OATS
The Horse-Healthy Grain

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EQUINE FEED OAT PROJECT

About the Equine Feed Oat Project

The Equine Feed Oat Project (EFOP) is an initiative of the Prairie Oat Growers Association (POGA), a volunteer farmer organization representing 20,000 hard-working Canadian oat growers.

The EFOP was created in 2009 to research, educate and communicate information about oats to the equine industry. One of the EFOP's first research efforts was commissioning Professor Laurie L. Lawrence, Ph.D., of the University of Kentucky's Department of Animal and Food Sciences, to review the existing research on oats as equine feed.
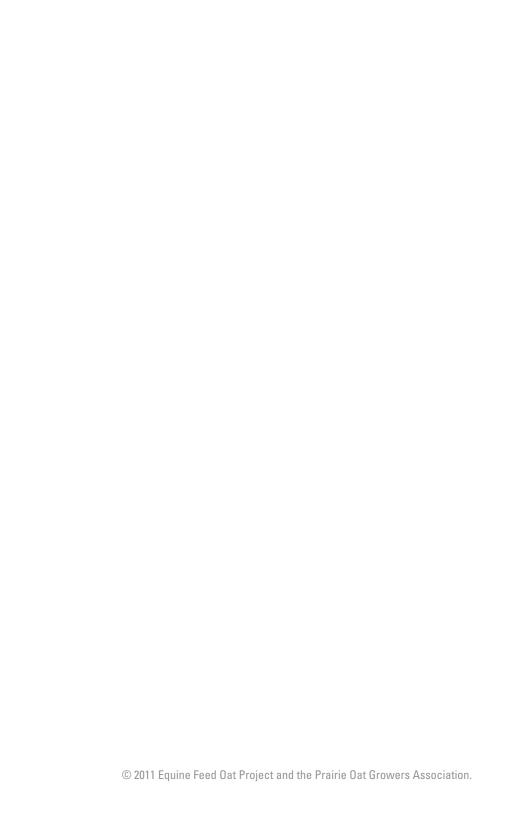
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Background and Context

Horses and the Horse Industry

The horse industry is much more diverse than any other livestock industry. Most livestock producers have the common objective of using nutrients to efficiently produce milk or meat. Horse owners have much different nutritional goals depending upon the type and use of their animals. In general, horses can be grouped into three classes: breeding, performance and recreational. Breeding horses, particularly broodmares and growing horses, have high nutrient requirements. The nutritional goals of horse breeders include maximizing reproductive efficiency and producing a marketable equine athlete. The mare has a long gestation period, and horses are not typically marketed until their yearling or two-year-old year, so producers have a significant economic investment by the time their product is sold. Improper nutrition can result in poor reproductive efficiency and may compromise the musculoskeletal development of growing horses. Developmental orthopedic diseases including osteochondrosis are of great concern to breeders as afflicted young horses have reduced value.

Performance horses include horses that are actively engaged in relatively high levels of regular competition, or in some cases other types of strenuous work. Racehorses, polo horses, three day eventing horses, endurance horses, elite show horses, and ranch horses are included in this category. Performance horses have relatively high nutrient requirements, and their owners seek feeding programs that will optimize performance, improve recovery and increase the duration of the horse's performance career. Performance horses are susceptible to gastric ulcers, inappetance and other gastrointestinal disturbances so diet quality is an important issue. Most breeding stock and performance horses can not meet their nutrient requirements on forage (pasture or hay) alone, so they are fed diets that utilize concentrate (typically a commercial sweet feed or pellet) as well as forage.

Horses in the recreational category may be used for trail riding, low level horse shows, riding lessons, etc. Some horses in the recreational category are not actually used for much of anything but are maintained as companions for other horses. Retired horses would also be included in this category. The recreational horse typically has relatively low nutrient requirements. These horses can be fed

diets consisting primarily of forage but in many cases they are fed relatively high levels of commercial feeds. Horse owners may utilize concentrates because they do not have access to good quality forage at an economical price. In addition, horse owners may provide concentrate to recreational horses as a means of strengthening the "human-animal" bond with their horse. The owners of recreational horses may not have a large economic investment in the purchase of their horses, but they often have a large emotional investment. The nutritional goals of recreational horse owners often include optimizing the health, longevity and welfare/behavior of their animals. Although many recreational horses are maintained in pasture-based management systems, many others are kept in urban or suburban areas where free exercise may be restricted. Confinement and/or inactivity are associated with an increase in stereotypic and redirected behaviors which are considered undesirable. Feeding practices that reduce these behaviors are of interest to horses. Also, obesity is not uncommon in recreational horses. Many geriatric horses may have metabolic or chronic disease issues that require careful dietary management.

The horses in the breeding segment probably comprise less than 10% of the total horse population. Similarly, the horses in the performance segment represent a relatively small percentage of the total, perhaps 25%. Typical daily concentrate intakes for breeding and performance horses may range from 3 to 15 lb/day. Most of the horses in the U.S. horse industry are kept for recreational purposes, and concentrate intakes probably range from 0 lb/day to 8 lb day. Total concentrate intake by all horses in the U.S. is not known, but a study conducted in Maryland estimated yearly concentrate consumption to be about 0.5 ton/horse (approximately 2.5-3 lb/horse/day).

Digestive Anatomy and Physiology of the Horse

The horse is a grazing animal by nature and has a relatively small, simple stomach. Food remains in the stomach for a brief period where it is mixed and acidified. Digesta then passes to the small intestine where enzymes from the intestinal mucosa and pancreas begin the digestive process. Fats are digested and absorbed from the small intestine, as are some minerals and vitamins. Protein is digested to amino acids and the amino acids are absorbed and used to replace body protein or synthesize new proteins.

Starch is digested in the small intestine to glucose, and the glucose is absorbed into the blood stream. Absorbed glucose can be used for energy by tissues, or it can be metabolized to form fat or glycogen, a carbohydrate storage compound in muscle and liver. When a horse consumes a meal high in starch or sugar, blood glucose levels increase within 30 to 90 minutes. Blood insulin levels also increase and the insulin signals tissues to take up the glucose. As the glucose moves from the blood to the tissues, blood glucose and insulin concentrations decrease back to basal levels.

Some horses, particularly those that are older, inactive and overweight, develop insulin resistance. The tissues of an insulin resistant horse are less sensitive to insulin and thus take up glucose more slowly. Sometimes this leads to persistently high blood glucose levels. However, many horses will compensate for the insulin resistance by releasing larger quantities of insulin. In these horses, glucose concentrations may be normal, but insulin concentrations may be elevated above the normal range. Equine insulin resistance has received a great deal of attention in the popular press in the last few years. Insulin resistance can be a component of some chronic diseases in horses including Cushing's Disease and laminitis. In addition, it is often associated with "equine metabolic syndrome". Horse owners have become more aware of insulin resistance in the last few years and, as a result, they have also become more aware of feed ingredients that cause an elevation in blood glucose and insulin concentrations. The actual number of horses that are detrimentally affected by insulin resistance is probably relatively low, but there is currently a perception among horse owners that the condition is widespread and potentially detrimental to their horses.

Material that is not digested in the small intestine passes to the large intestine. In the horse, the large intestine accounts for about 65% of the volume of the gastrointestinal tract. The large intestine has two major compartments: the cecum and the large colon. Both the cecum and the large colon are inhabited by a broad range of microbes. These microbes, primarily bacteria, are capable of breaking down fiber, starch and protein. However, the products of microbial digestion are not the same as for enzymatic digestion. Protein that escapes small intestinal digestion can be broken down and utilized by the microbial population. The microbes use the protein to synthesize the microbial protein in their cells, but some of the nitrogen in protein may be released by the microbes as ammonia.

The horse can absorb ammonia and utilize it to synthesize some amino acids. The amino acids that a horse can synthesize in adequate quantities are often referred to as "nonessential" or "dispensable" amino acids because they are not essential in the diet. There are several amino acids that the horse can not synthesize in adequate quantities to meet its needs and these are referred to as "essential" or "indispensible" because they must be present in the diet. Horses can not absorb appreciable amounts of amino acids from the large intestine; therefore, it is very important that the essential amino acids in the diet be absorbed in the small intestine.

The horse does not produce enzymes that break down cellulose or other types of fiber; therefore, a large portion of consumed forage is not digested in the small intestine. However, fiber can be fermented by the microbes in the large intestine. Large intestinal fermentation of fiber produces volatile fatty acids (VFA), primarily acetate, propionate and butyrate. VFA can be absorbed and used by the horse for energy, to synthesize fat and to synthesize glucose. Starch that reaches the large intestine can also be fermented to VFA, but in addition to the compounds listed above, lactic acid can be produced. If VFA and lactic acid levels are excessive, the pH in the large intestine can decrease and normal function may be disrupted. In addition, VFAs produced from the fermentation of starch can be used by the horse, but the efficiency of use is less than that for absorbed glucose. Overall, it is undesirable for large amounts of starch to reach the large intestine of the horse.

Oats: Past, Present and Future

Oats and Horses: Historical Perspective

In "Diseases of the Digestive Organs", Michener (1907) wrote that "Oats take precedence of all grains as a food for horses". Early research studies with work horses compared a ration of prairie hay and oats to a ration of prairie hay and corn and found that weight maintenance was superior on the oat ration; barley was also evaluated and found to be inferior to oats (McCampbell 1912; 1917). Similarly, rations containing oats, bran, oat hay and alfalfa hay were judged to be better for growing Percheron fillies than rations consisting of corn, bran, oat hay and alfalfa hay (Edmonds and Kammlade 1921). Even in these early studies, the researchers

suspected that protein quantity and quality was an important advantage of oats in comparison to corn. Morrison and Salisbury (1940) suggested that corn or sorghum could replace oats in the diet of growing horses only if a protein supplement was added. Others reported that corn was an acceptable grain when it was fed with a legume hay, but that oats would produce better results than corn when the grass hay was the principal forage.

Many feeding guidelines suggested that oats were the safest concentrate for horses (McCampbell 1917; Rooks and Jackson 1943; Albert 1972). Prentice (1948) suggested that oats can be consumed in large amounts without detrimental effects on digestion; whereas, several other authors believed that oats were safe because the presence of the hull reduced the tight packing of oats in the digestive tract (McCampbell 1917; Kays 1950; Morrison 1961). The looser mass caused by oats was also believed to facilitate more complete digestion of the nutrients in the oats. Oats were not perceived as the perfect feed because of their low level of calcium (Morrison and Salisbury, 1940; Rooks and Jackson, 1943); however, all cereal grains are low in calcium, so this was not a characteristic that affected its comparative value.

So, in the U.S., oats have been recognized as the preferred grain for horses for at least a century. Interestingly, it appears that the search for an "oat substitute" has been going on at least that long also. Dr. C.W. McCampbell (1912) wrote that "One of the most important problems that the average Kansas horseman must meet is to find a satisfactory substitute for oats". The need for an oat substitute appeared to be driven by availability and price (McCampbell 1917). Increasing cost and decreasing availability were also noted as limitations to using oats in horse feeds about 70 years later (Hintz 1983). Large variations in nutrient composition of oats has also been suggested as a disadvantage of oats (Hintz 1983; Lewis 1995).

It is probably less common for horse owners to feed "straight" oats today than it was 20 or 50 years ago. However, many horses still receive whole, crimped or rolled oats as a part of their diet. Corn has been the common replacement for oats in horse rations. It has traditionally been less expensive than oats on both a weight basis and on an energy basis (Kays 1950; Lewis 1982; Hintz 1983). However, because of the differences in protein content and fiber content, corn is not capable of replacing oats on a one-to-one basis in many cases. McCampbell (1917) found that it was necessary to add bran (for fiber) and linseed oil meal (for protein) to

corn to replace oats. Today, the vast array of available feed ingredients as well as modern feed technology makes it relatively easy to formulate and manufacture an "oat substitute". In addition, there has been a general movement away from manufactured feeds that contain high levels of starch towards feeds that are higher in fat and fiber. The typical sources of fiber that are added to manufactured feeds include beet pulp, alfalfa meal and soy hulls. Although these fiber sources have less digestible energy than cereal grains, the addition of fat (usually as a vegetable oil) offsets the difference. Commercial feeds are generally available in two forms: sweet feed (also called textured or open mixes) and pelleted. Both sweet feeds and pelleted feeds can contain non-traditional feed ingredients as well as grains.

Palatability

Two-choice preference tests are commonly used to assess palatability of horse feeds. Animals are offered two feeds for a limited time, and the amount of food consumed is measured; the food consumed in the largest amount is considered to be the most palatable/preferred. A series of two choice preference tests were used to assess the preference of ponies for various grains (Hintz 1983). The tests included whole oats, cracked corn, whole barley, whole corn, whole rye, whole wheat and cracked wheat. When ponies were offered cracked corn and whole oats, they consumed more oats. Similarly, when they were offered whole barley and whole oats, or whole rye and whole oats, they consumed more oats. Although direct comparisons between whole oats and whole wheat or cracked wheat were not reported, ponies preferred cracked corn to cracked wheat, suggesting that they would have preferred whole oats to wheat. Overall, oats are a highly palatable grain for horses.

Even though horses appear to like oats, they may not eat them as rapidly as some types of manufactured feeds. The amount of time to consume a 1 kg meal was measured in horses adapted to eating either whole oats, a large (1.2 cm) high fiber pellet, a small (0.4 cm) high fiber pellet, a small (0.4 cm) low fiber pellet, a high fat sweet feed or a low fiber sweet feed (Harbour 2004). Horses took longer to consume the whole oats (14.3 min) than the low fiber pellet (9.3 min) or the low fiber sweet feed (9.0 min). The time to consume the other feeds was intermediate. However, the researcher noted that the oats used in her study were somewhat dusty and that the relatively slow rate of consumption could have been due to this characteristic of the feed. However, Brokner et al (2008) did not find a difference

Table 1: DE content of oats fed to horses as reported in research studies

	DE (Mcal/lb)	% CP	% ADF	% NDF	% Fat
Thompson et al (1984)					
- Crimped oats	1.43	13.1	17.8	NA	5.3
Lopez et al (1998)					
- Whole oats	1.56	13.9	13.2	35.0	5.2
- Cleaned oats	1.71	13.3	13.5	35.0	5.7
- Cut oats	1.67	13.5	16.7	37.3	5.2
- Whole oats	1.44	12.0	16.5	35.6	8.5
- Cleaned oats	1.45	12.6	18.5	34.6	7.2
- Cut oats	1.39	11.8	18.6	34.2	6.6
Hintz el al (1991)					
- Whole oats	1.36	12.8	16.3	34.2	NA
- Pennuda oats	1.68	18.2	3.7	12.8	NA
Pagan (1998)					
- Oats	1.48*	NA	NA	NA	NA
Palmgren Karlsson et al (2000)					
- Whole oats	1.57	13.0	12.8	26.8	4.0

* Reported on an as fed basis and converted to dry matter using a dry matter value of 90%

in eating rate (kg/min) between whole oats and ground oats. These authors also reported that horses consumed pelleted concentrate more rapidly than whole or ground oats and that the horses had more jaw movements (chewing activity) when fed the whole oats compared to the pelleted feed. Riond et al (2000) also reported that chewing activity was less for pellets than for oats. Chewing activity may be related to saliva production; therefore, it is possible that whole oats might stimulate greater saliva production during eating. Increased saliva may be an advantage because saliva is an important buffer to the gastric acid secreted in the stomach. This topic will be discussed later.

Feeding Value and Nutrient Composition

Energy: Cereal grains are added to horse rations primarily to increase digestible energy (DE) intake. The digestible energy content of oats has been determined in several feeding studies with horses (Table 1). Some studies have reported

Table 2: Chemical composition of oats and other feeds (mean & range)*

	% CP	% NDF	% Starch	% NFC**	% Fat	DE (Mcal/lb)**
Oats	12.7	27.1	44.3	52.3	6.4	1.52
	10.5 – 14.9	17.9 – 36.3	35.2 – 53.5	43.6 – 61.0	4.6 – 8.2	1.39 – 1.66
Corn	9.3	9.9	70.1	76.7	4.3	1.76
	7.7 – 10.9	6.9 – 12.9	65.1 – 75.1	72.2 – 81.1	3.0 – 5.5	1.72 – 1.8
Barley	12.4	19.2	54.9	65.1	2.5	1.66
	10.0 – 14.7	12.8 – 25.5	46.2 – 63.5	57.3 – 72.9	1.5 – 3.5	1.56 – 1.75
Wheat Middings	18.4	37.9	26.5	37.2	6.4	1.52
	16.3 – 20.6	32.0 – 43.7	16.4 – 36.7	30.4 – 44.1	0 – 13.5	1.45 – 1.59
Corn Gluten Feed	24.0	36.0	14.9	33.5	4.0	1.57
	16.3 – 31.7	29.5 – 42.5	8.9 – 21.0	27.2 – 39.7	2.4 – 5.6	1.50 – 1.63
Distillers Grains	30.9	33.8	5.4	25.3	13.0	1.43
	26.9 – 34.8	29.2 – 38.3	1.0 – 9.8	18.8 – 31.7	10.0 – 16.0	1.34 – 1.52

* Source: Dairy One Feed Library

** NFC = nonfiber carbohydrates (calculated); DE = digestible energy; calculated

DE values of as low as 1.36 Mcal DE/lb (dry matter basis; Hintz et al, 1991) while others have found the DE content to exceed 1.6 Mcal DE/lb (dry matter basis; Lopez et al, 1988).

Dairy One, a commercial feed analysis laboratory in Ithaca, New York publishes the results from samples submitted to them. They do not measure DE content directly but provide estimates based on equations derived from feeding experiments. They report the normal range of DE content in oats to be 1.39 to 1.66 Mcal/lb; with a mean value of 1.52 Mcal. The appendix of this report contains the information on oats, barley, corn, wheat middlings, corn gluten feed and distillers grains (dry) from their website, but some of their values are summarized in Table 2. It is apparent that average oats are lower in DE than average corn or barley. Average oats contain approximately the same amount of DE as wheat middlings.

Oats are lower in starch, lower in DE, higher in acid detergent fiber (ADF) and have neutral detergent fiber (NDF) than many other cereal grains. Consequently, it would be expected that they would be lower in digestibility and feeding value. However, the differences are not always apparent in actual feeding experiments.

Table 3: Fatty acid composition of oats and corn					
	16:0	18:0	18:1	18:2	18:3
Oats*	13-25%	1-4%	18-47%	24-50%	1-5%
Corn**	10.9*	1.8%	24.2%	59%	0.7%

* Source: Zhou et al 1999; Holland et al 2001

** Source: NRC 1998

Mueller et al (2001) reported that a high concentrate diet based on corn had a higher dry matter digestibility than a similar diet based on oats. Also, in order to feed similar amounts of energy, it was necessary to feed approximately 10% more of the oat-based diet. Diets containing sorghum may have higher dry matter digestibility than similar diets containing oats (Al Jassim 2005), although another study did not find any difference in growth response or dry matter digestibility between diets containing oats or sorghum (Householder et al 1976). Coleman et al (1985) did not find a difference in dry matter digestibility between diets containing alfalfa and oats or alfalfa and barley. Gibbs et al (1987) compared the growth of yearling horses fed a diet of alfalfa hay and oats or alfalfa hay and a mixed concentrate (ingredients not disclosed). The yearlings that received the oats diet gained the same as those receiving the mixed concentrate, suggesting that the diets provided similar amounts of DE. However, the authors noted that the oat-based diet may have resulted in a higher rate of fat deposition. Hussein et al (2004) did not find significant differences in the dry matter digestibility of diets containing alfalfa and barley, alfalfa and corn, alfalfa and oat or alfalfa and naked oats. Overall, oats do not have a greater feeding value than other grains, but their value is not markedly lower than other grains when used in typical equine rations.

Starch is the primary energy constituent in cereal grains. Although oats contain less total starch than other grains, the structure of oat starch appears to be superior to the structure of starch from corn or barley. The utilization of starch by horses will be discussed later in this report. Other energy-containing compounds include fat and fiber. Oats contain more fat that other grains. Table 3 shows the approximate fatty acid composition of oats and corn oil. There is current interest in the ratio of n-6 (also called omega-6) fatty acids to n-3 (or omega-3) fatty acids. The ratio of n-6 to n-3 fatty acids may influence inflammatory and immune responses in animals. This area is just beginning to be investigated in equine nutrition. Although the differences are not great (Table 5), it appears that oats may

Table 4: Average amino acid content of oats and corn (dry matter basis)*

	Lysine	Threonine	Methionine	Tryptophan	Arginine
Oats	0.449	0.494	0.247	0.157	0.987
Corn	0.292	0.326	0.191	0.067	0.416

* NRC 1998

Table 5: Amino acid composition as a percentage of total protein

	Lysine	Threonine	Methionine	Tryptophan	Arginine
Oats	3.478	3.826	1.913	1.217	7.565
Corn	3.133	3.494	2.048	0.723	4.458

have a more desirable n-6:n-3 ratio than corn. Oats are typically higher in fiber than other grains. The most digestible type of fiber in oats would include hemicellulose which is found in the NDF fraction and beta-glucans and other soluble fibers that are not captured in any common analytical fraction.

Protein and Amino Acids

Although oats do not have a clear advantage over other grains in regard to energy value or dry matter digestibility, they do have an advantage in regard to crude protein (CP) content. Corn grain analyzed by Dairy One contained 7.7 to 10.9% CP (mean of 9.3%). Oat samples contained 10.5 to 14.9% CP (mean of 12.7%). The total tract digestibility of crude protein in oats appears to be 80% or higher (Gibbs et al, 1996; Woodward et al, 2009). One study reported that crude protein digestibility in a ration containing hay and oats was about 5% higher than in a ration containing hay and sorghum (Householder et al, 1977). However, other studies have not always shown the same result (Gibbs et al, 1996; Rosenfeld and Austbo 2009).

Oats also have an advantage over some other grains in regard to protein quality. Protein quality is estimated by the amount and balance of amino acids present in the feed. Amino acid digestibility is also important, particularly small intestinal amino acid digestibility. Amino acids digested and absorbed in the small intestine are directly available for protein synthesis in the horse, whereas amino acids that reach the large intestine are incorporated into microbial protein that is unavailable to the horse. The nitrogen fraction of some amino acids and other nitrogen containing substances that reach the large intestine may be liberated as

Table 6: Small intestinal digestible amino acids in oats and corn (dry matter basis)*

	Lysine	Threonine	Methionine	Tryptophan	Arginine
Oats	0.306	0.366	0.168	0.107	0.669
Corn	0.180	0.200	0.117	0.041	0.256

* Source: Calculated from Table 4 and small intestinal protein digestibility of 60% for corn and 68% for oats (Rosenfeld and Austbo 2009).

ammonia by the microbes. The ammonia can be absorbed by the horse and used to synthesize nonessential amino acids. Absorbed ammonia is not used to synthesize essential amino acids in significant quantities; therefore, essential amino acids must be absorbed from the small intestine.

Table 4 and Table 5 show the concentrations of several essential amino acids in corn and oats on a dry matter basis and as a percentage of total protein, respectively. Lysine is generally considered the first limiting amino acid in diets for growing horses. Oats contain about 50% more lysine on a dry matter basis than corn. The amount of lysine in oats would not usually be enough to meet the lysine requirements of growing horses so soybean meal is often added to mixed feeds to increase the lysine content. When oats are used as the energy source in a concentrate, the amount of soybean meal needed to provide adequate lysine will be less than when corn is the concentrate source. As noted above, the small intestinal digestibility of amino acids is important because it affects whether the essential amino acids will be absorbed intact. While more than 80% of the total protein in grains is absorbed across the total tract, less than 80% will be absorbed from the small intestine. Potter and coworkers (1992) did not find large differences in small intestinal digestibility of different grains, but more recently Rosenfeld and Austbo (2009) reported that the small intestinal digestibility of oat protein was higher than for barley protein and that corn protein was intermediate. Table 6 shows the estimated concentrations of small intestinal digestible lysine, threonine, methionine, tryptophan and arginine in oats and corn using the small intestinal digestibility values from Rosenfeld and Austbo (2009). Because corn protein is slightly less digestible than oat protein, the differences between the two grains are exaggerated by comparing them on a small intestinal digestible amino acid basis.

Although lysine is considered the first limiting amino acid, growth responses to threonine have also been reported in horses. Research on the requirements of horses for other amino acids has not been conducted. However, it is interesting that mare milk contains relatively high levels of arginine compared to milk from other animals. Whether the growing horse (or lactating mare) has a higher requirement for arginine than other animals is not known. However, as shown in Tables 4, 5 and 6, oats provide more arginine than corn.

Calcium and Phosphorus

Oats and all other cereal grains are low in calcium and moderate in phosphorus. Therefore, horse diets containing cereal grains or grain byproducts must contain a source of calcium. Legume hays contribute significant calcium to a total diet, but additional calcium is often needed if grasses form the forage component of the diet. Most commercial feeds contain enough supplemental calcium to at least balance the calcium:phosphorus ratio at 1:1.

The phosphorus in plants is often found as phytate-phosphorus (a salt of myo-inositol-1,2,3,4,5,6-hexaphosphoric acid). About 67% of the phosphorus in oats is found as phytate-phosphorus, compared to 73, 90 and 63% for wheat, wheat bran and barley, respectively (Steiner et al, 2007). Swine and poultry have limited ability to utilize phytate-phosphorus because they do not produce adequate amounts of the enzyme phytase. However, grains and grain byproducts contain varying levels of phytase that affect how well the phytate-phosphorus may be digested in the gastrointestinal tract. The amount of phytase in corn grain is relatively low compared to wheat and, as a result, the availability of phosphorus in corn-based diets is lower than in wheat-based diets for swine (NRC 1998). The amount of phytase in oats has been reported to be low in comparison to wheat, wheat bran and barley (Steiner et al, 2007). However, phosphorus availability in an oat-based diet fed to growing horses appeared to be higher than in a corn-based diet (Oliveira et al 2008). The phosphorus availability in the oat based diet was estimated to be 57.7%, which is much higher than the value used to calculate dietary phosphorus requirements for horses. Relatively little is known about the importance of plant-phytase activity in horses or the bioavailability of phosphorus in different types of grains. Attempts to add phytase to the diet to improve phosphorus digestibility of horse feeds have not been successful (Hainze et al, 2004; Patterson et al 2002). If the phosphorus in oats is more bioavailable than the phosphorus in corn, then the inclusion of oats in a diet would reduce the amount of

phosphorus that must be added to the diet. Increasing phosphorus bioavailability in a concentrate not only decreases the amount of phosphorus that must be added, but it also can decrease the excretion of phosphorus into the environment.

Digestion of Starch

Starch is the primary chemical constituent in cereal grains. Starch digestion across the total gastrointestinal tract (from feed to feces) is almost 100%, regardless of the amount or type of starch consumed. To maximize its energy value to the horse, starch must be digested and absorbed from the small intestine as glucose. As mentioned previously, digestion of starch in the large intestine is less energetically efficient because the end products that are absorbed by the horse are volatile fatty acids (VFA). Oats have lower amounts of starch than other grains, but research in the last 40 years has demonstrated that oat starch is more easily digested in the equine small intestine than starch from other cereal grains. Higher small intestinal digestion for oat starch may partly explain the lack of difference in feeding value that is sometimes observed between diets based on oats and diets based on other grains. There appear to be five dietary factors that affect the susceptibility of starch to digestion in the equine small intestine (Meyer et al, 1993):

1) Source of starch
2) Processing of starch
3) Amount of starch consumed
4) Source and amount of forage
5) Differences among individual horses

These factors have been investigated by a number of researchers using a variety of techniques. One method of estimating digestion in various segments of the digestive tract is to slaughter animals at various time points after a meal and evaluate the composition of the contents in each location. This method requires the slaughter of many animals, so alternative methods are usually employed. In many cases, researchers have used horses or ponies with a surgically inserted cannula in the distal small intestine, usually in the distal jejunum or the ileum. Different diets are fed to the horses, and samples of the digesta are collected at various times after a meal to assess the disappearance of starch. Another technique is to place samples of various feeds in very small, porous, nylon bags and intubate these bags into the horse's stomach. The bags then move through the horse's digestive tract, and the contents can be acted on by the digestive enzymes, etc. The bags are collected

at the cannula, and the disappearance of starch from the bag is measured. A disadvantage of this "mobile bag" technique is that the starch sources are often finely ground in order to place them in the bag, so the results may not represent what happens to starch sources in whole or partially-processed grains. In addition, fine grinding may result in the escape of some particles, so values must be adjusted for losses due to particle escape. It is also possible to obtain a qualitative assessment of small intestinal starch digestion by measuring changes to digestive variables in the large intestine (usually pH or VFA concentrations). These studies require access to the digesta of the large intestine through a cannula in the cecum or large colon. Because small intestinal starch digestion leads to an increase in blood glucose, the post-prandial blood glucose response of horses to a starch containing meal has also been used to provide information on the susceptibility of the starch in various feeds to digestion in the small intestine. This method requires the investigators to collect multiple blood samples for several hours after a meal to adequately describe the response. The least invasive method of assessing the extent of small intestinal starch digestion is to evaluate changes in the feces. This method does not provide a quantitative assessment of small intestinal starch digestion but does provide some qualitative information.

Using the slaughter technique, Hintz and coworkers (1971) observed that approximately 70% of the "available" carbohydrate in a high concentrate diet had disappeared by the time the digesta reached the posterior small intestine. The diet used in that study contained 63% ground corn, so it would be expected that most of the "available" carbohydrate was starch. A study reported in 1983 suggested that, although the total tract digestion of corn starch was almost 100%, less than 70% of the starch was digested before the large intestine (Hinkle et al, 1983). When ponies were fed corn, oats, barley or sorghum as the source of starch, the small intestinal starch digestibility was 80.9, 81, 95.9, and 80.3, respectively. Estimates were made from digesta collected from an ileal cannula, and the authors indicated that the high value observed for barley was due to one individual. In that study, ponies were fed starch at a rate of 1.2-1.5 grams per kg BW per meal, and starch disappearance across the total digestive tract was 98-99% for all diets (Potter et al, 1992). In a subsequent study, ponies were fed crimped oats, micronized oats, crimped sorghum or micronized sorghum to achieve starch intakes of 2.4-2.9 grams per kg BW. Total tract starch digestibility was about 94% for both grains, but the small intestinal digestion of starch was 48 and 62.3% for crimped and micronized oats, respectively and 36 and 59% for crimped and micronized sorghum (Potter et

al, 1992). Radicke and coworkers (1991) investigated the small intestinal digestibility of starch from coarsely ground corn or coarsely ground oats using two ponies with jejunal cannulae. Animals were adapted to the diet for 10 days and then fed a meal that contained 1.8 grams of starch per kg BW per meal. Samples of the digesta were collected for 7 hours after the meal. Small intestinal starch digestibility was estimated to be 98% for the diet containing the coarsely ground oats and 71% for the diet containing the coarsely ground corn. The investigators also examined the effects of the two diets on digesta characteristics in the large intestine using ponies with cecal cannulae. Cecal pH was lower at 3-4 hours after a corn meal containing 3-4 grams of starch/kg BW per meal compared to an oat diet. The lower pH was attributed to higher VFA concentrations when starch was fermented by the microbial population in the large intestine. Meyer et al (1993) compared small intestinal starch digestibility in ponies fed 1.3-2.1 g starch/kg BW per meal when the starch source was whole oats, rolled oats, whole corn, crushed corn, ground corn, popped corn and rolled barley. Small intestinal starch digestibility was 83.5 and 85.2% for the whole and rolled oats and 90.1 % for the popped corn. Markedly lower small intestinal starch digestibility was observed for whole corn (28.9%), crushed corn (29.9%), ground corn (45.6%) and rolled barley (21.1%).

The mobile bag technique was used to assess small intestinal starch digestibility of ground oats, ground wheat, corn and barley in horses adapted to either a high starch or a low starch diet (de Fombelle et al, 2004). The digestibility of ground oats and wheat were approximately 99%, whereas ground corn and barley had values between 85 and 91%. Prior adaptation of the horse to either the high starch or low starch diet had minimal effects on the results. This technique was also used to compare the effects of four different processing methods on corn, barley and oats (Rosenfeld and Austbo, 2009). Feeds were ground, pelleted, extruded or micronized prior to being ground in the laboratory and placed in the nylon bags. Horses were adapted to the type of grain being tested prior to being intubated with the nylon bags. The small intestinal starch digestibility across all processing methods was 95%, 71% and 66% for oats, barley and corn, respectively. The small intestinal digestibility of starch was 72%, 82%, 70% and 85% across all grains for ground, pelleted, extruded and micronized grains, respectively. The authors did not report individual values for each grain/processing combination.

Overall, the starch in oats appears to be more highly susceptible to digestion in the small intestine than starch in corn or barley. There are several possible explanations for this characteristic. Early publications on feeding horses suggested that the higher fiber of oats resulted in a looser mass in the gastrointestinal tract that would make it easier for digestive substances to have access to the oat particles. The presence of soluble fiber in some grains may affect viscosity of digesta but the relationship to starch digestibility is not clear (Svihus et al, 2005; White et al, 2008).

The structure of the starch granule as well as the composition of the starch itself may influence susceptibility to digestion (Kienzle et al,1997; Svihus et al, 2005). Starch is comprised of varying amounts of amylose and amylopectin, both of which contain multiple glucose units. Amylopectin is a relatively branched compound, whereas amylose is primarily unbranched (Fahey 1988). The ratio of amylopectin to amylose may be a factor influencing starch digestibility.

Characteristics of the starch granule that may impact digestibility include the size of the granule as well as the non-starch components of the granule. The surface of the starch granule may contain lipids and proteins that protect the granule from digestion (Svihus et al, 2005). Hydrophobic lipids may reduce the interaction between the starch and the surrounding aqueous environment in the digestive tract. The presence of specific types of proteins in corn has been reported to affect starch digestibility in ruminants (Larson and Hoffman 2008). Oats may have smaller starch granules than other grains which may contribute to higher digestibility. Kienzle et al (1997) suggested that the starch granules in oats were digested via exocorrosion (from the outside) whereas the starch granules from corn were digested through pin holes in the exterior of the granule (endocorrosion).

Starch digestion in the small intestine relies upon several enzymes including alpha amylase. There is some evidence that grains may contain amylase inhibitors (Svihus et al, 2005), but it appears that other factors can affect the activity of alpha amylase as well. The activity of alpha amylase in small intestinal chyme has been reported to increase after a meal (Radicke et al, 1992). A smaller increase was observed with a meal of hay than with a meal of grain (Kienzle et al, 1994). Oats appeared to result in a higher concentration of alpha amylase in small intestinal chyme than corn (Radicke et al, 1992) and the addition of alpha amylase to a corn-based diet increased small intestinal starch digestion from 45.6% to 57.7% (Meyer et al, 1993).

There appear to be differences among horses in the activity of alpha amylase in small intestinal chyme, and these differences were at least partly related to differences among horses in their ability to digest starch (Kienzle et al, 1994).

Disaccharidases in the gastrointestinal tract act upon maltose and other disaccharides to yield monosaccharides (particularly glucose) that can be transported across the wall of the small intestine and into the blood. The transport of glucose into the enterocytes is regulated by the sodium-glucose co- transporter SLGT1. Glucose movement out of the enterocytes occurs via another transporter GLUT2. The activity of the disaccharidases, sucrase and maltase have been measured in the horse and do not appear to be affected by diet (Dyer et al, 2002; Dyer et al, 2008). However, the transport of glucose across the intestinal wall may be increased by adaptation to a high-starch diet (Dyer et al, 2008). Whether this response is further affected by type of starch or other characteristics of a diet is not known. Perhaps if oat starch is more easily digested and absorbed as glucose, it would have a greater capacity to induce changes in carbohydrate digestion than other grains.

Colic and Other Digestive Disturbances in Horses

Colic: Colic (acute abdominal pain) and other digestive problems are the second leading cause of death in mature horses, second only to old age (NAHMS 2005). The economic losses associated with colic were estimated to be $115 million in 2001 (NAHMS 2001) but this estimate may be low. White (2009) reported that colic was responsible for approximately 24,000 surgeries annually at veterinary clinics. The cost of colic surgery is variable but at a conservative estimate of $3000/incident, surgeries alone could cost $72 million per year. Most horses with nonsurgical colic recover uneventfully, but the cost of veterinary treatment may still be significant.

A number of studies have investigated management factors that increase the risk of colic. Feed-related causes include hay quality, availability of water, a recent change in feed source or feeding schedule and amount or type of concentrate. Reeves et al (1996) found a positive relationship between concentrate intake and colic risk and particularly with the ingestion of whole grain corn. Feeding 2.5 kg of concentrate increased the odds ratio (OR) for colic by about 4 times, whereas feeding more than 5 kg of concentrate increased the OR about 6-fold (Tinker et al, 1997). In another epidemiological study, feeding more than 2.7 kg of oats increased the risk of colic, but increased risk was not reported with the feeding of other concentrates

(Hudson et al, 2001). The authors suggested that the relationship between the consumption of oats and increased risk of colic could have been due to another factor that was not included in the study, such as the amount of activity/exercise the horses received. Kaya et al (2009) did not find the consumption of oats to be different between horses with colic and control horses, but they did report that colic horses had been fed approximately 2.74 kg of total concentrate per day, compared to control horses that received 1.64 kg/d. Many cases of colic are associated with large intestinal dysfunction, but small intestinal dysfunction has also been associated with high concentrate intakes (Cohen et al, 2006). Not all studies report a relationship between colic incidence and concentrate intake (Cohen et al, 1999), but the preponderance of studies suggest that it is an important risk factor.

In a recent review on the nutritional causes of colic, it was suggested that the incomplete digestion of starch in the small intestine is an important link between increased colic risk and diet (Durham 2009). Starch that is not digested in the small intestine will reach the large intestine where it can be rapidly fermented by the microbial population. The introduction of small amounts of rapidly fermentable substrate to the large intestine may not be important, but larger amounts of starch have the potential to have significant effects on the environment of the large intestine. Willard et al (1977) demonstrated that a high concentrate diet reduced cecal pH in comparison to a hay diet, even after 2 weeks of adaptation. In their study, cecal pH ranged from 6.75 to 7.16 when the hay diet was fed. Cecal pH decreased below 6.8 within 3 hours of a meal of the high concentrate diet and stayed below 6.8 for several hours. The lowest value measured was 6.12. In another study, an abrupt change to a high concentrate diet resulted in a cecal pH at or below 6 from 6 to 8 hours after feeding (Goodson et al, 1985). These researchers also reported that the abrupt change resulted in changes to the microbial population in the cecum. More recent studies have also demonstrated that diets high in starch can alter the microbial population of the large intestine (Medina et al, 2002; Jouany et al, 2009). Changes in the microbial population can be associated with functional changes as well, including decreased fiber digestion and alterations in VFA production (Jouany et al, 2008). Development of large intestinal acidosis has also been suggested to depress appetite in horses (Jackson 1998).

Because the starch in oats is more easily digested in the small intestine, it is possible that high intakes of oats will have a smaller impact on the microbial population of the large intestine than other grains. At high levels of starch intake,

cecal pH was lower when horses were fed corn than when they received oats (Radicke et al, 1991). Similarly, fecal pH was lower when horses were fed sorghum than when they were fed oats (Al Jassim 2005). In a survey of race horses in Australia, fecal pH decreased as the amount of indigestible starch in the diet increased (Richards et al, 2006). Those authors found that 27% of the horses surveyed had a fecal pH below 6.2, which was suggested to be the lower limit for normal functioning of the microbial population in the large intestine. Diets high in fiber favor bacteria that use cellulose and produce acetate.

Diets that are high in cereal grains favor bacteria that use starch and sugar and produce lactic acid and propionate. Therefore, at high grain intakes some starch will reach the large intestine where it can fuel the proliferation of bacteria that prefer it as a substrate. Some of the bacteria that can be enhanced by a high-starch diet may be detrimental to the horse, resulting in diarrhea or possibly colic. Lopes et al (2004) reported that feeding large amounts of grain produced marked effects on fecal consistency in horses, but few studies have related diet composition to the incidence of pathogenic diarrhea in horses.

The effect of diet on the incidence of diarrhea in swine has been relatively well-studied. The addition of pearl barley to a rice-based diet increased the incidence of diarrhea in swine. That study also reported an increased colonization of the intestine with E. coli in the pigs fed the pearl barley (Hopwood et al, 2004). Pearl barley contains rapidly fermentable non-starch polysaccharides, and barley starch is also relatively resistant to small intestinal digestion. Therefore, the addition of pearl barley may have increased the substrate available for use by pathogenic bacteria in the large intestine. Similarly, pigs fed a diet containing a high level of raw potato starch (considered to be resistant to small intestinal digestion) had a higher incidence of diarrhea and a decline in the diversity of the bacteria in the colon (Bhandari et al, 2009). While high-starch diets appear to increase the incidence of diarrhea, diets that are relatively high in insoluble (less digestible) fiber reduce the incidence of diarrhea in swine (Horner et al, 2000; Partanen et al, 2002).

Gastric ulcers

Equine gastric ulcer syndrome (EGUS) affects a large number of performance horses. Horses with gastric ulcers may exhibit poor performance, lack of appetite, weight loss and possibly colic. Medical treatment for gastric ulcers is common in performance horses, but it is very expensive. Ulcers can affect both the glandular

portion of the stomach and the non-glandular portion. It has been suggested that ulcers in the glandular portion may arise from a decrease in the mucosal protective factors, whereas damage to the nonglandular portion is caused by excessive or prolonged exposure to gastric acid containing hydrochloric acid and volatile fatty acids (Nadeau and Andrews, 2009). Diet composition and feeding management may affect the incidence of ulcers of the nonglandular portion of the stomach.

In the horse, gastric acid is continuously secreted into the stomach. This may be a consequence of the evolution of the horse as a grazing animal that consumed feed more or less continuously throughout the day. However, in modern horse management, performance horses are frequently kept in a stable where they receive 2 large concentrate meals per day, often with restricted amounts of forage. The presence of food in the stomach may provide both a physical and chemical buffer to the gastric acid, so long periods of time without food may result in a loss of protection by the gastric contents (McCall 2005).

The chemical composition of the food may also be important. Damage to the nonglandular tissue of the stomach is increased by exposure to volatile fatty acids (Nadeau et al, 2001). Although the equine stomach is not a major site of microbial digestion of food, some fermentation does occur. Increased levels of lactic acid and other VFA have been reported in the stomach after feeding (Healy et al, 1995). Diets that are high in concentrate have the potential to increase the levels of lactic acid and volatile fatty acids in the stomach, and thus are expected to be more ulcerogenic than diets high in forage. In pigs, dietary particle size is inversely related to the incidence of ulcers. The effect of particle size or concentrate composition on the incidence or severity of gastric ulcers has not been examined in a methodical fashion. It is possible that whole grains would be less fermentable in the stomach than processed or pelleted grains. Gastric acid can be buffered to some extent by the bicarbonate and other cations (Ca, Mg, Na, K) in saliva. Salivation is stimulated by chewing so diets that take longer to consume stimulate more saliva. As discussed previously, whole oats are consumed more slowly than pelleted concentrate or sweet-feed concentrate and thus would be expected to elicit more saliva and enhanced gastric acid buffering.

Laminitis

Laminitis (also called founder) affects the dermal (sensitive) and epidermal (insensitive) laminae of the hoof. Laminitis is an important cause of lameness. Although mild cases may resolve without permanent damage, it has been estimated that 25% of affected horses will have long lasting effects and some may be euthanized (NAHMS 2000). Laminitis can result in a separation of the dermal and epidermal laminae which weakens the bond between the hoof wall and the bony structures of the foot. In very severe cases, the coffin bone in the hoof may penetrate the sole of the hoof, or the hoof may detach from the foot. Laminitis can result from a number of causes including systemic infectious disease, but one of the most common causes is excess consumption of rapidly-fermentable carbohydrates. In fact, one of the first experimental models used to study laminitis involved administration of large amounts of starch to produce severe large intestinal acidosis. In that study, dramatic changes in large intestinal pH, lactic acid levels and microbial populations were observed (Garner et al, 1978). It has been suggested that death of some organisms in the acid environment results in the release of bacterial endotoxins. Furthermore, the acidic pH may cause damage to the mucosal surface of the large intestine which will be permissive to the absorption of toxins (Clarke et al, 1990).

Most cases of laminitis arise from consumption of rapidly-fermentable carbohydrates in pasture (pasture-associated laminitis), but approximately 10 to 15% arise from over-consumption of grain, feeding-related problems or after diarrhea or colic (NAHMS 2000). Carbohydrate overload (pasture or grain), diarrhea, colic, and infectious diseases cause laminitis by producing a systemic inflammatory state that is mediated by toxins produced by infectious organisms or the microbes in the gastrointestinal tract (Belknap 2009). The laminae appear to be particularly susceptible to damage from this septicemia, possibly because of the structure of the hoof (an inelastic hoof wall), the anatomy of the blood vessels in the hoof or some other chemical or physical characteristic of the laminae.

Horses that have been affected by laminitis may be more susceptible to future episodes. Therefore, minimizing the amount of rapidly-fermentable carbohydrate that reaches the large intestine is important for the prevention of the initial bout of laminitis as well as subsequent bouts. A search of the literature did not find any reports that identified grain type as a risk factor for laminitis. However, in the original laminitis model, corn was the source of the rapidly fermentable starch.

Blood Glucose and Insulin Responses to Dietary Starch

Blood glucose concentration increases after a meal containing starch. Similarly, blood insulin concentrations increase following a starch-containing meal. The size and duration of the increase in either glucose or insulin can be influenced by a number of horse-related factors (age, physical fitness, health, etc.) and feed-related factors including the amount of starch consumed, the type of starch consumed, the extent of processing during or before mastication and the presence of other feeds/feed ingredients.

Many studies have compared the glucose and insulin responses of horses to various feeds. It would be expected that meals with more starch would produce greater blood glucose and insulin responses, so cereal grains produce greater responses than forages or high fiber-byproduct feeds (Stull and Rodiek, 1988; Pagan et al, 1999; Rodiek and Stull, 2007). In addition, it would be expected that starch that is more susceptible to small intestinal digestion (oats) would produce greater blood glucose responses than starch that is resistant to small intestinal digestion (corn and barley). Differences among cereal grains have been observed occasionally but not consistently. Rodiek and Stull (2007) did not find significant differences in blood glucose response to oats or corn when they were fed on an equal energy (but different weight) basis. Similarly, there were no differences in blood glucose responses when horses were fed oats, corn or barley on an equal energy basis (Arana et al, 1989). Pagan et al (1999) found a small but significant difference in mean post-feeding glucose concentration between equal-sized meals of cracked corn and whole oats. Vervuert and Coenen (2005) reported that on an equal starch basis, oats produced a higher blood glucose response than corn. However, in another study when steamed oat groats, cracked corn and rolled barley were fed on an equal starch basis, there were no differences in blood glucose or insulin responses to a meal (Jose-Cunilleras et al, 2004). Topliff and Freeman (1989) reported that a wheat-based concentrate produced a greater blood glucose response than an oat-based concentrate. Not all of the previously-mentioned studies measured blood insulin responses, but in those that did, a large amount of variation was commonly reported. There appear to be large variations in the insulin responses among horses and within a horse on a day-to-day basis (Staniar et al, 2009; Pratt et al, 2009).

The effect of grain processing on blood glucose and insulin responses has also been studied. Because processing can increase the small intestinal digestibility of starch, it would be expected that processing could increase the blood glucose responses to a particular meal. Hoekstra et al (1999) reported that steam flaked corn produced a greater blood glucose response than either cracked or ground corn. Vervuert and Coenen (2005) reported that processing did not affect the glucose responses to corn, oats or barley at low starch intakes but did increase the glucose response at moderate starch intakes (2 g/kgBW). Many horse owners perceive that sweet feed mixes will produce greater blood glucose and insulin responses than other types of concentrates, but this has not be consistently shown (Arana et al, 1989; Pagan et al, 1999; Harbour et al, 2003; Rodiek and Stull 2007). In fact, in two studies where the same feed was offered as a pellet or a sweet feed, the glucose responses were greater for the pelleted feed (Healy et al, 1995; Harbour et al, 2003). It was suggested that the grinding and pelleting process increased the susceptibility of the starch to small intestinal digestion, thus allowing more glucose to be absorbed into the blood.

There have been several attempts to classify horse feeds with a "glycemic index" (GI). A GI would allow the comparison of different feeds in regard to their ability to increase blood glucose levels. However, there are several obstacles to the practical application of this system in horses. Obviously one obstacle is the lack of consistent results among studies that have compared the same types of feeds. In addition, there is evidence that one ingredient can affect another. For example, adding fat to a grain or a sweet feed can alter the blood glucose response to that feed, even though the form and amount of starch offered may not have changed very much. There may also be differences in responses to concentrate meals that are fed before or after hay, and there are individual differences among horses.

Insulin, Insulin Resistance and Insulin Sensitivity

Insulin is an important regulatory hormone. It is most commonly known for its effects on glucose uptake by tissues, but it has other functions such as stimulating amino acid uptake, reducing fatty acid mobilization from adipose and inhibiting glucose release from the liver. Insulin secretion has been described as being a complex process that includes oral and gastrointestinal signals as well as signals related to changes in blood glucose or possibly to the fat and protein composition of the diet (Schmidt and Hickey 2009). Most of the information about

insulin regulation and action has been obtained in humans or laboratory animals and extrapolated to horses. However, in recent years there has been increased concern about horses that develop some degree of "insulin resistance."

In humans, insulin resistance is evidenced by a decreased ability of insulin to stimulate glucose uptake in muscle as well as a decreased ability to inhibit lipolysis in adipose and inhibit glucose release by liver. As a result, individuals with insulin resistance may have elevated blood glucose levels as well as elevated blood lipid levels. Alternatively, blood glucose and lipid levels may be relatively normal because elevated amounts of insulin are secreted in order to maintain homeostasis. There can be negative consequences of persistently elevated blood glucose and/or blood insulin concentrations. In horses, insulin resistance has recently been suggested as a risk factor for laminitis (Trieber et al, 2006; Carter et al, 2009). Prevention and management of insulin resistance is currently perceived to be a desirable health practice in equine management.

Insulin resistance can occur in horses with Cushing's Disease and in horses with Metabolic Syndrome, but in the general population, insulin resistance has been most commonly reported in older, overweight and inactive individuals. There has been a great deal of emphasis on diet as a means of managing or preventing insulin resistance. In general, it is suggested that insulin resistant horses be fed diets that are low in starch or sugar in order to reduce the levels of blood glucose and insulin. If the animal is overweight, it is more important that they are fed diets that reduce calorie intake so that weight loss can be accomplished. Insulin resistance can be reduced with weight loss (Freestone et al, 1992), whereas feeding a fat and fiber feed did not correct insulin resistance in obese geldings (Hoffman et al, 2003). Regular exercise is probably the most important preventative practice because performance horses have normal glucose and insulin concentrations regardless of amount of body fat (Pagan et al, 2009).

Insulin dysregulation associated with high starch diets has been suggested as a risk factor for developmental orthopedic diseases in growing horses (Glade and Belling 1986; Ralston 1996; Cubitt et al, 2005), although others have not supported this suggestion (Hoffman et al, 2003; Pagan et al, 2005; Nowelsky et al, 2009). Several studies have measured the glucose and insulin responses of horses fed high "sugar and starch" feeds and high "fat and fiber feeds." These studies have demonstrated that calorie source does alter the glucose and insulin responses to

a meal and that changes in insulin sensitivity may occur, but none demonstrated actual health benefits from a high fat and fiber feed (Hoffman et al, 1999; Williams et al, 2001; Cubitt et al, 2005; George et al, 2009; Nowelsky et al, 2009).

Essentially, all research on diet and equine insulin resistance has focused on manipulating the amount of starch, fat and fiber. Studies examining the effect of starch source on insulin resistance were not found. Also, insulin secretion and insulin action are influenced by many other nutrients including amino acids, several minerals and possibly the ratio of n-3 fatty acids to n-6 fatty acids. Further research is needed to fully understand the regulation of insulin sensitivity by diet in the horse.

Carbohydrate Use and Storage in Muscle

During high-intensity exercise, carbohydrates are an important energy source. Much of the carbohydrate used during high intensity exercise (such as racing) is derived from muscle glycogen stores. Muscle glycogen is also an important energy source during long-term moderate exercise (endurance), and liver glycogen is broken down to maintain blood glucose concentrations. When individuals begin exercise with suboptimal muscle glycogen concentrations, performance will be impaired. Similarly, depletion of muscle and liver glycogen stores during exercise is related to the onset of fatigue. Therefore, maintaining optimal carbohydrate stores is important for the performance horse. Performance horses must also receive adequate dietary calories. Very heavy work approximately doubles the energy requirement above maintenance for a mature horse. Horses can not consume enough forage to meet this need, so some forage must be replaced with concentrate. Currently, many feed manufacturers offer concentrate feeds designed specifically for performance horses.

The effect of concentrate composition on performance has been studied fairly extensively and the literature recently reviewed (NRC 2007). Replacing starch with fat has been reported to have no effect, a positive effect or a negative effect on metabolic and performance variables in exercising horses. Specific characteristics of the studies may have influenced the observed results including the level of conditioning of the horses, the type of exercise performed, the variables measured and the characteristics of the diets. Adaptation to a fat-supplemented diet may promote the use of fat during exercise, thus extending the period of time before the depletion of carbohydrate stores alter performance. In addition, replacing starch with fat can increase energy density, thus providing more total calories to horses engaged in strenuous work. Of course, replacing

starch with fat may also be beneficial to gastrointestinal health and function, as it may reduce the amount of starch that reaches the large intestine. Overall, there is good rationale for using fat-supplemented diets for performance horses.

Cereal grains have also been replaced in performance horse diets by digestible fiber sources. Replacing 50% of the oats in a diet with sugar beet pulp resulted in higher post-exercise muscle glycogen concentrations, but performance was not measured. Beet pulp has also been used in diets to increase the water holding capacity of the large intestine to create a reservoir to replace fluid losses from sweating (Warren et al, 1999). However, negative effects of increased fiber and water weight in the large intestine have also been reported (Mathiason-Kochan et al, 2001; Ellis et al, 2002).

As noted above, adequate carbohydrate stores are needed for optimal performance. Glycogen is synthesized from glucose; therefore, feeds that increase blood glucose may be desirable for performance horses. Glycogen repletion following exercise was reported to be slower if horses were fed only hay, rather than a combination of hay and concentrate (Snow et al, 1987). However, a more recent study did not show any difference in glycogen repletion rates in horses fed different practical diets (Lacombe et al, 2004). Exercising horses are sometimes affected by exertional rhabdomyolysis (tying up). Two general types of ER have been described: sporadic ER and chronic ER (Valberg 2005). Sporadic ER is likely to occur in horses that are worked beyond their level of training, and reoccurrence is not likely with an appropriate conditioning regime. Chronic ER involves repeated bouts of significant muscle stiffness and spasm that can occur even after light exercise. One form of chronic ER occurs in race-type horses and is related to a defect in calcium regulation during contraction and relaxation of the muscle. Although calcium regulation at the cellular level is involved in this disorder, dietary calcium is not a risk factor. There is some evidence that reduced starch-high fat diets may help prevent this type of ER, but diet alone is not successful in managing affecting horses.

Another form of chronic ER is polysaccharide storage myopathy (PSSM). This disorder occurs predominantly in Quarter Horses and is characterized by high concentrations of glycogen and other carbohydrates in skeletal muscle. Affected horses appear to be extremely sensitive to insulin and thus store abnormal amounts of absorbed carbohydrate in their muscles. Restricting the intake of feeds that elevate blood glucose and insulin is an important management practice for PSSM

horses. However, the most effective management also includes regular exercise to minimize carbohydrate accumulation in muscle (Valberg 2005). Many horses with PSSM are not used for strenuous work and therefore have low nutrient requirements. Their energy needs can often be met with forage alone and concentrates may not be needed at all. Although PSSM is a cause of concern for owners of affected horses, it occurs in a relatively small number of horses.

Diet and Behavior

The incidence of redirected or stereotypic behaviors by horses has been related to several management factors including diet. Wood chewing is considered a redirected behavior, but horses often exhibit stereotypic behaviors such as crib-biting (cribbing, windsucking), weaving and stall walking. The incidence of behavioral disorders appears to be increased when horses are fed concentrate or when roughage is restricted (McGreevy et al, 1995; Bachman et al, 2003). Gillham et al (1994) studied the effect of feeding concentrates or hay pellets to horses known to exhibit cribbing behavior. They reported that the greatest amount of cribbing activity was exhibited when the horses were offered the concentrates (sweet feed or pellets) rather than the hay pellets. They measured beta-endophin levels but were unable to detect a difference between treatments. In a four-year prospective study, the risk of young horses developing crib-biting behavior was increased by feeding concentrate (Waters et al, 2002), although the authors noted that the relationship was influenced primarily by observations on just one of the five farms that were studied.

One of the first studies to demonstrate an effect of diet on behavior was reported by Willard and coworkers in 1977. Geldings that were fed a high concentrate diet chewed more wood than horses fed a hay diet. Wood chewing was positively correlated with cecal propionate and inversely correlated with cecal acetate. Administration of a buffer reduced cecal propionate, increased cecal acetate and appeared to depress wood chewing. Administration of a compound to reduce hind gut acidosis in horses receiving high concentrate diets was also reported to reduce undesirable oral behavior (Johnson et al, 1998).

Gastric irritation has also been proposed as a stimulus for cribbing behavior in horses. Crib-biting foals had greater levels of gastric irritation and lower fecal pH than normal foals (Nicol et al, 2002). Administration of an antacid diet reduced the gastric irritation and may have reduced crib-biting. Administration of an antacid

has also been reported to reduce crib-biting in older horses (Mills and MacLeod 2002), although not in all cases (McCall 2009). Saliva is a natural buffer for gastric acid because it has a relatively high pH (8.5-9.1; Moeller et al, 2008). If crib-biting is related to gastric acidity, then perhaps it is a mechanism for increasing saliva flow to the stomach (Nicol 1999; Moeller et al, 2008). As noted previously, cribbing is increased with the consumption of concentrate in comparison to forage.

Saliva production is greater when forage is fed than when concentrate is fed (Meyer et al, 1991). No studies were found that compared cribbing behavior in horses fed oats or other types of feeds. However, the horses take longer to consume oats than sweet feed or pellets, so perhaps oats would increase saliva production, modify gastric pH and potentially reduce the incidence of cribbing.

A few studies have attempted to examine the effects of diet composition on other behavior characteristics such as excitability. Horses fed diets containing fat have been reported to be less reactive and excitable than horses fed diets without added fat, but results are inconsistent and observations comparing oats to other feeds were not found in this literature search. It is generally hypothesized that increased reactivity of horses receiving high starch diets is related to increased blood glucose; however, it is also possible that gastric or large intestinal acidity has an effect on these behavior characteristics.

Feed Hygiene

Mycotoxins in cereal grains have been reported to have deleterious effects on equine health. Signs of aflatoxicosis in horses include loss of weight, inappetance and liver damage (Murphy 1991). Deoxynivalenol and zearalonone have been reported to depress feed intake in horses (Raymond 2003; 2005). These mycotoxins can occur in a variety of grains, although oats are not usually implicated in naturally occurring cases of contaminated feed (Vesonder et al 1991; Raymond 2005). Fumonisin toxicity is usually associated with the consumption of contaminated corn or corn screenings. Acute fumonisin toxicity in horses is characterized by neurological disease (leukoencephalomalacia) and a high rate of mortality. Chronic consumption of low levels of fumonisin may result in liver disease. In the US, the Food and Drug Administration has made a specific recommendation that corn screenings not be used for horse feed because of the risk of fumonisin contamination.

Summary

Oats are a Horse-Healthy Grain

Oats have many characteristics that make them useful in horse feeds. Although oats contain less starch than other grains, they have a similar feeding value. Oats tend to be somewhat higher in fat, which is high in energy, and they also contain some digestible fiber. Therefore, their lower starch content is not a serious drawback. In fact, their lower starch content is probably an advantage as starch intake may be a risk factor for several undesirable digestive conditions and some undesirable behavioral conditions. Current knowledge suggests that oat starch is more readily digested in the small intestine than starch from other grains. Higher small intestinal starch digestion and lower dietary starch concentration result in less starch arriving at the large intestine. Excessive amounts of starch in the large intestine can lead to digestive upset. Therefore, oats should reduce the risk of digestive disorders in comparison to other grains.

Some of the advantage of oats over corn or barley (in regard to small intestinal starch digestion) is diminished by extensive processing (grinding, extruding, pelleting), but this would increase the cost of the other grains and, thus, reduce their competitive price advantage.

Oats are palatable to horses, but they are not consumed rapidly like sweet feeds or pelleted concentrates. Slower consumption and greater chewing may lead to increased saliva production which could buffer stomach acid and help minimize stomach ulcers. There is some indication that gastric or large intestinal acidity might be related to undesirable oral behaviors in horses (cribbing, wood chewing), so research could be designed to investigate whether oats has any effect on the incidence of these behaviors in comparison to other grains or commercial concentrates.

Oats have a more desirable amino acid profile than other grains, particularly corn. In addition, the amino acids in oats may be more easily digested in the small intestine than the amino acids in other grains. Overall, when oats are used, the need for additional protein supplementation should be less than when corn is used.

Oats also have a more desirable fatty acid composition than corn, and they may have more digestible phosphorus. These characteristics have implications for improved horse health and decreased environmental contamination, respectively. Lastly, oats are less likely to contain mycotoxins that threaten horse health. This characteristic is also fairly well-documented.

Bibliography

(includes items cited in the report as well as others)

Al Jassim, R.A.M. 2006. Supplementary feeding of horses with processed sorghum grains and oats. Anim. Feed Sci. Technol. 125 (1-2): 33-44.

Almeida, F.Q., S.C. Valadares Filho, J.L. Donzele, J.F. Coelho da Silva, A.C. Queiroz, M.I. Leao, P.R. Cecon. 1999. Prececal digestibility of amino acids in diets for horses. Pages 274-278 in Proc. 16th Equine Nutr. Phyisol. Symp., Raleigh, NC.

Anderson, D.M., J.M. Bell, G.I. Christison. 1978. Evaluation of a high-protein cultivar of oats (hinoats) as a feed for swine. Can. J. Anim. Sci. 58 (1): 87-96.

Andrews, F.M. 2009. Overview of gastric and colonic ulcers. Pages 347-354 in Advances in Equine Nutrition IV, J.D. Pagan, ed. Nottingham University Press, Nottingham, UK.

Anguita, M., J. Gasa, S.M. Martin-Orue, J.F. Perez. 2006. Study of the effect of technological processes in starch hydrolysis, non-starch polysaccharides solubilization and physicochemical properties of different ingredients using a two-step in vitro system. Anim. Feed Sci. Technol. 129 (1-2): 99-115.

Arana, M., A. Rodiek, C. Stull. 1989. Blood glucose and insulin responses to four different grains and four different forms of alfalfa hay fed to horses. Pages 160-161 in Proc. 11th Equine Nutr. Phyisol. Symp., Stillwater, OK.

Arnold, F.F., W.C. Ellis, G.D. Potter, J.L. Kreider, K.R. Pond. 1981. Prececal retention time of four feed fractions in ponies. Pages 240-242 in Proc. 7th Equine Nutr. Phyisol. Symp., Warrenton, VA.

Bachman I., L. Audige, M. Stauffacher. 2003. Risk factors associated with behavioral disorders of crib-biting, weaving and box-walking in Swiss horses. Equine Vet J.35:158-163

Bailoni, L., Mantovani, R., Pagnin, G., Schiavon, S. 2006. Effects of physical treatments on the resistant starch content and in vitro organic matter digestibility of different cereals in horses. Livestock Sci., 100 (1): 14-17.

Bhandari, S.K., Nyachoti, C.M. and Krause, D.O. (2009) Raw potato starch in weaned pig diets and its influence on postweaning scours and the molecular microbial ecology of the digestive tract. J. Anim. Sci. 87:984-993.

Barnett, D.T., R.A. Mowery, W.M. Hagler, Jr., D.G. Bristol, R.A. Mansmann. 1995. The correlation of selected mycotoxins to the incidence of colic in horses. Pages 242-247 in Proc. 14th Equine Nutr. Phyisol. Symp., Ontario, Canada.

Belknap J.K. 2009. Pathogenesis of laminitis. In, Current Therapy in Equine Medicine 6., Saunders-Elsevier, St. Louis MO

Bergsjo, B., Langseth, W., Nafstad, I, Jansen, J.H., Larsen, H.J.S. 1993. The effects of naturally deoxynivalenol-contaminated oats on the clinical condition, blood parameters, performance and carcass composition of growing pigs. Vet. Research Comm., 17 (4): 283-294.

Biel, W., K. Bobko, R. Maciorowski. 2009. Chemical composition and nutritive value of husked and naked oats grain. J. Cereal Sci., 49 (3): 413-418.

Boila, R.J., Strothers, S.C., Campbell, L.D. 1993. The concentration of selenium in the grain from wheat, barley and oats grown at selected locations throughout Manitoba. Can. J. Anim. Sci. 73 (1): 217-221.

Bonoma, T.A., A.C. Brogren, K.H. Kline, K.M. Doyle. 2007. Effects of feeding distillers dried grains and solubles on growth and feed efficiency of weanling horses. Pages 5859 in Proc. 20th Equine Sci. Soc., Hunt Valley, MD.

Boren, S.R., D.R. Topliff, D.W. Freeman, R.J. Bahr, D.G. Wagner, C.V. Maxwell. 1987. Growth of weanling Quarter Horses fed varying energy and protein levels. Pages 43-48 in Proc. 10th Equine Nutr. Phyisol. Symp., Ft Collins, CO.

Brand, T.S., vanderMerwe, J.P. 1996. Naked oats (avena nuda) as a substitute for maize in diets for weanling and grower-finisher pigs. Anim. Feed Sci. Technol., 57 (1-2): 139-147.

Brandt, J.A., Kruse, J.R., Todd, J. 1992. Supply, demand, and effects of alternative policies on the United-States oats industry. Am. J. Ag. Econ., 74 (2): 318-328.

Breuer, Jr., L.H. 1997. Selecting and utilizing manufactured feeds. Pages 675-684 in Current Therapy in Equine Medicine 4, N.E. Robinson, ed. WB Saunders, Philadelphia, PA.

Breuer, L.H. 1998. Protein and energy requirements of growing horses. Pages 407-414 in Advances in Equine Nutrition, J.D. Pagan, ed. Kentucky Equine Research, Inc., Versailles, KY.

Brewster-Barnes, T., L.M. Lawrence, L.K. Warren, P.D., Siciliano, A. Crum, K. Thompson. 1998. The effects of feeding after exercise on glucose and glycogen responses in the Horse. Pages 293-296 in Advances in Equine Nutrition, J.D. Pagan, ed. Kentucky Equine Research, Inc., Versailles, KY.

Brokner, C., P. Norgaard, T.M. Soland. 2006. The effect of grain type and processing on equine chewing time. Pferdeheilkunde, 22 (4): 453-460.

Brokner, C.P., P. Norgaard, H.H. Hansen. 2008. Effect of feed type and essential oil product on equine chewing activity. J. Appl. Physiol Anim Nutr. 92:621-630.

Brussow, N., K. Voigt, I. Vervuert, T. Hollands, D. Cuddeford, M. Coenen. 2005. The effect of feeding oats and chopped alfalfa to horses on the rate of feed intake and chewing activity. Pages 37-38 in Proc. 21st Equine Nutr. Conf., Hanover, Germany.

Buckely, T., A. Creighton, U. Fogarty. 2007. Analysis of Canadian and Irish forage, oats and commercially available equine concentrate feed for pathogenic fungi and mycotoxins. Irish Vet. J., 60 (4): 231-236.

Burk, J.R. 2009. Review of a statewide equine feed assessment over a 5 year period. J. Equine Vet. Sci., 29 (5): 458-459.

Bush, J.A., D.E. Freeman, K.H. Kline, N.R. Merchen, G.C. Fahey. 2001. Dietary fat supplementation effects on in vitro nutrient disappearance and in vivo nutrient intake and total tract digestibility by horses. J. Anim. Sci., 79 (1): 232-239.

Caloni, F., P. Gulden, L. Lanfranconi, M. Battini. 2009. Mycotoxins and mycotoxicoses in equine: Toxic effects of trichothecenes. Ippologia, 20 (2): 35-38.

Chatterton, N.J., K.A. Watts, K.B. Jensen, P.A. Harrison, W.H. Horton. 2006. Nonstructural carbohydrates in oat forage. Journal of Nutrition, 136 (7): 2111S-2113S (Suppl.).

Clarke L.L., M.C. Roberts, R. Argenzio. 1990. Feeding and digestive problems in horses. Vet. Cin NA: Equine Practice 6:433-450

Cohen, N.D., P.G. Gibbs, A.M. Woods. 1999. Dietary and other management factors associated with colic in horses. J. Am. Vet. Med. Assoc., 215 (1): 53-60.

Cohen, N.D., E. Toby, A.J. Toussel, E.L. Murphey, N. Wang. 2006. Are feeding practices associated with duodenitis-proximal jejunitis? Equine Vet J., 82 (12): 3625-3634.

Coleman, R.J. 1997. Feeds and feeding in the Northwestern United States and Western Canada. Pages 691-698 in Current Therapy in Equine Medicine 4, N.E. Robinson, ed. WB Saunders, Philadelphia, PA.

Coleman, R.J., J.D. Milligan, R.J. Christopherson. 1985. Energy and dry matter digestibility of processed grain for horses. Pages 162-167 in Proc 9th Equine Nutr. Phyisol. Symp., East Lansing, MI.

Crandell, K. 2005. Trends in feeding the American Endurance Horse. Pages 181-184 in Advances in Equine Nutrition III, J.D. Pagan, ed. Nottingham University Press, Nottingham, UK.

Cunha, T.J. 1991. Horse Feeding and Nutrition. Academic Press, San Diego CA

Cubitt, T.A., Burton Staniar, W., D.S. Kronfeld, B.M. Byrd, K.H. Treiber, P.A. Harris. 2005. Insulin sensitivity of Thoroughbred foals increases with age and is affected by feed energy source. Pages 137-138 in Proc. 19th Equine Sci. Soc., Tucson, AZ.

da Silva, L.P., M.D.S. Ciocca. 2005. Total insoluble and soluble dietary fiber values measured by enzymatic-gravimetric method in cereal grains. J. Food Comp. Analy., 18 (1): 113-120.

de Fombelle, A., A.G. Goacher, M. Varloud, P. Boisot, V. Julliand. 2003. Effect of the diet on prececal digestion of different starches in the horse measured with the mobile bag technique. Pages 115-116 in Proc. 18th Equine Nutr. Phyisol. Symp., East Lansing, MI.

de Fombelle, A., L. Veiga, C. Drogoul, V. Julliand. 2004. Effect of diet composition and feeding pattern on the prececal digestibility of starches from diverse botanical origins measured with the mobile nylon bag technique in horses. J. Anim. Sci., 82 (12): 3625- 3634.

de Fombelle, A., P. Frumholtz, D. Pollion, C. Drogout, C. Phillipeau, E. Jacotot, V. Julliand. 2001. Effect of the botanical origin of starch on its prececal digestibility measured with the mobile bag technique. Pages 153-154 in Proc. 17th Equine Nutr. Phyisol. Symp., Lexington, KY.

Duren, S. 1998. Feeding the Endurance Horse. Pages 351-364 in Advances in Equine Nutrition, J.D. Pagan, ed. Kentucky Equine Research, Inc., Versailles, KY.

Durham A.E. 2009. The role of nutrition in colic. Veterinary Clinics NA: Equine 25:67-78

Dyer J., E. Fernadez-Castano Meridiz, KSH Salman, C. Proudman, G.B. Edwards, S.P. Shirazi-Beechy. 2002. Molecular characterization of carbohydrate digestion and absorption in the equine small intestine. Equine Vet. J. 34:349-358

Dyer, J., M. Al-Rammahi, L. Waterfall, K.S.H. Salmon, R.J. Geor, L. Boure, G.B. Edwards, C.J. Proudman, S.P. Shirazi-Beechey. 2009. Adaptive response of equine intestinal Na+/glucose co-transporter (SGLT1) to an increase in dietary soluble carbohydrate. Pflugers Archiv-European Journal of Physiology, 458 (2): 419-430.

Edmonds, J.L., C.W. Crawford. 1925. Feeding Purebred Draft Fillies. Bul. No. 262, University of Illinois, Urbana.

Edmonds, J.L., W.G. Kammlade. 1921. Feeding Pure-Bred Draft Fillies. Bul. No. 235, University of Illinois, Urbana.

Ellis, J.M., T. Hollands, D.E. Allen. 2002. Effect of forage intake on body weight and performance. Equine Vet J. Suppl 34:66-70

Fahrenholz, C. 1998. Cereal Grains and Byproducts: What's in Them and How are They Processed? Pages 57-70 in Advances in Equine Nutrition, J.D. Pagan, ed. Kentucky Equine Research, Inc., Versailles, KY.

Fahey G. 1988. Carbohydrate nutrition of ruminants. In, The Ruminant Animal. Waveland Press, Prospect Heights, IL

Flis, M., A. Maslanek, Z. Zdunczyk, J. Juskiewicz. 2004. Protein utilization and caecal fermentation in rats fed on wheat-, barley- or naked oat-diets supplemented with beta-glucanase. J. Anim. Feed Sci., 13 (4): 665-676.

Freestone J., R. Beadle, K. Shoemaker, KJ. Wolfsheimer, C. Church. 1992. Improved insulin sensitivity in hyperinsulinemic ponies through physical conditioning and controlling feed intake. Equine Vet j. 24:187-190

Gallagher, K., J. Leech, H. Stowe. 1992. Protein, energy and dry-matter consumption by racing Thoroughbreds - A field survey. J. Equine Vet. Sci., 12 (1): 43-48.

Garner, H.E., J.N. Moore, J. H. Johnson. 1978. Changes in the caecal flora associated with the onset of laminitis. Equine Vet J. 10:249-252.

George, L.A., W.B. Staniar, K.H. Treiber, P.A. Harris, R. J. Geor. 2009. Insulin sensitivity and glucose dynamics during pre-weaning development in response to maternal diet composition. Domestic Anim. Endo. 37; 23-29

Gibbs, P.G., D.H. Sigler, T.B. Goehring. 1987. Influence of diet on growth and development of yearling horses. Pages 37-42 in Proc. 10th Equine Nutr. Phyisol. Symp., Ft. Collins, CO.

Gibbs, P.G., G.D. Potter, G.Y. Schelling, J.L. Kreider, C.L. Boyd. 1996. The significance of small vs large intestinal digestion of cereal grain and oilseed protein in the equine. J. Equine Vet. Sci. 16:60-65

Gillham S.B., N.H Dodman, L. Shuster, L.,R. Kream, W. Rand,. 1994. The effect of diet on cribbing behavior and plasma endorphin in horses. Appl. Animal Behav. Sci. 41: 147-153

Glade M.J., T.H. Belling. 1987. A dietary etiology for osteochondrotic cartilage. J. Equine Vet. Sci., 6:151-157.

Goodson J., W.J. Tyznik, B.A. Dehority. 1985. Effects of an abrupt change from all hay to all concentrate on anaerobic bacterial numbers, protozoal numbers, and pH of the cecum. Proc. 10th Equine Nutr. Physiol. Symp. Ft. Collins, CO, p. 52-63

Gordon, M., M. Jerina, R. Raub, K. Davison, K. Young, S. King. 2007. The effects of feed form on consumption time and glucose and insulin response to a concentrate meal. Pages 97-99 in Proc. 20th Equine Sci. Soc., Hunt Valley, MD.

Graham, P.M., E.A. Ott, J.H. Brendemuhl, S.H. Tenbroeck. 1994. The effect of supplemental lysine and threonine on growth and development of yearling horses. J. Anim. Sci., 72 (2): 380-386.

Graham-Thiers, P.M. 2007. Feeding practices of hunter/jumper horses in the Midatlantic region of the United States. Pages 270-271 in Proc. 20th Equine Sci. Soc., Hunt Valley, MD.

Graham-Thiers, P.M., J.A. Wilson. 2007. Relationships between diet, plasma and muscle amino acids in horses in maintenance and horses in early lactation. Pages 108-109 in Proc. 20th Equine Sci. Soc., Hunt Valley, MD.

Hainze, M.T.M., K.A. Condon, C.A. McCall, R.B. Muntifering. 2001. Fiber digestibility in yearling horses fed four typical diets with and without enzyme supplementation. Page 61 in Proc. 17th Equine Nutr. Phyisol. Symp., Lexington, KY.

Hainze, M.T.M., R.B. Muntifering, C.W. Wood, C.A. McCall, B.H. Wood. 2004. Faecal phosphorus excretion from horses fed typical diets with and without added phytase. Anim. Feed Sci. Technol., 117 (3-4): 265-279.

Hainze, M.T.M., R.B. Muntifering, C.W. Wood, C.A. McCall. 2003. Fiber digestion in horses fed typical diets with and without exogenous fibrolytic enzymes. J. Equine Vet. Sci., 23 (3): 111-115.

Harbour, L.e., L.M. Lawrence, S.H. Hayes, C.J. Stine, D.M. Powell. 2003. Concentrate composition, form, and glycemic response in horses. Pages 329-330 in Proc. 18th Equine Nutr. Phyisol. Symp., East Lansing, MI.

Harris, P. 1997. Feeds and feeding in the United Kingdom. Pages 698-703 in Current Therapy in Equine Medicine 4, N.E. Robinson, ed. WB Saunders, Philadelphia, PA.

Hassel, D.M., B.M. Aldridge, C.M. Drake, J.R. Snyder. 2008. Evaluation of dietary and management risk factors for enterolithiasis among horses in California. Research in Vet. Sci., 85 (3): 476-480.

Healy, H.P., P.D. Siciliano, L.M. Lawrence 1995. Effect of concentrate form on blood and gastric fluid variables in ponies. J. Equine Vet. Sci. 15: 423-428.

Hemmingsen, A.K.T., A.M, Stevik, I.C. Clausen, K.K. Lundblad, E. Prestlokken, M. Sorensen, T.M. Eikevik. 2008. Water absorption in feed ingredients for animal pellets at different temperatures, particle size and ingredient combinations. J. Equine Vet. Sci., 29 (9): 665-674.

Hessel, E.F., F. Garlipp, H.F.A. Van den Weghe. 2009. Generation of airborne particles from horse feeds depending on type and processing. J. Equine Vet. Sci., 29 (9): 665-674.

Hinkle, D.K., G.D. Potter, J.L. Kreider. 1983. Starch digestion in different segments of the digestive tract in ponies fed varying levels of corn. Proc. 8th Equine Nutr. Phys. Sym., p227-229

Hintz, H.F., D.E. Hogue, E. Walker, J. E. Lowe, H.F. Schryver. 1971. Apparent digestion in various segments of the digestive tract of ponies fed diets with varying roughagegrain ratios. J. Anim. Sci. 32:245-249.

Hintz, H. F. 1983. Horse Nutrition: A practical guide. Arco Publishing, NY, NY.

Hintz, H.F. 1992. High-fat oats - Feed of the future. Equine Practice, 14 (7): 6-7.

Hintz, H.F., B. Morrison, J. Williams, T. Hernandez. 1991. Evaluation of naked oats for ponies. Pages 33-36 in Proc. 12th Equine Nutr. Phyisol. Symp., Calgary, Alberta, Canada.

Hintz, H.F., J. Scott, L.V. Soderholm, J. Williams. 1985. Extruded feeds for horses. Pages 174-176 in Proc. 9th Equine Nutr. Phyisol. Symp., East Lansing, MI.

Hoekstra, K.E., K. Newman, M.A. P. Kennedy, J. D. Pagan. 1999. Effect of corn processing on glycemic response in horses. Proc. 16th Equine Nutr. Physiol. Symp. Raleigh, NC. p144-148.

Hoffman R.M., R.C. Boston, D. Stefanovski, D. Kronfeld, P.A. Harris. 2003. Obesity and diet affect glucose dynamincs and insulin sensitivity in thoroughbred geldings. J. Anim. Sci. 81:2333-2342.

Hoffman, R.M., Haffner, J.C., C.A. Crawford, H. Eiler, K.A. Fecteau. 2009. Nonstructural carbohydrate and glycemic response of feeds: how low is "low" starch? J. Equine Vet. Sci., 29 (5): 379-380.

Holland, J.L., D.S. Kronfeld, T.N. Meacham. 1996. Behavior of horses is affected by soy lechithin and corn oil in the diet. J. Anim. Sci., 74 (6): 1252-1255.

Hopwood, D.E., Pethick, D.W., Pluske, J.R. and Hampton, D.J. (2004). Addition of pearl barley to a rice-based diet for newly weaned piglets increases the viscosity of the intestinal contents, reduces starch digestibility and exacerbates post-weaning colibacillosis. Br. J. Nutr. 92:419-427.

Horner, K.L., LeBoeuf, R.C., McFarland, L.V., and Elmer, G.W. (2000). Dietary fiber affects the onset of Clostridium difficile disease in hamsters. Nutr. Res. 20:1103- 1112.

Hothersall, B., C. Nichol. 2009. Role of diet and feeding in normal and stereotypic behaviors in horses. Vet Clinics NA: Equine 25:167-181

Householder, D.D., G.D. Potter, R.E. Lichtenwalner, J. Hesby. 1976. Growth and digestion in horses fed sorghum or oats. J. Anim. Sci. 43:254 (abstract)

Householder, D.D., G.D. Potter, R.E. Lichtenwalner. 1977. Nutrient utilization in different segments of the equine digestive tract. Pages 44-45 in Proc. 5th Equine Nutr. Physiol. Symp., St. Louis, MO.

Householder, D.D., G.D. Potter, R.E. Lichtenwalner. 1977. Digestible energy and protein requirements of yearling horses. Pages 126-128 in Proc. 5th Equine Nutr. Physiol. Symp., St. Louis, MO.

Hudson, J.M., N.D. Cohen, P.G. Gibbs, J.A. Thompson. 2001. Feeding practices associated with colic in horses. J. Am. Vet. Med. Assoc. 219 (10): 1419-1425.

Hudson, R.S. 1934. Liberal vs. Limited Rations for Draft Colt in Michigan. Sp. Bul. No. 253. Michigan State College, East Lansing.

Huntington, P.J., G.J. Jenkinson. 1998. Feeding Practices in Australia and New Zealand. Pages 331-340 in Advances in Equine Nutrition, J.D. Pagan, ed. Kentucky Equine Research, Inc., Versailles, KY.

Hussein, H.S., L.A. Vogedes, G.E. J. Fernandez, R.L. Frankeny. 2004. Effects of cereal grain supplementation on apparent digestibility of nutrients and concentrations of fermentation end-products in the feces and serum of horses consuming alfalfa cubes. J. Anim. Sci., 82 (7): 1986-1996.

Hyslop, J.J., N.S. Jessop, G.J. Stefensdottir, D. Cuddeford. 1997. Compariative degradation in situ of four concentrate feeds in the caecum of ponies and the rumen of steers. Pages 116-117 in Proc. 15th Equine Nutr. Phyisol. Symp., Ft. Worth, TX.

Inhyuck, H., J. Hollars, M. Lancaster, R. Mowery, M. Yoder. 2009. An economic impact analysis of the North Carolina equine industry. J. Equine Vet. Sci., 29 (5): 463-464.

Jackson, S.G. 1998. Feeding the western performance horse. Pages 373-382 in Advances in Equine Nutrition, J.D. Pagan, ed. Kentucky Equine Research, Inc., Versailles, KY.

Jackson, S.G. 1998. Growth management of young horses to achieve different commercial endpoints. Pages 437-446 in Advances in Equine Nutrition, J.D. Pagan, ed. Kentucky Equine Research, Inc., Versailles, KY.

Jackson, S.G. 1998. Myths and wives' tales of feeding horses "some truth, some fiction." Pages 307-318 in Advances in Equine Nutrition, J.D. Pagan, ed. Kentucky Equine Research, Inc., Versailles, KY.

Jackson, S.G. 1998. The digestive tract of the horse - practical considerations. Pages 1- 12 in Advances in Equine Nutrition, J.D. Pagan, ed. Kentucky Equine Research, Inc., Versailles, KY.

Johnson K., J. tyrell, J.B. Rowe, D.W. Pethick. 1998. Behavioural changes in stabled horses given nontherapeutic levels of virginaimycin. Equine Vet. J. 30:1015-1037

Jose-Cunillears, L.E. Taylor, K.W. hinchcliff. 2004. Glycemic index of cracked corn, oat groats and rolled barley in horses. J. Anim. Sci. 82:2623-2629 Jouany, J.P., J. Cobert, B. Medina, G. Bertin,V. Julliand. 2008. Effect of live yeast culture supplementation on apparent digestibility and rate of passage in horses fed a high fiber or high starch diet. J. Anim. Sci. 86:339-347.

Jouany, J.P., Medina,B., Bertin, G. and Julliand, V.. (2009). Effect of live yeast culture supplementation on hindgut microbial communities and their polysaccharidase and glycoside hydrolase activities in horse fed a high fiber or a high starch diet. J. Anim. Sci. 87:2844-2852.

Jozefiak, D., A. Rutkowski, B.B. Jensen, R.M. Engberg. 2006. The effect of betaglucanase supplementation of barley- and oat-based diets on growth performance and fermentation in broiler chicken gastrointestinal tract. British poultry Sci., 47 (1): 57-64.

Kamphues, J., H. Fimmen, S. Kustermann, H. Meyer. 1991. Lipopolysaccharides in feedstuffs for horses. J. Equine Vet. Sci., 11 (1): 36-41.

Kamphues, J. 2005. A systematic approach to evaluate the hygenic quality of feedstuffs for horses. Pages 15-18 in Proc. 21st Equine Nutr. Conf., Hanover, Germany.

Kamphues, J., H. Fimmen, S. Kustermann, H. Meyer. 1989. Lipopolysaccharides in feedstuffs for horses. Pages 169-174 in Proc. 11th Equine Nutr. Phyisol. Symp., Stillwater, OK.

Karlsson, C.P., J.E. Lindberg, M. Rundgren. 2000. Associative effects on total tract digestibility in horses fed different ratios of grass hay and whole oats. Livestock Prod. Sci., 65 (1-2): 143-153.

Kaya, G., I. Sommerfield-Stur, C. Iben. 2009. Risk factors of colic in horses in Austria. J. Anim. Physiol. Anim. Nutr. 93 (3): 339-349.

Kays, J.M. 1950. The Care of Light Horses. Cir. 353 University of Missouri, Columbia.

Keller, K., B. Queiroz, L.A. Keller, J. Ribeira, L. Cavaglieri, C. da Rocha Rosa. 2005. Mycological survey and mycotoxins detection in equine feeds samples. Pages 19-20 in Proc. 21st Equine Nutr. Conf., Hanover, Germany.

Kern , D.L., L.L.Slyter, J.M. Weaver, E.C. Leffel, G. Samuelson. 1973. Pony cecum vs steer rumen-effect of oats and hay on the microbial ecosystem. J. Anim. Sci. 37:463- 469.

Kienzle, E., J. Pohlenz, S. Radicke. 1997. Morphology of starch digestion in the horse. J. Vet. Medicine Series A-Physiology Pathology Clinical Medicine, 44 (4): 207-221.

Kienzle, E., S. Radicke, E. Landes, D. Kleffken, M. Illenseer, H. Meyer. 1994. Activity of amylase in the gastrointestinal tract of the horse. J. Anim. Physiol. Anim. Nutr. 72:234- 241

Kienzle, E., S. Radicke, S. Wilke, E. Landes, H. Meyer. 1992. Praeileal starch digestion in relation to source and preparation of starch. Pferdeheilkunde Sonderausgabe, Sept: 103-106.

Klendshoj, C., G.D. Potter, R.E. Lichtenwalner, D.D. Householder. 1979. Nitrogen digestion in the small intestine of horses fed crimped or micronized sorghum grain or oats. Pages 91-94 in Proc. 6th Equine Nutr. Physiol. Symp., College Station, TX.

Krusic, L., J.D. Pagan, J. Lorenz, A. Pen. 2001. Influence of high carbohydrate and high fibre diet on caecum content of organic matter and volatile fatty acids. Pages 425-434 in Proc. 17th Equine Nutr. Phyisol. Symp., Lexington, KY.

Lacombe, V.A., K.W. Hinchliff, C.W. Kohn ,S.T. Devor, and L.E. Taylor. 2004. Effects of feeding meals with various soluble carbohydrate content on muscle glycogen synthesis after exercise. Amer. J. Vet. Res. 65:916-923

Larson J, P.C. Hoffman. 2008. Technical note: A method to quantify prolamin proteins in corn that are negatively related to starch digestibility in ruminants. J. Dairy Sci. 91:4834-4839

Lasztity, R. 1998. Oat grain - A wonderful reservoir of natural nutrients and biologically active substances. Food Review Int., 14 (1): 99-119.

Lavin, T.E., B.D. Nielsen, N.L. Trottler, A.D. Woodward, C.I. O'Connor-Robinson, G.M. Hill. 2009. Impact of different dietary constituents on phosphorus balance in mature horses. J. Equine Vet. Sci., 29 (5): 359-360.

Lewis, L. 1995. Equine Clinical Nutrition. Williams and Williams, Media, PA.

Lawrence, L.M. 2005. Feeding more and getting less: Effects of high grain intakes on digestive capacity and gastrointestinal health of performance horses. Pages 227-233 in Advances in Equine Nutrition III, J.D. Pagan, ed. Nottingham University Press, Nottingham, UK.

Lindberg, J.E. 2005. Use of non-starch carbohydrate energy sources in performance horse feeds. Pages 249-264 in Advances in Equine Nutrition III, J.D. Pagan, ed. Nottingham University Press, Nottingham, UK.

Lindberg, J.E., C.P. Karlsson. 2001. Effect of partial replacement of oats with sugar beet pulp and maize oil on nutrient utilisation in horses. Equine Vet. J., 33 (6): 585-590.

Longland, A.C., M. Moore-Colyer, J.J. Hyslop, M.S. Dhanoa, D. Cuddeford. 1997. Comparison of the in sacco degradation of the non-starch polysaccharide and neutral detergent fibre fractions of four sources of dietary fibre by ponies. Pages 120-121 in Proc. 15th Equine Nutr. Phyisol. Symp., Ft. Worth, TX.

Longland, A.C., P.A. Harris. 2009. The ethanol- soluble carbohydrate content and composition of some common horse feeds. J. Equine Vet. Sci., 29 (5): 396-397.

Lopez, N.E., J.P. Baker, S.G. Jackson. 1988. Effect of cutting and vacuum cleaning on the digestibiltiy of oats by horses. J. Equine Vet. Sci., 8 (5): 375-378.

Lowman, R.S., M.K. Theodorou, D. Cuddeford. 2002. The effect of sample processing on gas production profiles obtained using the pressure transducer technique. Anim. Feed Sci. Technol., 97 (3-4): 221-237.

Lowman, R.S., M.K. Theodorou, M.S. Dhanoa, J.J. Hyslop, D. Cuddeford. 1997. Evaluation of an in vitro gas production technique for estimating the in vivo digestibility of equine feeds. Pages 1-2 in Proc. 15th Equine Nutr. Phyisol. Symp., Ft. Worth, TX.

Marquart, L., K.L. Wiemer, J.M. Jones, B. Jacob. 2003. Whole grain health claims in the USA and other efforts to increase whole-grain consumption. Proc. Nutr. Society, 62 (1): 151-159.

Mathiason-Kochan K.J., G.D. Potter, S. Caggiano, E.M. Michael. 2001. Ration digestibility, water balance and physiological responses in horse fed varying diets in hot weather. Proc. 17th Equine Nutr. Physiol Symp, Lexington, KY, p 261-262

McCall, C. 2009. Equine behavior: A nutritional link? Pages 77-87 in Advanced Equine Nutrition IV, J.D. Pagan, ed. Nottingham University Press, Nottingham, UK.

McCall, C.A., P.J. Tyler, W.H. McElhenney, T.R. Fenn. 2009. Effect of hourly concentrate feed delivery on crib-biting in horses. J. Equine Vet. Sci., 29 (5): 427-428.

McCampbell, C.W., Cochel, W.A. 1912. Feeding Work Horses. Bul. 186, Kansas State Agricultural College, Manhattan.

McCampbell, C.W. 1917. Feeding Work Horses. Bul. 186 (abr.), Kansas State Agricultural College, Manhattan.

McGreevy, P., C.J. Nicol, P. Cripps, L. Green and N. French. 1995. Management factors associated with stereotypic and redirected behaviors in the thoroughbred horse. Equine Vet. J. 27:86-91

McIlwraith, C.W. 2009. Update on bone disease: The impact of skeletal disease on athletic performance. Pages 101-121 in Advanced Equine Nutrition IV, J.D. Pagan, ed. Nottingham University Press, Nottingham, UK.

Medina B., L.D. Girard, E. Jacotot, V. Julliand. 2002. Effect of a preparation of Saccharomyces cervisiae on microbial profiles and fermentation patterns in the large intestine of horse fed a high fiber or high starch diet. J. Anim. Sci. 80:2600-2609

Meyer, H., M. Coenen, C. Gurer. 1985. Investigations on saliva production and chewing effects in horses fed various feeds. Pages 38-45 in Proc. 9th Equine Nutr. Phyisol. Symp., East Lansing, MI.

Meyer, H., S. Radicke, E. Kienzle, S. Wilke, D. Kleffken, M. Illenseer, M. 1995. Investigations on preileal digestion of starch from grain, potato and manioc in horses. Journal of Veterinary Medicine Series A-Zentralblatt Fur Veterinarmedizin Reihe APhysiology Pathology Clinical Medicine, 42 (6): 371-381.

Meyer, H., S. Radicke, E. Kienzle, S. Wilke, D. Kleffken. 1993. Investigations on preileal digestion of oats, corn, and barley starch in relation to grain processing. Pages 92-97 in Proc. 13th Equine Nutr. Phyisol. Symp., Gainsville, FL.

Michner, C.B., In, Special Report on Diseases of the Horse, 1907. USDA- Gov. Printing Office, Washington DC

Milinovich, GJ, P.C. Burrell, C.C. Pollitt, A. V. Klieve, L.L. Blackall, D. Ouwerkerk, E. Woodland, D. J. Trott. 2008. Microbial ecology of the equine hindgut during oligofructose-induced laminitis. ISME J. 2:1089-1100 Mills DS, CA

MacLeod. 2002. The response of crib biting and windsucking in horses to dietary supplementation with an antacid mixture. Ippologia 13:33-41 (abstract only)

Miyaji, M., Ueda, K., Nakatsuji, H., Tomioka, T., Kobayashi, Y., Hata, H., Kondo, S. 2008. Mean retention time of digesta in the different segments of the equine hindgut. Anim. Sci. J., 79 (1): 89-96.

Moeller, B.A., C.A. McCall, S.J. Silverman, W.H. McElhenney. 2008. Estimation of saliva production in crib biting and normal horses. J. Equine Vet. Sci. 28: 85-90

Moore-Colyer, M.J.S., Hyslop, J.J., Longland, A.C., Cuddeford, D. 1997. Degradation of four dietary fibre sources by ponies as measured by the mobile bag technique. Pages 118-119 in Proc. 15th Equine Nutr. Phyisol. Symp., Ft. Worth, TX.

Moore-Colyer, M.J.S., J.J. Hyslop, A.C. Longland, D. Cuddeford. 2000. Intra-caecal fermentation parameters in ponies fed botanically diverse fibre-based diets. Anim. Feed Sci. Technol., 84 (3-4): 183-197.

Morrison, F.B. 1961. Feeds and Feeding, Abridged. Morrison Publishing, Claremont, Ont. Canada

Morrison, F.B., G.W. Salisbury. 1940. New Developments in the Feeding and Nutrition of Horses and Mules. Booklet No. 257, Horse and Mule Assn. of America, Chicago, IL.

Mueller, R.K., S.R. Cooper, D.R. Topliff, D.W. Freeman, C. MacAllister, S.D. Carter. 2001. Effect of dietary cation-anion difference on acid-base status and energy digestibility in sedentary horses fed varying levels and types of starch. J. Equine Vet. Sci., 21 (10): 498-502.

Murphy, M. 2005. Hidden killers: Molds and mycotoxins. Pages 139-168 in Advances in Equine Nutrition III, J.D. Pagan, ed. Nottingham University Press, Nottingham, UK.

Murray J., B. Scott, P. Hastie. 2009. Fermentive capacity of equine faecal inocula obtained from clinically normal horses and those predisposed to laminitis. Animal Feed Science and Tech. 151:306-311

Nadeau, J.A., F.M. Andrews, C.S. Patton, A.M. Saxton and R.A. Argenzio. 2001. Pathogenesis of acid injury in the nonglandular region of the equine stomach. Proc. 17th Equine Nutr. Phyisol. Symp., Lexington, KY, p. 39-40

Nadeau, J.A., F.M. Andrews. 2009. Gastric ulcer syndrome. In Current Therapy in Equine Medicine 6, Saunders Pub.

NAHMS-USDA. 1998. Part II: Baseline Reference of 1998 Equine Health and Management. USDA: APHIS: VS: CEAH, Fort Collins, CO.

NAHMS-USDA. 2000. Lameness and laminitis in US Horses. USDA: APHIS: VS: CEAH, Fort Collins, CO.

NAHMS-USDA. 2001. National economic cost of equine lameness, colic and EPM in the United States . USDA: APHIS: VS: CEAH, Fort Collins, CO.

NAHMS- USDA. 2005. Part II: Changes in the U.S. Equine Industry, 1998-2005. USDA: APHIS: VS: CEAH, Fort Collins, CO.

National Research Council (NRC) 2007. The Nutrient Requirements of Horses. National Academy Press. Washington DC.

National Research Council (NRC) 1989. The Nutrient Requirements of Horses. National Academy Press. Washington DC.

National Research Council (NRC) 1978. The Nutrient Requirements of Horses. National Academy Press. Washington DC.

National Research Council (NRC) 1973. The Nutrient Requirements of Horses. National Academy Press. Washington DC.

Nicol, C.J., H. Davidson, P.A. Harris, A.J. Waters, A.D. Wilson. 2002. Study of crib-biting and gastric inflammation and ulceration in young horses. Vet. Rec. 151:658-662.

Nelson, M.L., R.M. Jordan. 1975. The effect of kind of forage and grain and pelleting on growth of ponies and their ability to tolerate stress. Pages 98-113 in Proc. 4th Equine Nutr. Physiol. Symp.

Noble, G.K.,Y.M. Brockwell, K.J. Munn, P.A. Harris, H.R.B. Davidson, X. Li, D. Zhang, M.N. Silence. 2008. Effects of a commercial dose of L-tryptophan on plasma tryptophan concentrations and behavior in horses. Equine Vet. J., 40 (1): 51-56.

Nowelsky, E.A., J.K. Morrissey, E.A. Jedzejewski, P.A. Harris, W.B. Staniar. 2009. Biomarkers of cartilage metabolism and IGF-1 as influenced by dietary starch. J. Equine Vet. Sci., 29 (5): 397-398.

Oliverira, A.A.M.A., C.E. Furtado, M.S.S. Vitti, F.D. Resende, S.L.S. Cabral, H. Tosi, B. Winkler. 2008. Phosphorus bioavailability in diets for growing horses. Livestock Sci., 116 (1-3): 90-95.

Ordakowski-Burk, A.L., J.L. Antelman. 2005. Feeding management practices of Thoroughbred racehorse trainers in Maryland. Page 269 in Proc. 19th Equine Sci. Soc., Tucson, AZ.

Ott, E.A. 1997. Feeds and feeding in the Southern United States. Pages 684-691 in Current Therapy in Equine Medicine 4, N.E. Robinson, ed. WB Saunders, Philadelphia, PA.

Ott, E.A., G.L. Richardson. 1977. Effect of protein quality on growing foals. Pages 113- 125 in Proc. 5th Equine Nutr. Physiol. Symp., St Louis, MO.

Owens, E. 2005. Sport horse nutrition - An Australian perspective. Pages 185-192 in Advances in Equine Nutrition III, J.D. Pagan, ed. Nottingham University Press, Nottingham, UK.

Pagan, J.D. 1998. Measuring the digestible energy content of horse feeds. Pages 71-76 in Advances in Equine Nutrition, J.D. Pagan, ed. Kentucky Equine Research, Inc., Versailles, KY.

Pagan, J.D. 1998. Protein requirements and digestibility: A review. Pages 43-50 in Advances in Equine Nutrition, J.D. Pagan, ed. Kentucky Equine Research, Inc., Versailles, KY.

Pagan, J.D. 1998. Energy and the performance horse. Pages 141-148 in Advances in Equine Nutrition, J.D. Pagan, ed. Kentucky Equine Research, Inc., Versailles, KY.

Pagan, J.D. 1998. Carbohydrates in equine nutrition. Pages 29-42 in Advances in Equine Nutrition, J.D. Pagan, ed. Kentucky Equine Research, Inc., Versailles, KY.

Pagan, J.D. 2005. The relationship between glycemic response and the incidence of OCD in Thoroughbred weanlings: A field study. Pages 433-437 in Advances in Equine Nutrition III, J.D. Pagan, ed. Nottingham University Press, Nottingham, UK.

Pagan, J.D., P. Harris, S.E. Duren, S.G. Jackson. 1999. Feed type and intake affects glycemic response in Thoroughbred horses. Pages 149-150 in Proc. 16th Equine Nutr. Phyisol. Symp., Raleigh, NC.

Pagan, J.D., S.G. Jackson. 1991. Distillers dried grains as a feed ingredient for horse rations: A palatability and digestibility study. Pages 49-54 in Proc. 12th Equine Nutr. Phyisol. Symp., Calgary, Alberta, Canada.

Pagan, J.D., O.A. Martin, N.L. Crowley. 2009. Relationship between body condition and metabolic parameters in sport horses, pony hunters, and polo ponies. J. Equine Vet. Sci., 29:418-420

Palmgren Karlsson, C., A. Jannson, B. Essen-Gustavsson, J. Lindberg. 2002. Effect of molassed sugar beet pulp on nutrient utilization and metabolic parameters during exercise. Equine Vet. J. Suppl. 34:44-49

Partanen, K., Siljander-Rasi,H., Alaviuhkola, T., Suomi, K. and Fossi, M. (2002). Performance of growing-finishing pigs fed medium or high fibre diets supplemented with avilamycin, formic acid or formic-acid sorbate blend. Livestock Prod. Sci. 73:139-152.

Patterson, D.P., S.R. Cooper, D.W. Freeman and R.G. Teeter. 2002. Effects of varying levels of phytase supplementation on dry matter and phosphorus digestibility in horses fed a common textured ration. J. Equine Vet. Sci. 22:456-459

Perttila, S., J. Valaju, T. Jalava. 2005. Apparent ileal digestibility of amino acids and metabolisable energy value in grains from broilers. Ag.Food Sci., 14 (4): 325-334.

Pettersson, A., J.E. Lindgerg, S. Thomke. 1997. Nutritive value of oats of different composition evaluated by intact and fistulated pigs. Acta Agrulturae Scandinavica Section A-Animal Science, 47 (4): 247-253.

Placinta, C.M., J.P.F. D'Mello, A.M.C. Macdonald. 1999. A review of worldwide contamination of cereal grains and animal feed with Fusarium mycotoxins. Anim. Feed Sci. Technol., 78 (1-2): 21-37.

Plumlee, K.H. 1997. Mycotoxins. Pages 668-670 in Current Therapy in Equine Medicine 4, N.E. Robinson, ed. WB Saunders, Philadelphia, PA.

Potter, G., F.F. Arnold, D.D. Householder, D.H. Hansen, K.M. Brown, 1992. Digestion of starch in the small and large intestines of the horse . Pferdeheilkunde Sonderausgabe, Sept: 107-111.

Potter, G., P. Gibbs, R. Haley, C. Klendshoj. 1992. Digestion of protein in the small and large intestines of equines fed mixed diets. Pferdeheilkunde Sonderausgabe, Sept: 140-143.

Powell, D.M., L.M. Lawrence, B.P. Fitzgerald, K. Danielsen, A. Parker, P. Siciliano, A. Crum. 1998. The effect of feeding restricted diets on thyroid hormone concentrations and metabolic responses in the exercising horse. Pages 277-278 in Advances in Equine Nutrition, J.D. Pagan, ed. Kentucky Equine Research, Inc., Versailles, KY.

Powell, D.M., L.M. Lawrence, B.P. Fitzgerald, K. Danielsen, A.Parker, P. Siciliano, A. Crum. 2000. Effects of short-term feed restriction and calorie source on hormonal and metabolic responses in geldings receiving a small meal. J. Anim. Sci., 78 (12): 3107- 3113.

Pratt S.E., P.D. Siciliano, L. Wlaston. 2009. Variation of insulin sensitivity estimates in horses. J. Equine Vet. Sci. 29:507-512

Prentice, A. 1948. Your Horse and His Care. 3rd ed. Alex Pettigrew, LTD., at the Atlas Works, Coatbridge.

Radicke, S., E. Kienzle, H. Meyer. 1991. Preileal apparent digestibility of oats and corn starch and consequences for cecal metabolism. Pages 43-48 in Proc. 12th Equine Nutr. Phyisol. Symp., Calgary, Alberta, Canada.

Radicke, S., E. Landes, E. Kienzle, H. Meyer. 1992. Activity of amylase in the digestive tract of horses in relation to diet type. Pferdeheilkunde Sonderausgabe, Sept: 99- 102.

Ralston, S.L. 1996. Hyperglycemia/hyperinsulinemia after feeding a meal of grain to young horses with osteochondritis dissecans (OCD) lesions. Pferdeheilkunde, 12 (3): 320-322.

Ralston, S.L. 1992. Effect of soluble carbohydrate content of pelleted diets on postprandial glucose and insulin profiles in horses. Pferdeheilkunde Sonderausgabe, Sept: 112-115

Rammerstorfer, C., G.D. Potter, T.A. Cudd, P.G. Gibbs, D.D. Varner, D.D. Householder. 1997. Physiological responses of mature Quarter Horses to reining training when fed conventional and fat-supplemented diets. Pages 45-50 in Proc. 15th Equine Nutr. Phyisol. Symp., Ft. Worth, TX.

Raymond, S.L., T.K. Smith, H.V. Swamy. 2003. Effects of feeding a blend of grains naturally contaminated with Fusarium mycotoxins on feed intake, serum chemistry and hematology of horses. J. Anim. Sci. 81:2123-2130

Raymond, S.L., T.K. Smith, H.V. Swamy. 2005. Effects of feeding a blend of grains naturally contaminated with Fusarium mycotoxins on feed intake, metabolism and indices of athletic performance of exercised horses. J. Anim. Sci. 83:1267-1273

Respondek, F., J.L. Lambey, C. Drogoul, V. Julliand. 2003. Feeding practices in racehorses stables in France. Pages 244-246 in Proc. 18th Equine Nutr. Phyisol. Symp., East Lansing, MI.

Reeves M.J., M.D. Salman, G. Smith. 1996. Risk factors for equine acute abdominal disease (colic): Results from a multi-center case-control study. Prev. Vet. Med. 26:285-301

Rice, O., R. Geor, P. Harris, K. Hoekstra, S. Gardner, J. Pagan. 2001. Effects of restricted hay intake on body weight and metabolic responses to high-intensity exercise in Thoroughbred horses. Pages 273-278 in Proc. 17th Equine Nutr. Phyisol. Symp., Lexington, KY.

Richards, N., G.N. Hinch, J.B. Rowe. 2006. The effect of current grain feeding practices on hindgut starch fermentation and acidosis in the Australian racing. Australian Vet. J., 84 (11): 402-407.

Rodiek, A.V., C.L. Stull. 2007. Glycemic index of ten common horse feeds. J. Equine Vet. Sci., 27 (5): 205-211.

Roeckl, A., H. Leinemann. 2004. Intradermal allergy testing in horses. Tierarztliche Praxis Ausgabe Grosstiere Nutztiere, 32 (5): 291-297.

Rooks, C.F., W.C. Jackson. 1943. Light Horses. Iowa Horse and Mule Breeders Assn., Des Moines.

Rosenfeld, I., D. Austbo. 2009. Digestion of cereals in the equine gastrointestional tract measured by the mobile bag technique on caecally cannulated horses. Anim. Feed Sci. Technol., 150 (3-4): 249-258.

Rosenfeld, I., D. Austbo. 2009. Effect of type of grain and feed processing on gastrointestinal retention times in horses. J. Anim. Sci., 87: 3991-3996.

Salo, M.L., T. Alaviuhkola. 1980. Normal and light weight oats as feed for growing-pigs. Journal of the Scientific Agricultural Society of Finland, 52 (5)L 435-440.

Sandin A., F.M. Andrews, J.A. Nadeau, G. Nilsson. 2000. Effect of nervous excitation on acid secretion in horses. Acta. Physiol. Scand. 168:437-442

Sarkijarvi, S., M. Saastamoinen. 2006. Feeding value of various processed oat grains in equine diets. Livestock Science, 100 (1): 3-9.

Schmidt., H.L. 1989. Frequency-distribution of microbial numbers in feed grade cereals and the situation of microbiological attack on oats. Landwirtschaftliche Forschung, 42 (1): 20-28.

Schmidt S.L., M. L. Hickey. 2009. Regulation of insulin action by diet and exercise. J. Equine Vet. Sci. 29:274-284

Schwarz, F., H. Sliwindki, M. Schuster, E. Rosenberger. 2005. Variation in the nutrient composition of different feedsuffs for horses. Pages 910 in Proc. 21st Equine Nutr. Conf., Hanover, Germany.

Sheldon, L. L. Taylor, S. Pratt. 2005. Effects of high-oil, hull-less oats on serum chemistry and complete blood counts. Page 304 in Proc. 19th Equine Sci. Soc., Tucson, AZ.

Sirois, P.K. 2009. Making Nutrient Composition Tables Relevant. Pages 7-15 in Advanced Equine Nutrition IV, J.D. Pagan, ed. Nottingham University Press, Nottingham, UK.

Sliwinsky, H. P Krabisch, Rosenberger, E., F.J. Schwarz. 2005. Hygienic quality of different forages and concentrates for horses. Page 26 in 21st Equine Nutr. Conf., Hanover, Germany.

Smith, N.J., G.D. Potter, E.M. Michael, P.G. Gibbs, B.D. Scott, H.S. Spooner, M. Walker. 2005. Influence of dietary protein quality on calcium balance and bone quality in immature horses. Pages 127-128 n Proc. 19th Equine Sci. Soc., Tucson, AZ.

Southwood, L.L., D.L. Evans, W.L. Bryden, R.J. Rose. 1993. Nutrient intake of horses in Thoroughbred and Standardbred stables. Australlian Vet. J., 70 (5): 164-168.

Spangfors, P. 1998. Some aspects of feeding the endurance horse. Pages 341-350 in Advances in Equine Nutrition, J.D. Pagan, ed. Kentucky Equine Research, Inc., Versailles, KY.

Staniar, W.B., H.S. Grube, E.A. Jedrzejewski. 2009. Inter-animal variation in glycemic and insulinemic response to different carbohydrate sources. J. Equine Vet. Sci., 29 (5): 377-379.

Staniar, W.B., W.E. Thomason, R.J. Geor, D.S. Kronfeld, T.L. Smith. 2007. Comparison of hulless barley with crimped oats as carbohydrate sources in equine feeds. Pages 95- 96 in Proc. 20th Equine Sci. Soc., Hunt Valley, MD.

Steiner, T., R. Mosenthin, B. Zimmermann, R. Greiner, S. Roth. 2007. Distribution of phytase activity, total phosphorus and phytate phosphorus in legume seeds, cereals and cereal by-products as influenced by harvest year and cultivar. Anim. Feed Sci. Technol., 133 (3-4): 320-334.

Stull, C.L., A.V. Rodiek. 1988. Responses of blood glucose, insulin and cortisol concentrations to common equine diets. J. Nutr. 118:206-213.

Stull, C.L., L.C. Witham, A.V. Rodiek. 1997. Refeeding of the malnourished horse. Pages 195-196 in Proc. 15th Equine Nutr. Phyisol. Symp., Ft. Worth, TX.

Stull, C.L., P.J. Hullinger, DVM, A.V. Rodiek. 2001. Metabolic responses of fat supplementation to alfalfa diets in refeeding the starved horse. Pages 159-160 in Proc. 17th Equine Nutr. Phyisol. Symp., Lexington, KY.

Svihus, B., A.K. Uhlen, O.M. Harstad. 2005. Effect of starch granule structure, associated components and processing on nutritive value of cereal starch: A review. Anim. Feed Sci. Technol., 122 (3-4): 303-320.

Svihus, B., M. Gullord. 2002. Effect of chemical content and physical characteristics on nutritional value of wheat, barley and oats for poultry. Anim. Feed Sci. Technol., 122 (3-4): 303-320.

Swyers K.L., A.O. Burk, T.G. Hartsock, E.M. Ungerfeld, J.L. Shelton. 2008. Effects of direct-fed microbial supplementation on digestibility and fermentation end products in horses fed low and high starch concentrates. J. Anim. Sci. 86:2596-2608

Taylor, L.E., T.M. Johnson, C.D., Markert, K.L. Braun, M.J. Kanter. 2003. Palatability and safety of oat oil for horses. Page 133 in Proc. 18th Equine Nutr. Phyisol. Symp., East Lansing, MI.

Thacker, P.A. 2000. Recent advances in the use of enzymes with special reference to beta-glucanases and pentosanases in swine rations. Asian-Australasian J. Anim. Sci., 13(S.I.): 376-385.

Thacker, P.A., G.P. Widyaratne, B.G. Rossnagel. 2009. Comparison of normal and low lignin hull/high-oat groat oat as energy sources for broiler chicks. J. Sci. Food. Agric. 89 (13): 2236-2242.

Thompson, K.N., J.P. Baker, J.P. Lew, C.J. Baruc. 1981. Digestion of hay and grain fed in varying ratios to nature horses. Pages 3-7 in Proc. 7th Equine Nutr. Phyisol. Symp., Warrenton, VA.

Thompson K.N., S.G. Jackson, J.P. Baker. 1984. Apparent digestion coefficients and associative effects of varying hay:grain ratios fed to horses. Nutr. Rep. Internat. 30:189-197.

Thorne, J.B., D. Goodwin, M.J. Kennedy, H.P.B. Davidson, P. Harris. 2005. Foraging enrichment for individually housed horses: Practicality and effects on behaviour. App. Anim. Beh. Sci., 94 (1-2): 149-164.

Tinker, M.K., N.A. White, P. Lessard, C.D. Thatcher, K.D. Pelzer, B. Davis, D.K. Carmel. 1997. Prospective study of equine colic risk factors. Equine Vet J., 29 (6): 454-458.

Topliff, D.R., D.W. Freeman. 1989. Plasma glucose concentrations and digestibility of dry matter, energy and crude protein in mature geldings fed wheat and oat based diets. Pages 157-159 in Proc. 11th Equine Nutr. Phyisol. Symp., Stillwater, OK.

Treiber K.H., D.S. Kronfeld, R.J. Geor. 2006. Insulin resistance in equids: Possible role in laminitis. J. Nutr. 36:2094S-2098S.

Valberg, S., A. Firshman. 2009. Insulin resistance - What is It and how do we measure it? Pages 355-383 in Advanced Equine Nutrition IV, J.D. Pagan, ed. Nottingham University Press, Nottingham, UK.

Valberg, S.J., R. Geor, J.D. Pagan. 2005. Muscle disorders: Untying the knots through nutrition. Pages 473-483 in Advances in Equine Nutrition III, J.D. Pagan, ed. Nottingham University Press, Nottingham, UK.

Vervuert, I., M. Coenen. 2005. The glycemic and insulinemic index in horses. Pages 55- 63 in Advances in Equine Nutrition III, J.D. Pagan, ed. Nottingham University Press, Nottingham, UK.

Vervuert, I., K. Voight, T. Hollands, D. Cuddeford, M. Coenen. 2009. The effect of mixing and changing the order of feeding oats and choppped alfalfa to horses on: glycaemic and insulinaemic responses, and breath hydrogen and methane production. J. Anim. Physiol. Anim. Nutr., 93 (5): 631-638.

Vervuert, I., K. Voigt, N. Brussow, T. Hollands, D. Cuddeford, M. Coenen. 2005. Insulinaemic and glycaemic responses following changes in the order of feeding oats and chopped alfalfa to horses. Pages 55-63 in Advances in Equine Nutrition III, J.D. Pagan, ed. Nottingham University Press, Nottingham, UK.

Vervuert, I., M. Coenen, C. Bothe. 2003. Effects of oat processing on the glycaemic and insulin responses in horses. J. Anim. Physiol. Anim. Nutr. 87 (3-4): 96-104.

Vervuert, I., M. Coenen, C. Bothe. 2005. Glycemic and Insulinaemic indexes of different mechanical and thermal processed grains for horses. Pages 154-155 in Proc. 19th Equine Sci. Soc., Tucson, AZ.

Vervuert, I., M. Coenen, S. Plumhoff. 2005. In vitro fermentation patterns of different carbohydrates: ranking of grass meal (cellulose), sugar beet pulp (pectin), oats (starch) and jerusalem artichoke (fructans). Pages 156-157 in Proc. 19th Equine Sci. Soc., Tucson, AZ.

Vervuert, I., M. Coenen. 2005. Glycaemic index of feeds for horses. Pages 79-82 in Proc. 21st Equine Nutr. Conf., Hanover, Germany.

Wang, S.C., S.W.A. Bligh, C.L. Zhu, S.S. Shi, Z.T. Wang, Z.B. Hu, J. Crowder, C. Branford-White, C. Vella. 2008. Sulfated beta-glucan derived from oat bran with potent anti-HIV activity. J. Agric. Food Chem. 56 (8): 2624-2629.

Wang, W.M., C.F. Klopfenstein. 1993. Effect of twin-screw extrusion on the nutritional quality of wheat barley, and oats. Cereal Chem., 56 (8): 2624-2629.

Warren L.K., L.M. Lawrence, T. Brewster-Barnes, D.M. Powell. 1999. The effect of dietary fiber on hydration status after dehydration with furosemide. Equine Vet. J. Suppl. 30:508-513.

Waters, A.J., C.J. Nicol and N.P. French. 2002. Factors influencing the development of stereotypic and redirected behaviors in young horses: findings of a four year prospective epidemiological study. Equine Vet. J. 34: 572-579.

Willard J., J. Willard, S. Wolfram, J. Baker. 1977. Effect of diet on cecal pH and feeding behavior of horses. J. Anim. Sci. 45:87-93

White, G.A., F.J. Doucet, S.E. Hill, J. Wiseman. 2008. Physicochemical properties and nutritional quality of raw cereals for newly weaned piglets. Animal, 2 (6): 867-878.

White, N.A. 2009. Colic prevalence, risk factors and prevention. Pages 313-326 in Advanced Equine Nutrition IV, J.D. Pagan, ed. Nottingham University Press, Nottingham, UK.

Whitehouse, R.N. 1970. Prospects of breeding barley, wheat and oats to meet special requirements in human and animal nutrition. Proc. Nutr. Soc. 29 (1): 31-39.

Williams C.A., D. S. Kronfeld, W.B. Staniar, P.A. Harris. Plasma glucose and insulin responses of Thoroughbred mares fed a meal high in starch and sugar or fat and fiber. J. Anim. Sci. 79:2196-2201

Willing B., A .Voros, S. Roos, C. Jones, A. Jansson, J.E. Lindberg. 2009. Changes in faecal bacteria associated with concentrate and forage-only diets fed to horses in training. Equine Vet J41:908-914.

Wolf, P., M. Coenen, J. Kamphues. 2005. A survey of the hygenic standard of feeds for horses associated with diseases. Pages 24-25 in Proc. 21st Equine Nutr. Conf., Hanover, Germany.

Woodward, A.D., T.E. Lavin, B.D. Nielsen, J. Liesman, N.L. Trotter. 2009. Estimation of nitrogen digestibility and utilization of alfalfa, mixed grass hay and oats. J. Equine Vet. Sci., 29 (5): 368-369.

Zeyner, A., C. Geissler, A. Dittrich. 2004. Effects of hay intake and feeding sequence on variables in faeces and faecal water (dry matter, pH value, organic acids, ammonia, buffering capacity) of horses. J. Anim. Physiol. Anim. Nutr. 88 (1-2): 7-19.

Zimonja, O., B. Svihus. 2009. Effects of processing of wheat or oats starch on physical pellet quality and nutritional value for broilers. Anim. Feed Sci. Technol., 149 (3-4): 287-297.

Zimonja, O., H. Hetland, N. Lazarevic, D.H. Edvardsen, B. Svihus. 2008. Effects of fibre content in pelleted wheat and oat diets on technical pellet quality and nutritional value for broiler chickens. Can. J. Anim. Sci. 88 (4): 613-622.

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