prececal digestibility of the two starch sources averaged 84% and 29% for oats and corn, respectively.

In another experiment from Dr. Meyer's laboratory, Radicke *et al* (1992) measured amylase activity in the jejunum of horses fed either hay, corn or oats. The amylase activity increased in the jejunal chyme with all rations, with low values after feeding hay, moderate values after feeding corn and high values after feeding oats. Thus, the type of grain appears to affect the amount of amylase produced by the horse.



**Figure 1** Starch content in the small intestine of horses fed either corn or oats.

At KER's laboratory, we measured blood glucose concentration for four hours after feeding four horses either 1 kg of cracked corn or 1 kg of oats. Peak blood glucose and the overall shape of the glucose curve were similar for the oats and corn even though 1 kg of corn provides much more starch (~700 grams) than 1 kg of oats (~500 grams). This demonstrates that the horse's ability to digest starch in the small intestine is different for different grains.

If starch is not digested in the small intestine, it travels to the large intestine. Here bacteria that normally make up only a small portion of the intestinal flora undergo a population explosion as they feed on the starch. These bacteria are quite efficient at breaking down starch, so that the total tract digestibility of starch is very high (>95%) regardless of the source. One of the end products of microbial starch fermentation is lactic acid, which irritates the gut lining as well as changing the pH of the intestine.

This causes other formerly more prevalent bacteria to die, releasing endotoxins into the gut which are absorbed into the bloodstream. These circulating endotoxins can lead to laminitis.

## PROCESSING OF STARCH

Since oat starch is already extremely digestible in the horse's small intestine, processing has little effect on prececal starch digestibility. Corn starch digestibility, on the other hand, benefits greatly from processing. Dr. Meyer showed that grinding corn increased its prececal digestibility from 29% to 45%. Cooking the corn starch by either steam rolling, extruding or micronizing will result in an even higher degree of digestibility. Popping corn increased prececal digestibility to 90%.

Barley also benefits greatly from some type of heat or steam processing. Simply dry rolling or crushing grain does not increase prececal starch digestibility, probably because by chewing the whole grain, the horse grinds the starch finer than does the rolling or grinding. Of course, if your horse has bad teeth, then any type of grinding will help.

## AMOUNT OF STARCH INTAKE

The amount of starch intake will also affect prececal starch digestibility. Radicke *et al* (1991) measured pH in the large intestine after feeding ponies corn or oat starch at three different levels of intake (figure 2). The pH in the large intestine was unaffected by the level of oat intake. Higher levels of corn intake (3-4 g/kg BW), however, resulted in a drop in cecal pH indicating that starch escaped digestion in the small intestine. This level of corn intake would be comparable to feeding a 500 kg horse between 2 and 3 kg of corn in a single meal. Both the corn and oats in this experiment were coarsely ground and had not undergone heat treatment. Potter *et al* (1992) reported that research at Texas A&M suggests that the upper limit to starch digestion in the small intestine of the meal-fed equine may be an amount of starch in the range of 0.35-0.4% of body weight per feeding. This would equal about 2.5 to 2.85 kg of corn and is in agreement with the German findings.

## SOURCE AND TIMING OF FORAGE FEEDING

Surprisingly, the type of forage and time that it is fed relative to grain can have a large effect on prececal starch digestibility. Meyer *et al* (1993) showed that substituting grass hay for ground alfalfa meal resulted in a decrease in the prececal starch digestibility of ground corn from 45% to 16%. He attributed this drop to changes in rate of passage and dilution of substrates and enzymes in the chyme by increased secretion of digestive juices.



The horses were offered water each hour during the experiment. They consumed the highest amount of water 2-3 hours after being fed hay. This increased water intake coincided with an increased total plasma protein (TPP). TPP is an indirect measure of plasma volume where a higher TPP correlates with a reduced plasma volume. Eating hay stimulated saliva production and an increase in the secretion of digestive juices into the intestines. Much of the fluid in these secretions came from blood plasma, resulting in a drop in plasma volume. Decreased plasma volume stimulated a thirst response and the horses drank more water. All of these factors, combined, increased the dilution of the intestinal contents and increased rate of passage. Starch digestibility in the small intestine was reduced and glycemic response diminished.

## INDIVIDUAL DIFFERENCES BETWEEN HORSES

There can be large differences in individuals' ability to digest starch. These may be due to differences in rate of intake, rate of passage, or the amount of digestive enzymes produced by an individual.

## **Measuring carbohydrates in horse feed**

Directly measuring the amount of sugar in the horse's ration is not easy to do and can be quite expensive. Instead, it is preferable to indirectly estimate the sugar content of feeds and forages by measuring several components of a feed and calculating non-structural carbohydrate (NSC) content. The equation to calculate NSC on an as fed basis is:  $NSC (\%) = 100 - \text{moisture} (\%) - \text{crude protein} (\%) - \text{crude fat} (\%) - \text{neutral detergent fiber (NDF)} - \text{ash} (\%)$ .

This calculation will measure all forms of sugar in the feed including simple sugars as well as polysaccharides such as starch. All of these carbohydrates will be absorbed as simple sugars if they are digested by the horse's digestive enzymes, so nutritionally speaking they can be lumped into this single category.

Table 2 shows the NSC composition of some common feedstuffs along with their digestible energy contents.

As you can see, there is a wide range in DE and NSC among common horse feeds. Typically, the NSC content is lowest in straw and mature hays. Legume hays are usually higher in NSC than grass hays and cereal grains have the highest concentration of NSC. Molasses is also high in NSC, containing a level between corn and barley, but its overall DE content is lower because it contains 25% water. As a rule, the lower the cell wall content of a feed, the higher the NSC and energy density. This is because horses digest over 95% of the NSC and typically only about 40-50% of the cell wall. There are certain feedstuffs, however, that contain much more digestible cell wall such as beet pulp and soy hulls. These have digestible energy values that are intermediate between hays and cereal grains.



pronounced in one horse. Why adding molasses affected corn and oats differently may be explained by the rate with which they consumed each diet. When fed straight oats and corn, the horse's average rate of intake was equal to 107 and 105 grams/minute, respectively. When molasses was added to oats, intake rose to 122 grams/minute, a 14% increase. When molasses was added to corn, rate of intake rose to 156 grams/minute, an increase of 49%! At this high rate of intake, the sugar in the molasses was digested rapidly, resulting in a large increase in blood glucose. Combining molasses with a more digestible starch source (oats) with a lower rate of intake buffered the glycemic response of the molasses. Therefore, it appears that the way that molasses affects blood glucose in horses will depend to a large degree on what other NSC sources are in the feed and how quickly the horse eats its grain.

### **Time of feeding before competition**

The most common question that is asked about feeding the performance horse is when to feed before a competition. Theoretically, feeding should be timed so that all of the nutrients from a meal have been digested, absorbed and stored before starting exercise, but not so long before exercise that the horse begins to mobilize fuels just to maintain its resting body functions. To test this hypothesis, KER conducted an exercise experiment in conjunction with the Waltham Centre for Equine Nutrition and Care (Pagan *et al.*, 1996). Six trained Thoroughbreds performed a Standardized Exercise Test (SET) at three different times after eating a grain based meal. The exercise was performed either 1) 8 hours after eating, 2) 3 hours after eating, or 3) after an overnight fast. This SET, carried out on the high speed treadmill, consisted of a 2 minute warm-up walk, 1/2 mile trot, 1/2 mile slow gallop, 1 mile fast gallop (25 miles per hour) and a warm-down trot and walk. Heart rate was monitored throughout exercise and blood samples were taken before feeding, hourly until the beginning of the SET, throughout exercise and 15 and 30 minutes post exercise. Blood was analyzed for glucose, insulin and lactate.

Heart rate was higher at the slow gallop and during the warm-down trot when the horses were exercised 3 hours after feeding. Insulin was significantly higher in the 3 hour fed horses at the beginning and throughout exercise. Blood glucose was also higher after the 3 hour feeding at the beginning of exercise. During exercise, however, blood glucose dropped in the horses exercised 3 hours after eating while it increased in the horses fasted overnight or fed 8 hours before work. Lactate increased with exercise, but was unaffected by time of feeding.

The large drop in blood glucose experienced by the horses worked 3 hours after feeding is not desirable. Basically, the horse has three sources of energy to fuel muscle contraction during exercise. It can use fat, either from the diet or from body stores, it can use muscle glycogen, or it can use blood glucose. Fat stores are plentiful and are good sources of energy during slow work. As exercise intensity increases, faster fuel is needed and glucose is oxidized. If this glucose originates from muscle glycogen,

stores are fairly plentiful and depletion is unlikely at distances shorter than endurance rides. Blood glucose is the most limited fuel available to the horse. Blood glucose is maintained primarily from mobilization of liver glycogen and these stores are small compared to the amount of glycogen stored in the muscle. If blood glucose is used extensively by the muscle, then blood glucose will fall and this may lead to a central nervous system fatigue since glucose is the primary fuel used by the nervous system.

The horses exercised three hours after feeding experienced a large drop in blood glucose because insulin was elevated at the onset of exercise. This caused an increased uptake of glucose by the working muscle. The horses exercised after an overnight fast or 8 hours post feeding began work with resting levels of both glucose and insulin. During exercise, blood glucose actually increased, indicating that the horses were mobilizing liver glycogen at a faster rate than the glucose was being cleared from the blood.

Time of feeding had no effect on lactic acid accumulation during exercise, suggesting that time of feeding only affected how fuels were used for aerobic exercise. Anaerobic energy generation was unaffected. This means that during really intense exercise of short duration such as a Thoroughbred race, time of feeding is not nearly as important as strenuous exercise of longer duration such as the cross country phase of a Three-day Event.

All of the parameters measured responded basically the same whether the horses were fed 8 hours before work or fasted overnight. It is probably better to exercise horses 8 hours after feeding rather than fasting them overnight, since an overnight fast may disrupt digestive function and there is evidence that fasting horses may lead to stomach ulcers.

## **Feeding and behavior**

There is certainly a great deal of controversy about whether the type of feed you give your horse will affect its behavior. There are two schools of thought about whether feed affects behavior. The more traditional one held by many scientists is that the only important factor governing feeding and behavior is caloric intake. If a horse is underfed and in negative energy balance, then it will not be as active or aggressive as when it is well nourished. Advocates of this point of view insist that when a horse's behavior changes when it is on full feed, all the owner is really seeing is an expression of that individual's "true colors." They are more likely to suggest that the horse simply needs more training to become controllable when it is well fed. They would further insist that all you will get when you overfeed your horse grain is a fat horse.

A second school of thought acknowledges that what so many horsemen believe is indeed real. Certain types of feed may affect some behaviors in some horses. As of yet there is not concrete proof that this happens, but I would like to propose a mechanism of how feed might affect behavior. I must emphasize, however, that at this point this is only a theory and much more research is needed before it can be stated as fact.

I have been involved in a couple of experiments that suggest that feed may affect behavior. The first one was with Standardbred horses at the veterinary college in Sweden (Pagan *et al.*, 1987). When horses were fed a high carbohydrate diet, they appeared subjectively to be more excitable and their heart rates were higher during an exercise test than when the same horses were fed a high fat diet. In more recent studies at KER's research facility using more objective measures of behavior, a difference was detected when horses were fed the same number of calories from different sources.

Why would grain affect behavior? As we have already shown, when a grain meal is fed, blood glucose levels increase. The extent of increase depends on the type of diet and some horses have much higher blood glucose peaks than others. This much is fact. Now for the theory. In humans, it has been suggested that many mental disorders such as schizophrenia, mania and depression are the result of uncontrollable fluctuations of brain glucose levels acting in conjunction with insulin resistance (Holden *et al.*, 1995). These fluctuations affect the production of the neurotransmitter serotonin. The behavioral disorder mania has been associated with hyperglycemia (high blood sugar) and hyperserotonergia (too much serotonin). Mania is defined as excitement of psychotic proportions manifested by mental and physical hyperactivity, disorganization of behavior and elevation of mood. Does that sound like a horse you know?

Horses evolved eating diets that were fairly low in NSC, so in the wild they would not experience wide fluctuations in blood glucose and insulin. Insulin resistance is also common in certain horses, so it is conceivable that these horses may experience high levels of glucose and insulin in the brain. In rats, injection of insulin caused an increase in 5-HT (the major metabolite of serotonin) (Vahabzadeh *et al.*, 1995). KER has conducted research demonstrating that supplemental trivalent chromium (from chromium yeast) increased the sensitivity of tissue to insulin so that less insulin was produced in response to a grain meal (Pagan *et al.*, 1995). Blood glucose was also lower indicating that it was more efficiently cleared from the blood. Interestingly, there have been numerous reports from the field that horses given supplemental chromium appeared calmer and experienced a lower incidence of tying up. Since nervousness is associated with many cases of tying up, it is intriguing to speculate whether these two problems (nervousness and tying-up) are related to insulin resistance in certain horses.

Again, it should be emphasized that the connection between behavior and feeding is only a theory, but if we assume that it is true, then what should we feed to reduce the high peaks in blood glucose seen in certain horses?

1. Keep meal sizes small. Blood glucose increases in response to the size of the meal.
2. Feed plenty of forage. Feed at least 1% of body weight to all horses and increase that to at least 1.5% in horses that are particularly excitable. If nothing else, they will spend more time eating and less time being bored.

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3. Add fat to the diet. Substituting fat for carbohydrates will reduce glycemic response. Fat (usually vegetable oil) contains about 3 times as much digestible energy (DE) as oats and 2.5 times as much DE as corn. Also, research at KER (Pagan et al, 1995) has shown that adding fat will actually reduce glycemic response of the NSC fraction of the diet, possibly by slowing gastric emptying.
4. Substitute fermentable fiber for NSC. Certain fiber sources (beet pulp, soy hulls) can replace part of the grain in a horse's concentrate.
5. Feed supplemental chromium. Unfortunately, chromium has not yet been approved for inclusion in horse feeds, so you must get it from your health food store (it is approved for humans) or from your veterinarian.

Even if feeding doesn't affect behavior, guidelines 1-4 listed above will result in a healthy digestive system and reduce the danger of starch overload in the large intestine.

### **Conclusions**

Carbohydrates are an essential part of a horse's diet, making up around 75% of the total ration. Much of this carbohydrate is made of cell wall which is only digestible by bacteria living in the hindgut. Every equine diet should include at least 25% cell wall (NDF). The non-structural carbohydrate (NSC) content of the horse's diet can vary tremendously depending on the class of horse and energy requirement. Mature idle horses need little added NSC in their diets while the diets of high performance horses should contain 32-36% NSC.

It is probably preferable to wait several hours after feeding the horse before it is strenuously exercised. This will allow blood glucose and insulin to return to a resting level and prevent a rapid drop in blood glucose at the onset of exercise. Feeding hay with grain may decrease the digestibility of starch in the small intestine. Horses should have free choice access to hay so that they will eat small amounts continually. If this is not possible, it may be best to feed grain a few hours before hay to allow complete digestion of the grain's starch in the small intestine.

Large fluctuations in blood glucose and insulin may affect behavior in horses. If this is true, then meal size should be small and a portion of the concentrate's DE should come from fat and fermentable fiber. A single meal should never supply over 0.3-0.35% of the horse's body weight as non-structural carbohydrate (NSC) since higher levels of grain intake will result in starch overload which may lead to colic and laminitis.

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