Energy and the Performance Horse

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Introduction

Among the nutrients that are important to the performance horse, energy is the dietary factor most affected by exercise. Energy is not a nutrient *per se* but is, rather, a measure of a feed's potential to fuel body functions and exercise. This discussion of equine energetics will encompass two separate, yet closely related, topics. The first deals with the particular pathways and substrates used by the horse to produce a chemical intermediate that fuels muscle contraction during exercise and depends on the intensity and duration of the exercise. The second topic is related to how various sources of energy in the horse's diet can be used to provide or replace the energy used during exercise.

Energy generation during exercise

The main productive function in horses is work. This may vary from high speed racing at speeds up to 45 miles/hour for short distances to endurance racing at slower speeds for 50 miles or more, to draft work where horses pull or carry heavy loads for variable amounts of time. The basic driving force behind all of these different types of equine performance is the conversion of chemically bound energy from feed into mechanical energy for muscular movement.

Since horses do not eat continuously while they exercise, feed energy must be stored in the horse's body for later release. There are a number of different storage forms that the horse can utilize, including intramuscular glycogen and triglycerides and extra muscular stores such as adipose tissue and liver glycogen. Many factors determine the proportion of energy derived from each storage form including speed and duration of work, feed, fitness, muscle fiber composition and age of the horse.

Work capacity depends on the rate at which energy (ATP) is supplied to and used by muscles for contraction. The most direct way to form ATP is by the cleavage of creatine phosphate (CP). However, since muscle contains only small amounts of CP and ATP, the supplies are exhausted after a short duration of exercise. Prolonged exercise would not be possible unless there were ways for ATP to be resynthesized at the same rate at which it were used. Two fundamental reactions resynthesize ATP:

1) *Oxidative phosphorylation* breaks down carbohydrates, fats and protein into energy (ATP) with the involvement of oxygen. The use of oxygen qualifies this as an aerobic reaction.
2) *Glycolysis* breaks down glucose or glycogen into lactic acid. This reaction doesn't use oxygen and is considered anaerobic.

Large quantities of energy can be derived from the utilization of intramuscular (triglyceride and glycogen) and extracellular (free fatty acids from adipose and glucose from the liver) fuels. The total amount of fuel stored in a 1,000 lb (450 kg) horse is shown in Table 1.

Muscle fiber types

The horse has three basic types of muscle fiber: Type I, IIA, and IIB. These fiber types have different contractile and metabolic characteristics (table 2). Type I fibers are slow contracting fibers while types IIA and IIB are fast contracting. The type I and IIA fibers have a high oxidative capacity and can thus utilize fuels aerobically while type IIB fibers have a low aerobic capacity and tend to depend on anaerobic glycolysis for energy generation. All three fiber types are very high in glycogen while only type I and IIA have triglyceride storage.

Table 1. AMOUNTS OF FUEL STORED IN HORSE MUSCLE.

Fuel	*Tissue*	*Grams*
triglyceride	muscle	1,400-2,800
triglyceride	adipose	40,000
glycogen	muscle	3,150-4,095
glycogen	liver	90-220

Table 2. METABOLIC CHARACTERISTICS OF DIFFERENT MUSCLE FIBER TYPES.

		Type I	*Type II*
Classification	*ST*	*FTH (II A)*	*FT (II B)*
Speed of contraction	slow	fast	fast
Max. tension developed	low	high	high
Oxidative capacity	high	intermediate to high	low
Capillary density	high	intermediate	low
Lipid content	high	intermediate	low
Glycogen content	intermediate	high	high
Fatiguability	low	intermediate	high

Substrate utilization during exercise

The amount of ATP used by a muscle depends directly on how fast it is contracting. While walking, the muscles contract very slowly and expend relatively small amounts of ATP. During this type of exercise, type I fibers are primarily recruited and energy generation is entirely aerobic. At this speed, the muscle burns predominantly fat. Fat stores are plentiful and they can be mobilized and metabolized fast enough to regenerate what ATP is used at a walk. As speed increases from a walk to a trot to a canter, type I fibers alone are no longer capable of contracting rapidly enough to propel the horse. At this point, type IIA fibers are also recruited. These fibers are also aerobic, but they use a combination of glycogen and fat for energy generation. Glycogen (or glucose) can be metabolized aerobically twice as fast as fat for ATP generation and as speed increases, fat becomes simply too slow a fuel for energy generation. As the horse increases speed to a fast gallop, type IIB fibers are recruited and energy generation no longer remains purely aerobic. Anaerobic glycolysis is the fastest metabolic pathway available to generate ATP and the horse must depend heavily on this to maintain high rates of speed. Anaerobic glycolysis results, however, in lactic acid accumulation and fatigue soon develops as the pH in the muscle begins to fall.

The endurance horse typically travels at speeds which can be maintained almost entirely through aerobic energy generation. Only during hill climbing and for short intervals is the horse's ATP demand too great for aerobic regeneration. Fatigue in endurance horses is much more likely to result from glycogen depletion than from lactic acid accumulation.

Racehorses, eventers and many of the western performance horses perform at much higher intensities of exercise. These horses depend heavily on anaerobic glycolysis for energy generation and fatigue is most likely to result from lactic acid accumulation rather than glycogen depletion.

Substrate utilization in the horse can be investigated by using biopsy techniques of both the muscle and the liver. These biopsies are safe and can be taken repeatedly to determine how much muscle glycogen is used at different intensities of work. In addition, substances in the blood and respiratory gases can be used to paint a metabolic picture of substrate utilization during various intensities of exercise. The middle gluteal muscle is the most convenient muscle to biopsy when studying intramuscular substrate utilization. This muscle typically contains between 500 and 700 millimole (mmol) of glycogen per kilogram (kg) of dry weight. During endurance exercise (7.5 to 11.5 mph), horses will typically use muscle glycogen at a rate from 0.5 to 1.5 mmol/kg/min. The remainder of the energy generated at this rate of speed comes from fat oxidation. As speed increases, muscle glycogen utilization increases. At a speed of around 650 meters/min. (a 2:25 mile), ATP production can no longer be completely satisfied by aerobic pathways. At this point, anaerobic pathways become an important source of energy. In shifting to this type of energy production, the use of glycogen and the accumulation of lactic acid increase exponentially.

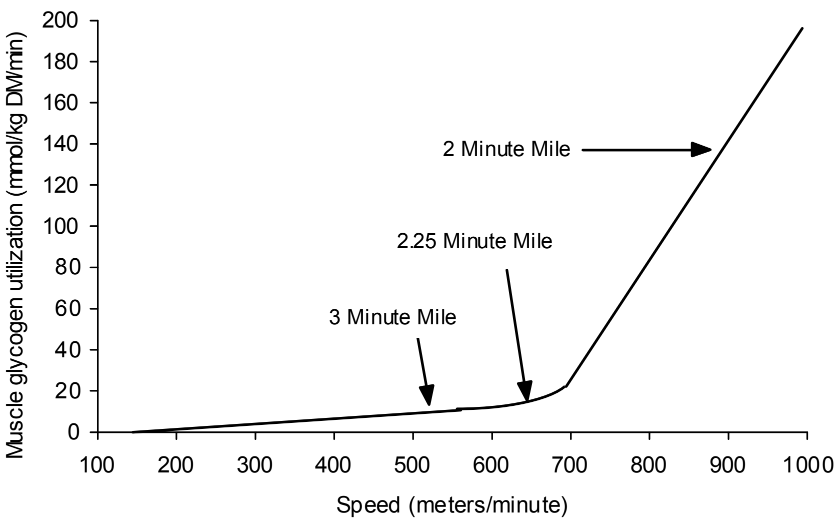

Figure 1 shows the amount of muscle glycogen used per minute in relation to speed. These data are compiled from a number of different breeds. Notice that when the horse runs at speeds of less than 650 meters/minute, very little glycogen is used. However, when speed is increased, the horse crosses what is known as its *"anaerobic threshold"* and the use of muscle glycogen increases dramatically.

The basic reason for this increase is that anaerobic glycogen utilization is 12 times less efficient than aerobic glycogen utilization. When glycogen is metabolized aerobically, 36 ATPs are produced, but when glycogen is metabolized anaerobically, only 3 ATPs are produced (2 molecules of lactate are also produced).

Dietary energy considerations

Dietary energy is usually expressed in terms of megacalories (Mcal) or megajoules (MJ) of digestible energy. Digestible energy (DE) refers to the amount of energy in the diet that is absorbed by the horse. Digestible energy requirements are calculated based on the horse's maintenance DE requirement plus the additional energy expended during exercise. Basically, DE can be provided by four different dietary energy sources: starch, fat, protein and fiber.

Starch

Starch, a carbohydrate composed of a large number of glucose molecules, is the primary component of cereal grains, making up 50 to 70% of the grain's dry matter. Of the grains commonly fed to horses, corn has the highest starch content. Starch is a versatile energy source for the performance horse. Horses break down starch into glucose units in the small intestine, where it is absorbed into the blood. Once in the blood, these glucose units can be used for a number of different purposes:

1) They can be oxidized directly to produce ATP.
2) Blood glucose can be used to make muscle glycogen, liver glycogen or body fat.

Muscle glycogen is an important fuel for energy generation during exercise. In addition, glycogen is stored in the liver where it is available for the production and release of glucose into the blood during exercise. Maintaining blood glucose levels during exercise is of prime importance since glucose is the only fuel that is available to the central nervous system. Hypoglycemia is another potential cause of fatigue in exercised horses.

Starch is the dietary energy source of choice for glycogen synthesis since starch digestion results in a direct rise in blood glucose and insulin, two of the most important factors involved in glycogen synthesis.

There is a limit, however, to the amount of starch which a performance horse's ration should contain. If large amounts of starch are fed in a single meal, the small intestine's ability to digest and absorb the starch may be overwhelmed, and a substantial amount of the starch may pass into the large intestine where it will be rapidly fermented to lactic acid by bacteria. An increase in acid will lower the pH of the hind gut. This may kill other bacteria and lead to the release of endotoxins into the blood. The combination of these two factors may lead to colic or laminitis.

Fat

Fat is an attractive alternative energy source for performance horse rations, supplying a large number of calories in a concentrated form. Even though horses do not consume large quantities of fat in the wild, they do a very good job of digesting fats, particularly vegetable oils. Most vegetable oils contain long chain (16-18 carbon) unsaturated fats. These fats are liquid at room temperature and are used extensively as human foods for cooking and salad oils. A notable exception is coconut oil which contains a high level of medium chain (12 carbon) saturated fats. Animal fats, on the other hand, tend to be more saturated than vegetable oils and often are solid at room temperature. Horses typically digest vegetable oils better than animal fat. Once adapted, horses will digest over 90% of the vegetable oil in a ration, even when fed at levels as high as 500-600 ml per day. High levels of oil intake should be reached slowly, however, since some horses may develop loose, greasy feces when switched to a high oil diet too quickly.

The energy density of vegetable oils is quite high, averaging about 2.25 times that of starch. Vegetable oil has about 2.5 times as much digestible energy (DE) as maize and 3.0 times as much DE as oats. Because of its high digestibility, fat is a very safe energy source. Even if some oil escapes digestion in the small intestine, it will not cause major disruptions of fermentation in the hindgut since bacteria cannot ferment long chain oils.

A wide range of vegetable oils can be used in performance rations, but maize oil is considered to be the most palatable. Soya oil is another good choice, combining high palatability and digestibility at a more affordable price. Flax oil is often fed to horses and is high in omega 3 fatty acids. All oils tend to be a more expensive source of energy, costing about twice as much per calorie as cereal grain.

The level of oil included in an equine ration will depend to a large degree on what the horse is doing. Horses that are lightly ridden or used predominately for show require less oil in their rations. As little as 70-80 ml of oil per day will have a beneficial effect on the horse's hair coat, but will only provide about 2.5% of a lightly exercised horse's DE requirement. Higher levels of oil intake are needed for more strenuous exercise. A horse in heavy training should receive around 400 grams (~450 ml) of vegetable oil per day. This is equal to around 10% of its total daily DE intake and around 18-20% of the DE supplied by the concentrate. Five or six kg of a 10% fat grain mix would supply this level of supplemental vegetable oil.

During low to moderate intensity exercise, horses fuel a large proportion of the energy used for muscle contraction from fat oxidation. Free fatty acids are mobilized from adipose tissue and delivered to the working muscle for oxidation. The amount of fat burned by muscle is directly proportional to the concentration of FFA in the blood. Long term fat supplementation in combination with appropriate training will result in increased mobilization of free fatty acids (FFA) and increased speed of mobilization along with an increased speed of uptake of FFA into muscle. Additionally, feeding fat has a glucose and glycogen sparing effect which may delay fatigue during endurance exercise. A recent study conducted by Kentucky Equine Research with Arabian horses demonstrated this sparing effect. After 10 weeks of fat supplementation (10% fat), the horses used 30% less glucose and muscle glycogen during an endurance exercise test.

Protein

If the protein requirement of a performance horse exceeds its requirement, then the extra protein can be used as a source of energy. The amino acids from this extra protein are broken down by the liver, and the nitrogen from the protein is excreted as ammonia. The carbon "skeletons" that are left can be oxidized to produce ATP or used to make glucose or fat.

Excessive protein intake should be avoided in the exercised horse for a number of reasons:

1) Water requirements increase with increased protein intake.
2) Urea levels increase in the blood leading to greater urea excretion into the gut, which may increase the risk of intestinal disturbances such as enterotoxemia.
3) Blood ammonia increases causing a number of problems such as nerve irritability and disturbances in carbohydrate metabolism.

Increased ammonia excretion in the urine may also lead to respiratory problems because of ammonia buildup in the stall.

Fiber

Fiber is an energy source that is often overlooked in horse nutrition. Horses have a highly developed hind gut which houses billions of bacteria and protozoa capable of fermenting large quantities of fiber. The endproducts of fiber fermentation can be used as energy sources throughout the day since fermentation continues long after a meal has been eaten.

Since proper gut function is essential to the health and well-being of the horse, fiber should be considered an essential nutrient. Hay should be fed at a rate of intake equal to at least 1% of body weight per day and for endurance horses even higher intakes are recommended. Grasses that are less mature at harvest make the best horse hay. An interesting alternative energy source for performance horses is beet pulp, a by-product of the sugar beet industry, made by drying the residual pulp after the sugar has been extracted. It contains a high percent of fermentable fiber and its DE content is similar to oats.

Conclusion

The rations of performance horses should include a mixture of energy sources. In this regard, moderation is the key. Excessive amounts of starch should be avoided as this may lead to colic, founder, or “tying up” in horses. Excessive protein may lead to problems associated with ammonia production. Fiber must be included in the diet to maintain proper hind gut function. Including the correct mixture of these energy sources in the performance horse’s ration should reduce problems associated with feeding and allow the horse to utilize energy generating substrates most efficiently during exercise.