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Omega-3 Fatty Acids

Many horse owners are interested in supplementing their horses with omega-3 fatty acids, based on the belief that they confer anti-inflammatory and/or immune "boosting" benefits. Omega-3 fatty acids include alpha-linolenic acid (C18:3n-3), eicosapentaenoic acid (EPA), and docosahexaenoic acid (DHA). It is the longer-chain EPA and DHA fatty acids that have the most biological activity in the body, serving as the substrates for hormone-like substances known as eicosanoids (eg, prostaglandins, leukotrienes) and affecting gene expression and communication between cells involved in the immune system.

While omega-3 fatty acids have not been as well-studied in horses compared to humans and other species, there has been a significant amount of work done in this area in the past 5 to 10 years. Omega-3 fatty acid supplementation, as well as the feeding of high fat diets for horses, have been covered extensively in previous proceedings of the Annual Horse Breeder's and Owner's Conference (see 2004, 2006 and 2009); thus the reader is referred to those articles for additional information. What will be presented here is a summary of what we have learned about omega-3 fatty acids in horses in recent years, and where the research seems to be heading.

Summary of Current Research Findings:
-Feeding flaxseed or flaxseed oil can increase alpha-linolenic acid in plasma and tissues, but will likely have little impact on the longer-chain, more biologically active omega-3 fatty acids such as EPA and DHA in the body. Supplementing fatty acids with a marine oil or algae is more effective at increasing EPA or DHA supply to tissues [1].
-Forages (pasture or hay) are very rich sources of the omega-3 fatty acid alpha-linolenic acid, often providing more omega-3 fatty acids than can be achieved by supplementing a flax-based supplement [2,3].
-Young and mature horses have the ability to convert alpha-linolenic acid provided in the diet to the longer-chained, more biologically active EPA and DHA [4].
-Supplementing the mare can increase the omega-3 content of her milk, thereby enhancing

supply to the foal [5].
-Supplementation of DHA may improve semen motility or morphology in response to cooling or freezing in some, but not all, stallions [6,7].
-Supplementation of horses with omega-3 fatty acids (either from flaxseed or fish oil) can reduce markers of inflammation in the body, but the effects are inconsistent and generally require fairly high levels of supplementation [1,8,9,10].
-Although omega-3 fatty acids have been promoted for treating horses with osteoarthritis, limited scientific evaluation of this practice has generally confirmed the anti-inflammatory nature of omega-3's but no clinical signs of improvement [11,12].
-Supplementation of horses with either flaxseed or fish oil appears to have limited effect on the ability of immune cells to perform routine functions; however, fish oil (high omega-3) or corn oil (high omega-6) have both been shown to enhance antibody response to vaccination [1,13,14].
-The addition of a large quantity of fish oil to a high starch meal may reduce glycemic response, but does not appear to improve insulin sensitivity [15,16].

Future Research for Omega-3 Fatty Acids:
-Most research evaluating the anti-inflammatory and immune function properties of omega-3 fatty acids have utilized clinically normal, healthy horses. Because omega-3 fatty acids have the potential to mitigate problems associated with excessive inflammatory response, osteoarthritis, insulin resistance, and immunosuppression, there is a need to evaluate supplementation strategies and effectiveness in horses with clinical disease.
Because omega-3 (and omega-6) fatty acids serve as precursors for prostaglandin synthesis, and they appear to modulate inflammation, there is interest in evaluating omega-3 fatty acid supplementation in broodmares for potential benefits to fertility and maintenance of pregnancy, as well as management of endometritis.
-DHA is found in high concentrations in the brain and other neural tissue, including the retina of the eye. In humans, supplying DHA to pregnant and lactating women or directly supplying it to infants via formula has shown improvements in cognitive function and learning ability in infants and children. As a result, there is interest in determining if DHA supplementation can improve learning ability and trainability in horses.
-Difficulty in interpreting the outcome of many of the equine studies results from the varying amounts and sources of omega-3 fatty acids fed. Additional research is needed to determine the minimum amount needed to achieve a desired effect (because this affects cost), as well as the efficiency with which different sources of omega-3 fatty acids (flax, fish oil, algae, etc) can produce a desired outcome.
-In humans and other species that routinely consume higher fat diets (eg, dogs), emphasis is often placed on the ratio of omega-6 to omega-3 fatty acids, rather than the absolute quantities consumed. The ideal ratio of omega-6 to omega-3 has not been determined in the horse, nor has it been determined if the ratio is more important that the amount.
-Are omega-6 fatty acids really the bad guys? Horses are known only to have a linoleic acid (omega-6) requirement. Omega-6 fatty acids are essential to have in the diet and play key regulatory roles in the body. In contrast with humans, current research in horses does not indicate that omega-6 fatty acids are pro-inflammatory or harmful, even in diets supplemented with relatively large quantities of corn oil or soybean oil that are rich in omega-6. The difference

between humans and horses with regard to omega-6 fatty acids likely relates to the relatively low fat diets consumed by horses (where a “high fat” diet may only be 15% of daily intake), coupled with the daily consumption of forages that are rich in omega-3 fatty acids.

Relationship Between Diet and Insulin Resistance
By far the greatest volume of equine research generated in the past 10 years has been on the topic insulin resistance. Insulin is a hormone produced by the pancreas in response to a rise in blood glucose, such as occurs after a meal high in starch or sugar. Thus insulin is responsible for maintaining a consistent level of glucose in the blood by stimulating uptake of glucose into cells. When a normal amount of insulin fails to produce a normal physiological response (eg, fails lower blood glucose after a meal), this is described as “insulin resistance.” The body attempts to correct this deficient response by secreting more insulin. In the end, blood glucose returns to normal, but it takes much more insulin to do the job. Insulin resistance in humans is a precursor to type II diabetes. By comparison, horses can develop insulin resistance, but they rarely develop type II diabetes.

Why is high insulin bad? Insulin not only regulates whole-body glucose homeostasis, it also exerts influence on blood flow, fat metabolism, and inflammation. As a result, high levels of circulating insulin can lead to laminitis, muscle wasting, redistribution of fat around vital organs, increased susceptibility to infection, reduced reproductive function, and reduced exercise performance. High insulin has also been suggested to contribute to developmental orthopedic disease in growing horses, although a cause-and-effect relationship has not been demonstrated in vivo.

From regional studies, it has been estimated that about 3% of the horse population is clinically insulin resistant. Most (though not all) insulin resistant horses are also overweight. Similar to the obesity epidemic in humans (and in pets), the number of overweight horses seems to be on the rise, with an estimated 20% of horses being overweight or obese. Ongoing research in both horses and humans is attempting to determine which comes first – does being overweight cause insulin resistance, or does being insulin resistant lead to obesity? There has also been a lot of research assessing the link between insulin resistance and laminitis. With regard to diet and insulin resistance, there has been interest in the calorie sources used in equine diets (eg, starch vs. fat), dietary supplements that can improve insulin sensitivity, and management strategies to slow consumption of a meal with the intent of lessening glucose load. The following is a summary of recent research findings on diet and insulin resistance.

Summary of Current Research Findings:
-Growing and mature horses fed diets high in starch and sugar have been shown to have lower

insulin sensitivity compared to horses fed isocaloric diets low in starch and high in fat and fiber [17,18]. This should not be taken as proof that diets high in starch and sugar cause insulin resistance; rather it demonstrates an altered insulin response in horses adapted to diets high in non-structural carbohydrates (ie, they may be conditioned to produce more insulin because of the greater glucose load of a high grain diet).
-Omega-3 fatty acid supplementation has been proposed to improve insulin responsiveness in human diabetic patients. In horses, a relatively low dose of fish oil failed to alter the glucose and insulin response to a high starch meal [15]. Another study adapted horses to a larger quantity of daily fish oil and observed a lowered glucose response after a dose of glucose, but insulin sensitivity was not improved [16].
Supplementation of ponies with lipoic acid (10 mg/kg BW) reduced insulin response to an intravenous dose of glucose [19]. Although lipoic acid may prove useful as an insulin sensitizing agent, its effects on insulin sensitivity and its effectiveness when added to the diets of insulin resistant horses has not yet been evaluated.
-Cinnamon is found in several dietary supplements marketed for horses with metabolic disorders. Cinnamon extract ingestion has been shown to alter insulin signaling at the cellular level in rats. However, cinnamon extract (1.5 g/day) supplementation failed to improve insulin sensitivity in horses known to be insulin resistant [20].
-Chromium is a mineral that is often found in dietary supplements marketed for equine metabolic disorders because it is thought to augment insulin action. Chromium yeast fed to insulin resistant overweight ponies resulted in a modest decrease in peak insulin concentrations in response to an oral dose of starch [21]. Further studies are needed, however, to determine the effect of chromium supplementation on insulin sensitivity.
-Increased consumption of soluble, prebiotic fibers has been shown to modulate glucose and insulin responses in diabetic humans. In horses, supplementation with psyllium was shown to lower postprandial glucose and insulin in responses [22], and supplementation with short-chain fructo-oligosaccharides was shown to improve insulin sensitivity [23]. However, the addition of small quantities of pectin to a grain meal had no effect on glucose or insulin response [24].
-Post-prandial insulin response was attenuated by the insertion of obstacles (bocce balls) in the feed bucket, which prolonged the time it took horses to consume a meal of grain [25]. This strategy may serve as a less labor-intensive alternative to providing smaller, more frequent meals for reducing glucose load and large insulin spikes. Whether such strategies improve insulin sensitivity remains to be determined.
-For horses where starch intake may be a concern, how low is “low starch”? By measuring glucose responses to meals with varying levels of nonstructural carbohydrate (NSC), one researcher concluded that intake of more than 0.3 g NSC/kg BW would significantly increase blood glucose response (and insulin), but intake at or below 0.3 g NSC/kg BW would have minimal impact [26]. For a 500-kg horse fed a traditional sweet feed with 35% NSC, this would translate into a 0.4-kg (~l Lb) meal. For a typical “low-starch” feed with 12% NSC, the meal size could be increased to 1.25 kg (2.75 Lbs) before reaching this threshold. Although the 0.3 g NSC/kg BW per meal threshold can be used as a guideline, glycemic responses are known to vary widely between horses, and may not always be correlated with relative insulin response.

Oats, barley, corn and molasses have been given a “bad rap” in recent years, in large part because of the research associated with insulin resistance and the perceived negative effects of starch and sugar in equine diets. On the positive side, this has resulted in one of the biggest changes to commercial feed formulation in the past 30 years – feeds where fat and highly digestible fiber sources have replaced traditional high starch ingredients as the predominant calorie sources. These fat- and/or fiber-added feeds can be useful for feeding many types of horses, even if they are "normal." But misinterpretation of, and overreaction to, research associated with insulin resistance has also created a sense of "fear" of starch and other nonstructural carbohydrates. A very small percentage of the horse population actually suffers from insulin resistance. In addition, the vast majority of horses perform well and stay healthy with reasonable levels of starch and sugar in their diet. In fact, some horses such as those competing in high speed sports like racing, roping, timed events (eg, barrel racing), and polo actually need soluble carbohydrates like starch in order to help fuel intensive exercise and maintain and replenish muscle glycogen stores. In contrast, horses at greatest risk for having problems that could be exacerbated by high levels of starch in the diet include those with a history of laminitis, those that are overweight, horses with chronic exertional myopathies (eg, RER or PSSM), geriatric horses, horses with Cushing's disease (pituitary pars intermedia dysfunction), and those with confirmed insulin resistance. For all other horses (the largest proportion of the equine population), starch is not the "bad guy" if fed appropriately (eg, a grain meal no larger than 5 Lbs for typical 500-kg horse).

Research on insulin resistance continues, and we are likely to see further characterization of this metabolic aberration in the coming years. We still have much to learn about the interaction of diet and insulin response, and what it means for both clinically normal and insulin resistant horses. Meanwhile, for horses that have insulin resistance, the following is a summary of currently acceptable feeding practices:
-Avoid feeding grain or sweet feeds
-Restrict or eliminate access to pasture
-Feed a grass hay with less than 10% NSC
-Feed a ration balancer (protein, vitamin, mineral supplement) to ensure key nutrient requirements are met
-If the horse is overweight, institute a weight reduction regime (eg, increase exercise and reduce caloric intake through diet restriction and/or feeding mature, stemmy forage)
-If the horse is not overweight and requires additional calories due to heavy work, pregnancy or lactation, provide additional calories in the form of vegetable oil (1 to 2 cups per day) and/or unmolassed beet pulp or pelleted soybean hulls.

Impact of Feeding Practices on the Environment

No animal is 100% efficient at digesting and absorbing the nutrients consumed in the diet. If you spend much time cleaning your horse's stall, you have a good appreciation at how inefficient they can be! Nutrients that are not absorbed or fed in excess of the horse’s needs are excreted in the feces. Additional nutrients end up in the urine and feces due to normal tissue turnover and excretion of nutrients that had been absorbed but were not needed by the body. On average, 30 to 70% of the nitrogen and phosphorus consumed by the horse is excreted in the manure.

Nutrient excretion in the manure of livestock has come under increased scrutiny over the past 10 years because of concern that these nutrients (eg, phosphorus, nitrogen) can accumulate in soils and be lost to storm water runoff or leach into groundwater, thus contributing to degradation of water quality and eutrophication of lakes and streams. While manure handling regulations have had greater impact on intensive livestock operations such as dairies, cattle feedlots, swine operations, and poultry facilities, horse stables and show facilities are subject to the same laws.

The nutrient composition of manure is influenced primarily by the nutrient content of the diet. Therefore, feeding programs that reduce total nutrient output in manure, as well as dietary strategies that yield nutrients in a more environmentally-stable form in the manure are desirable. Research into the effects of diet on nutrient excretion has been ongoing in cattle, swine and poultry for many years, but it is a relatively new area of research in equine nutrition. The following is a summary of some of the key findings from the limited amount of research conducted in horses to date.

Summary of Current Research Findings:
-Surveys indicate horses are commonly overfed protein and phosphorus. In one study, dietary protein ranged from 80–260% and phosphorus ranged from 114–300% of the horse’s requirements [27].
-When mature horses were fed all-forage diets that provided just enough phosphorus to meet their requirements, the vast majority of phosphorus (60-100%) in the manure was in a water-soluble form [28]. Water-soluble phosphorus is believed to pose the greatest environmental risk as it can be carried away in storm water and leach into ground water.
-Feeding horses a legume hay resulted in greater total phosphorus excretion, yet less of this phosphorus was in a water-soluble form compared to results observed when horses consumed grass forage (phosphorus intake was the same for all forages) [28].
Inorganic phosphorus sources, such as monosodium phosphate, are often included in fortified feeds as source of phosphorus. Supplementing mature horses with an inorganic phosphorus source, which supplied phosphorus in excess of requirements, was shown to increase the total and water-soluble phosphorus concentration of the manure [29].
-Much of the phosphorus in grains and grain by-products is organically bound in the form of phytate-phosphorus, making it unavailable to the animal. Adding the enzyme phytase to swine and poultry diets has been shown to improve phosphorus digestion and reduce phosphorus excretion in the manure by 25 to 50%. A handful of studies have investigated the addition of phytase to the diets of horses; however, no improvements in phosphorus digestion were

observed [30,31].
-Overfeeding protein results in greater nitrogen and ammonia excretion in manure [32,33].
-Fecal output was lower when horses were fed alfalfa forage compared to timothy hay or timothy-oat diets [33].
-Although protein intake was similar, nitrogen excretion was higher in when horses consumed early or mid-blood alfalfa compared to late-bloom alfalfa [33].
-Feeding timothy hay with 0.2 to 0.4% of body weight as oats markedly enhanced protein digestibility without increasing nitrogen excretion in manure [33].
-Horses don't have a protein requirement per se, but instead have an amino acid requirement. Unfortunately, ingredients routine included in equine rations often do not provide amino acids in the right proportions for the horse, resulting in the elimination of unessential amino acids via nitrogen excretion in the manure. Increased availability of crystalline amino acids may permit amino acid requirements to be met with a lower level of total protein intake. Feeding mature horses a diet with 7.5% crude protein supplemented with 0.5% lysine and 0.3% threonine reduced urea-nitrogen excretion in urine nearly 50% compared to a diet with 14% crude protein [34].

Future Research on Diet and the Environment:
-Additional study on the amino acid requirements, as well as the use of amino acids to reduce total dietary protein and nitrogen excretion in horses, is warranted. This "ideal protein" concept is currently applied in swine nutrition.
-Exogenous enzymes, such as phytase and cellulase may help improve nutrient utilization, thereby reducing manure output and nutrient excretion. Although phytase has been investigated already in horses, the design of the studies may have precluded the ability to assess phytase as a viable strategy for reducing phosphorus excretion in horses, thus further study is warranted.
-Interactions between dietary calcium and phosphorus have been shown to influence soluble phosphorus excretion in other species of livestock. Raising the level of calcium in the diet may provide a fairly easy, cost-effective means of reducing soluble phosphorus excretion in horses.
-Organic (chelated) trace minerals have been shown to be more bioavailable than inorganic (sulfate, oxide) forms of trace minerals. Research should examine whether replacement of inorganic minerals with organic trace minerals in fortified feeds can reduce the level of supplementation needed in the diet, thereby reducing excretion of minerals in the manure.
-Basing commercial feed formulation on the type of forage it will be paired with (eg, grass vs. legume hay) may help reduce overfeeding of protein and minerals, thereby reducing excretion of nitrogen and phosphorus. Similarly, the concept of "phase feeding" used in swine nutrition may help fine-tune feeding programs based on stage of growth or production in horses.

References:
[1] Vineyard et al (2010) J Anim Sci 88:248.
[2] Warren & Kivipelto (2007) J Anim Sci 85(Suppl 1):140.
[3] Warren & Kivipelto (2007) J Anim Sci 85(Suppl 1):141.
[4] Warren et al (2010) J Anim Sci 88(E-Suppl 2):203.

[5] Stelzleni et al (2006) J Anim Sci 84(Suppl. 1):392.
[6] Brinsko et al (2005) Theriogenology 63:1519.
[7] Harris et al (2005) Anim Reprod Sci 89:234.
[8] Henry et al (1990) Circ Shock 32:173.
[9] Morris et al (1991) Am J Vet Res 52:528.
[10] Hall et al (2004) J Vet Intern Med 18:871
[11] Manhart et al (2009) Prof Anim Sci 25:155.
[12] Ross et al (2011) J Equine Vet Sci 31:356.
[13] Vineyard et al (2007) Proc Equine Science Soc Symp
[14] Vineyard et al (2008) J Anim Sci (E-Suppl 2):86.
[15] Vervuert et al (2010) Vet J 184:162.
[16] Hoffman et al (2011) J Equine Vet Sci 31:252.
[17] Trieber et al (2005) J Anim Sci 83:2357.
[18] Quinn et al (2008) J Equine Vet Sci 28:728.
[19] Berg et al (2011) J Equine Vet Sci 31:250.
[20] Earl et al (2011) J Equine Vet Sci 31:249.
[21] Vervuert et al (2008) Proc 12th Congress European Soc Vet Clin Nutr, p 40.
[22] Moreaux et al (2011) J Equine Vet Sci 31:160.
[23] Respondek et al (2011) J Anim Sci 89:77.
[24] Vervuert et al (2009) J Equine Vet Sci 29:380.
[25] Kutzner-Mulligan (2011) J Equine Vet Sci 31:300.
[26] Hoffman et al (2009) J Equine Vet Sci 29:379.
[27] Harper et al (2009) J Equine Vet Sci 29:401.
[28] Warren et al (2011) J Equine Vet Sci 31:270.
[29] Westendorf & Williams (2011) J Equine Vet Sci 31:306.
[30] Patterson et al (2002) J Equine Vet Sci 22:456.
[31] van Doorn et al (2004) J Anim Sci 82:1756.
[32] Williams et al (2011) J Equine Vet Sci 31:305.
[33] Woodward et al (2011) J Anim Sci 89:4081.
[34] Graham-Thiers et al (2000) J Equine Vet Sci 20:516.