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New insights related to the nutritional management of endurance horses.

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Endurance races are very hard from a metabolic point of view . Today, most endurance rides ranges from 30 to 160 km, or 100 + 100 km to be run in two days, since 500 km to be run in 5 days (Duren, 2000; Sosa Leon, 1998).
Arabian horses, compared to Thoroughbreds, are better adapted to endurance work because of their superior oxidative capacity (Prince et al., 2001).
Endurance competitions are subjected to very strict veterinary control to spare the horse's health. In a overview on 7117 starts on international races, only 50% of the subjects completed the ride, and 30% were eliminated: 63% because of lameness, 24% for metabolic reasons and 13% for other causes (Burger and Dollinger, 1998). Metabolic troubles causes then the elimination of 7.2% of horses starting in international races, but some other are retired for the same reasons between two veterinary gates during the race, and some others have troubles after the final veterinary examination.
For this reason, the correct metabolic management of the endurance horse is of the utmost importance; moreover, for these races, lasting more than 1 to 11 hours (and more), there is a huge possibility, for correct feeding and nutrition, to influence the performance.
The main goals for the correct feeding and nutrition of endurance horses is to provide them both nutrients to met requirements, and a number of substances to help them to avoid metabolic troubles and to use energy substrates and different nutrients sources in the best way. For this reason, new substances for oral administration and specific supplements are on the market.

Energy for endurance horses

Energy supply and utilization is probably the most important item for endurance horses; it must come mainly from the utilization of fatty acids, and more closely both from volatile fatty acids from the hindgut and long chain fatty acids from administered or stored fats. Ideally, an endurance horse's diet must provide 75% energy from hindgut fermentation (Spangfors, 2000). However, for muscle contraction the available energy source is ATP (the "currency" for muscle contraction, according to Duren, 2000); the synthesis of ATP can occur by oxidative phosphorilation, breaking down carbohydrates, fats and protein, and glycolysis, breaking down glucose or glycogen into lactic acid (Duren, 2000).
Endurance horses fed on diets based on good quality forages are able to compete properly in endurance rides (Ralston, 1988), because the hindgut can serve as a reservoir for water and electrolytes (Schott and Hinchcliff, 1998). A correct fibre source is then essential in the feeding of endurance horses. Good quality hay, containing about 80 – 90 g crude protein/kg as fed (Spangfors, 2000), seems to be the best choice, also to prevent nitrogen excess (see above), because it helps to retain sodium. On the contrary, starch excess escapes small intestine digestion, and will hold water in the large intestine: as a result, it will be more difficult to use this water to compensate for dehydration during endurance rides.

Endurance horses, performing aerobic work, use mostly NEFA as a source of ATP regeneration. Despite the fact that these NEFA come from the hindgut fermentation and the mobilization of stored fat, the use of fat enriched diets for horses can be beneficial for long distance exercise. Fat is, moreover, a good source of important fat soluble nutrients, as essential fatty acids and fat soluble vitamins, in particular vitamin E, that have antioxidant properties. In fact, horses fed fat enriched diets can mobilize and utilize fat more properly during long distance exercise (Pagan et al., 1987); fat adapted horses have also higher speed at which lactate began to increase sharply during incremental exercise, and lower LA blood concentrations during aerobic work (Kronfeld et al., 2001).
Many fat sources are added to endurance horses diets; corn oil and soybean oil are the most common (Duren, 2000). Spangfors (2000) advises the use of a fluid vegetable fat with 30% linoleic acid at a 5-6% rate in the ration. Duren (2000) proposes grains top dressed with 7-10% fat for endurance horses as optimal, and an added fat limit level of 20%, as the threshold for palatability.

Protein
The protein need of endurance horses is comparatively very low. On the other hand, it is important to avoid excess nitrogen that is not useful and can be considered harmful for these horses. The use of amino acids for energy production, and the fermentation of excess protein into the hindgut, involves ammonium release, its conversion to urea into the liver and its excretion in the urine. During endurance races, the filtration rate is lowered, in order to save water. Urea level in blood thus increases, and for this reason to start a race with high urea blood levels can led to metabolic troubles (Spangfors, 2000).
Many amino acids are extremely important for endurance work, and in particular branched chain amino acids (BCAA) and tryptophan; this will be discussed later, because specific supplements, based on BCAA, are available for endurance horses.

Water
As to water, the requirement related to work is very important. Exercise conduced in hot, humid environment may increase the water requirement by 300%, giving a total daily water requirement of 90 litres (Duren, 2000). Endurance exercise, indeed, influences horse's body weight, body water and packed cell volume (Bergero et al., 2001).
Fatigue and exhaustion may occur when compensatory mechanism fail due to severe water and electrolyte losses and insufficient replacement (Flaminio and Rush, 1998). Water loss connected to endurance work is a major concern because of some evidences that, even after an overnight recovery, and despite an apparent rapid return of plasma volume and ionic composition to near normal values, substantial depletion of body fluid and electrolyte store persist after completing 50 or 100 miles endurance competitions (Schott et al., 1997).

Electrolytes
Electrolytes are minerals that dissociates in solutions into electrically charged ions (Na^+, K^+, Cl^-, Ca^{++}, Mg^{++}). They are lost with faeces, urine and sweat. In particular, sweat losses of electrolytes causes the onset of peripheral fatigue and weakness. For this reason, good nutritional management of endurance horses requires the replenish of these losses by orally administered salts. The sweat losses appear to be important in particular for potassium and chloride, whose concentrations in sweat are greater

than in plasma; substantial plasma decreases of those minerals are recorded during long distance exercise (Rose et al., 1980). During extreme sweating, the administration of 5 litres of water with 30 g of NaCl and 15 g sucrose or glucose, is recommended for a 500 kg horse (Frape, 1988).
At present, there are no data to support the concept of "electrolyte loading" of equine athletes by feeding supplemental electrolytes for several days prior to competition. The additional electrolytes are quickly excreted within a few hours by the kidney. Nevertheless, electrolytes administered in the few hours immediately before a prolonged exercise competition may be of benefit if adequate water is also ingested (Schott and Hinchcliff, 1998). This is the main reason to supply electrolytes to endurance horses during the competition, to recover immediately from losses. Magnesium losses can cause muscle troubles in endurance horses. Because calcium and magnesium are chemically alike, both ions use the same uptake and transport mechanism in the body. In the competition between the two ions, calcium is commonly the winner, because its absorption is regulated by hormones and vitamin D. For this reason, magnesium deprivation can occur for diets containing normal amounts of this ion (Spangfors, 2000). Then, diets containing calcium excess (e.g. based on good quality alfa alfa hay as the only forage source) must be avoided. Replacement of fluid and electrolytes should be based on sweat losses occurring per hour of exercise, which, in most cases, will be 2 to 5 l but can be higher (10-15 l) if exercise is performed in hot and humid environments.
For rides of approximately 100 km or more which are run at a slow place (about 2-4 m/s), 2 to 5 l of fluid can be given per hours of exercise.

Trace elements and vitamins
Endurance horses, as all other sport horses, must receive an adequate amount of a basal balanced premix supplying optimal levels of trace elements and vitamins. Many trace elements are indeed involved in the production and utilization of chemical energy, such as iron, copper and zinc. Many vitamins of the B group are also involved in the energy metabolism: thiamine, riboflavin, niacin, pyridoxine, panthotenic acid, cyano-cobalamin and biotin. The role of vitamin E for endurance work will be discussed as an antioxidant compound. It is, therefore, very difficult to assess, under field condition, the nutritional status of an horse: laboratory analyses are expensive and unpractical, and new tools need more detailed studies to be used under field conditions with good results (Bergero et al., 2002c). The use of a vitamin and trace elements premix is then advisable, as a basic feeding practice, in the endurance horse.

Background for the use of specific premixes
Apart from the use of basal vitamin and mineral premixes, it is very common, for endurance horses, to use specific supplements aimed to the control of specific needs or troubles of single horses, or to the best use of energy substrates, to improve performances. In this section, the use of different active ingredients and molecules that are the basis for oral products for endurance horses will be presented.

Anti-oxidants
Reactive oxygen species (ROS) play an important role in the skeletal muscle damage and inflammation after strenuous exercise. It is recognised, for example, that the physical exercise can modify malonilaldehyde and glutathione content of horse's blood (Chiaradia et al., 1998). During endurance rides, the high demand of antioxidants to scavenge ROS decreases blood levels of vitamin C and glutathione;

the blood level of vitamin E, on the contrary, increases, because of the release from adipose tissue associated with fat mobilization during the race (Hargreaves et al., 2001).
The dietary supplementation of oil rich in polyunsaturated fatty acids (PUFAs), that received a great deal of interest also in horse nutrition (Bergero et al., 2002a and b), because these molecules are believed to enhance performances, is also an important factor in the onset of cellular peroxidation. The use of dietary PUFAs without appropriate antioxidants supplementation could in fact unbalance the antioxidant / pro-oxidant ratio of the organism and could consequently cause damages to the cellular membranes.
The dietary supplementation of horse diets with fats, containing large amounts of polyunsaturated fatty acids in particular, can influence the oxidative status of horses, and this can be modulated by adding vitamin E (Bergero et al., 2002b), even if studies on dietary utilization of antioxidants to reduce exercise induced muscle troubles is still discussed (Sacheck and Blumberg, 2001). According to White et al. (2001), the administration of vitamin C could decrease the oxidative stress produced by racing exercise in Thoroughbred horses, but can not prevent muscle damage. Heat can increase oxygen radicals production during exercise, but there is not enough evidence to propose nutritional needs in these conditions (Burke, 2001). Vitamin C and E are added at high doses (compared to the "normal" levels listed in the requirements tables) to achieve the desired antioxidant effect. Different natural compounds have a very good antioxidant effect, and are used for horses premixes: coenzyme Q10, bio-flavonoids, lipoic acid, glutathione, selenium compounds, and several herbal extracts (e.g. those obtained from *Curcuma longa*).

Branched chain amino-acids

During exercise, the fatigue can rise from both peripheral and central causes. For the endurance horse, the amino acid catabolism could have an important role on the central fatigue onset, together with the decrease of the glycaemia, that could involve the onset of both kind of fatigue.
The utilization of branched chain amino acids (BCAA: leucine, isoleucine and valine) in the muscle fibres, during exercise, as fuel sources involves a decrease in their blood plasma concentration, thus involving a decrease in the blood BCAA/free tryptophan ratio; at the same time, the rise in the non-esterified fatty acids (NEFA) blood level involves the increase in the utilization of albumins as carrier proteins for the same NEFA and a lesser utilization as a tryptophan (Try) carrier. The plasma level of free tryptophan is then increased, and can pass through the haematic – encephalic barrier; this is also made easier by the plasma decrease of BCAA, that makes a large number of carriers available to cross the barrier.
In the brain, an increase in the Try availability involves an increase in the serotonine (a neuro – transmitter involved in the rise of fatigue) production (Dillon, 1992).
Recent studies on endurance horses seem to indicate an interpretation for the catabolism of BCAA similar to the one confirmed for human athletes, in particular for the aspects related to the duration of workload (Assenza et al., 2000; Arcigli et al., 2002; Assenza et al., 2002).
The products that supply BCAA for sport horses normally contain also other important essential amino acids and glutamic acid, together with vitamins of the B group implied in the energy utilization.

Digestion control

One of the problems that is common to all competing horses is the high level of stress and the frequent travelling: both those situations imply possible disturbances of the normal hindgut environment and following risks of digestion troubles, colic, diarrhoea and severe consequences (e.g. laminitis). To fight against this problem, many specific products are on the market. The older are simply based on brewer's yeast, but other micro organisms (e.g. *Lactobacillus sporogenes*) are today used, together with different substrates for the growth of fermentative bacteria (lactulose, lactitol, FOS, MOS), ground specific clays (zeolites, such as clinoptilolite and phillipsite), and herbal extracts (ginger, *Glycyrrhiza glabra*). The administration of these products during the competition days, transportations and recovery is, frequently, very useful.

Oral pastes for rehydration

Water intake during endurance exercise seems to be improved by the use of hypertonic oral pastes (Dusterdieck et al., 1999), even if Nyman et al. (1996) report an adverse effect of this salt administration, thus advising the oral utilization of 0.9% NaCl saline solution. In fact, many oral pastes are now available and extensively used for endurance horses. These pastes (about 35% dry matter) normally contain salts (disodium phosphate, KCl, sodium citrate, $MgSO_4$, $CaCl_2$, calcium gluconate, magnesium gluconate, NaCl), vitamins (ascorbate, mainly), glucose or molasses, glycine. It is important to underline that the use of these pastes, normally, restore the pre-ride levels of all electrolytes, except sodium, that is lost in very large amounts. For this reason, NaCl must be added, at the doses specified above, to the drinking water or the meals.

Energy utilization enhancers

A lot of substances, the so called "ergogenic aids", are used to improve the energy utilization by the endurance horse, both directly and by providing materials to improve the efficacy of particular metabolic pathways. Some metabolites, for example, are implied in the onset of fatigue, as it is the case of inosine monophosphate, a product of adenine nucleotide degradation (Essen-Gustaffson et al., 1999). Another important molecule, that decreases the blood LA levels during and after exercise, is dimethylglycine (DMG), also available on the market. Several products are mix of different molecules active as energy utilization enhancers as carnitine, ribose, different vitamins and trace elements used at high doses.

Joint safety

As mentioned in the introduction, lameness is a big threatening illness for horses competing in endurance; the possibility to use non-doping substances that can help in maintaining joints healthy is then of the utmost importance. Among the other active molecules, we can list here the omega 3 fatty acids, glucosamine and other glycans, methyl-sulpho-methane (MSM).

Pain control

As mentioned above, the market for "natural" substances that modulate pain is increasing. Of course, there is no way to stop the use of steroids, butazolidine and some other drugs for the pain control during severe illnesses, but during competitions, it could be very useful to have a tool to increase the welfare of the horse. Among these substances, some herbal extracts from *Boswellia serrata*, *Harpagophytum procumbens*, *Equisetum arvense*, *Glycyrrhiza glabra*, *Oenothera biennis*. Bromeline and cetyl myristoleate can also have an important role in the control of inflammation.

Immunity

Another side effect of the stress that is typical of the performance horse is the decrease in the efficacy of the immune system. To maintain a good immunity level is then, nowadays, one of the most important concerns of riders and owners. To achieve this result, the products on the market are mainly based on herbs, as *Echidnacea*, *Astragalus*, Reishi mushrooms, *Uncaria tomentosa* and others, together with other substances such as aminoacids, ascorbate, vitamins of the group B.

Anemia

It is worth to consider, at the end, the products that are designed to avoid the sport horse anaemia. This problem is still common, and in particular for endurance horses anaemia reduces the oxygen delivery to the muscle cells during effort, thus decreasing the anaerobic threshold. The ultimate result is a great loss in performance. The premixes designed for this problem contain, normally, vitamin B_{12}, folacin, vitamin K, iron, copper, cobalt, niacin, but rutin, *Ginko biloba* extract, bioflavonoids are also used with good results.

Time of feeding

The coming of energy bearing metabolites from the gut, and their immediate utilization or storage, is mainly regulated by two hormones: insulin and thyroxine. Thyroxine, in particular, promotes the breakdown of glycogen, increases the oxygen consumption by muscle cell and involves the formation of glucose from volatile fatty acids and glycerol, thus promoting energy utilization. For these reasons, for endurance horses, large starch based meals must be avoided, because they determine a post prandial glycaemic peak and consequently an insulin blood level peak. On the contrary, small meals, based on fibrous foods, possibly pelletted, leave the small intestine in a short time, reducing the insulin peak (Spangfors, 2000): in this way it is possible to fed horses before endurance rides without troubles, and to fed them during the ride for fresh energy metabolites supply. According to Pagan (2000), for endurance horses feeding grains 1 – 4 hours before the race should be avoided, but feeding grains immediately before exercise or at vet checks will not upset fat utilization, since the exercise-induced peak of adrenaline decreases the release of insulin from the pancreas.

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