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Advances in Equine Nutrition

Volume I

Edited by

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THE DIGESTIVE TRACT OF THE HORSE - PRACTICAL CONSIDERATIONS

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The horse is classified, based on the anatomy of the digestive tract, as a non-ruminant herbivore. More specifically the horse is a hindgut fermenter and as such combines some of the advantages of the strict monogastric animal and the ruminant. Failure to understand the anatomy of the gastro-intestinal (GI) tract and basic digestive physiology is the root of many feeding errors involving both nutritional management and feed formulation.

Basic anatomy

The digestive process begins with prehension of food. Feed is supplied as fresh pasture, long hay or variations of stored forage and as concentrate feed containing processed or unprocessed cereal grains. In order to properly start the digestive process, the horse needs a sound, functional mouth. This means the teeth should be in good condition with functional occlusive surfaces. The mature horse has 18 upper and 18 lower teeth consisting of six upper and six lower incisors and 12 upper and lower molars. The function of the teeth is prehension (gathering) and chewing of food. The teeth participate in the digestive process primarily by reducing the particle size of food. Chewing also stimulates the flow of saliva which may initiate chemical digestion of feed and lubricates feed prior to its passage to the remainder of the tract. Dental problems resulting from wear and genetic defects such as parrot mouth interfere with dental function. Many times horses that waste feed, bolt their feed or are finicky eaters have dental anomalies which once corrected allow the horse to utilize feed more efficiently. Horses should have annual dental exams and should have their teeth floated should sharp edges be detected on the upper (outside) or lower (inside) molar arcades. Older horses which through normal wear have lost functional dentition or younger horses with dental problems may benefit from use of pelleted concentrate rations since the particle size has been mechanically reduced in the pelleting process. Certainly examination of the teeth should be an integral part of the nutritional management program on a farm.

The esophagus is a muscular tube connecting the mouth and the stomach. Food is forced down the esophagus by peristaltic waves or muscle contractions. Saliva produced by secretory glands in the mouth lubricates the feed and prevents the feed from becoming lodged in the esophagus. Although there is a great deal of discussion about choke in the horse, it is actually quite rare for the horse to choke or for esophageal obstruction to occur.

The stomach of the horse is relatively small when compared to the capacity of the entire tract. The horse really evolved as a continuous grazer and is better equipped to utilize small frequent meals rather than large meals of concentrates. Rate of passage through the stomach is such that ingesta remains in the stomach only a very short time. Figure 1 shows the relative size of the stomach when compared to the other segments of the GI tract. The pH of the stomach is quite acidic. Kern (1974) measured pH in various segments of the horse's GI tract and these values are shown in Table 1. Although the major impact of the stomach on ingesta is acid hydrolysis and enzymatic digestion of protein, there is a significant amount of lactic acid produced from the fermentation of soluble sugars by microbes located in the fundic region of the stomach.

A Stomach
B Small intestine
C Cecum
D Colon

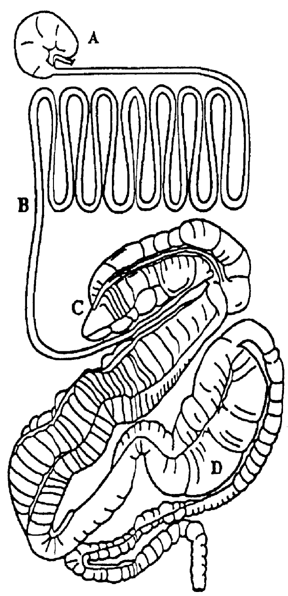

Figure 1 The horse's digestive tract

The chyme (ingesta) passes from the stomach into the small intestine. The small intestine is composed of the duodenum, the jejunum and the ileum (figure 1). The small intestine is 21 meters long and has a capacity of about 56 liters of ingesta. The small intestine receives a continuous flow of pancreatic juice which increases due to nervous or hormonal factors associated with a meal. The small intestine is, or should be if the feeding program is properly designed, the major zone of absorption for simple sugars derived from starch digestion, of amino acids from protein digestion, of free fatty acids resulting from digestion of the lipid component of the diet, of fat soluble vitamins A, D & E and of some minerals.

Table 1 pH IN VARIOUS REGIONS OF THE EQUINE DIGESTIVE TRACT

Region	*pH*
Stomach-fundic	5.4
Stomach-pyloric	2.6
Ileum	7.4
Cecum	6.6
Terminal Colon	6.6

Kern 1974 JAS

Material not digested in the foregut passes through the ileo-cecal orifice into the cecum. The cecum and large colon are analogous to the rumen and reticulum of the cow and sheep, and house billions of bacteria and protozoa which serve in a symbiotic relationship with the horse enabling the digestion of cellulose and other fibrous fractions of the feed. Additionally, the cecal and colonic microbes synthesize B vitamins and vitamin K which are available to the horse to help meet the requirements for these nutrients.

There is a significant amount of microbial protein synthesized in the horse's hindgut. Whether the microbial protein is available to the horse to contribute to meeting amino acid requirements is still somewhat controversial.

The rectum is the posterior part of the digestive tract and serves primarily as a storage area for fecal products which have not been digested. Material is held in the rectum until sufficient material accumulates which then results in nervous stimulation and voiding of feces through the anus.

Effects of feed processing on digestion

The aim of feed processing is to change the physical or chemical form of ingredients resulting in greater nutrient availability to the target animal while preserving the quality of the nutrients in the raw material for as long as possible. The most frequently used method of feed processing is the mechanical reduction of particle size. This is done by cracking, crimping or grinding ingredients.

There are pros and cons associated with this reduction of particle size. The major disadvantage is the reduction of storage life of cereal grains by exposing the starchy endosperm and seed lipids to oxidation once the seed coat is broken. This disadvantage is for many ingredients far outweighed by the advantages of reducing preconsumption particle size. For horses, crimping or rolling of oats results in about a 5% increase in digestibility and may or may not be worth the increased milling cost, either to the feed manufacturers or to the consumer. On the other hand, some kind of mechanical milling of barley, wheat, milo and corn is a must in horse diets. Meyer (1993) has shown, for instance, that prececal digestibility of corn starch is significantly altered by feed processing (Table 2). The increase in prececal digestibility of starch is a result of increasing the surface area exposed to digestive enzymes, and in the case of popping, gelatinization of the starch molecule which increases digestibility. It is important to note that cracking corn resulted in no increase in prececal digestibility whereas corn starch that was heat treated was nearly entirely digested prececally (90.1%). These data would indicate that milling of corn is important if the site of digestion of the starch is of concern (later we will see that it is).

Hintz and Loy (1966) compared the digestibility of a pelleted or loose ration fed to horses. The loose diet consisted of rolled barley, ground alfalfa, wheat, molasses and tallow (2%). The pelleted ration was of the same composition but ground and pelleted. There was no difference between the two diets in terms of total tract digestibility of protein, crude fiber or nitrogen free extract. However, rate of passage was significantly greater for the pelleted diet at 33 hours post feeding. By 45 hours post feeding, 95.6 and 95.8% of a digestibility marker (Styrofoam beads) had been recovered in the feces for the loose and pelleted diets respectively.

Table 2 PREILEAL STARCH DIGESTIBILITY IN THE HORSE AND EFFECT OF GRAIN PROCESSING (MEYER, 1993)

Ingredient	*Preileal Digestibility %*
Whole Oats	83.5
Rolled Oats	85.2
Rolled Barley	21.4
Whole Corn	28.9
Cracked Corn	29.9
Ground Corn	45.6
Popped Corn	90.1

More recently, Freeman, *et al* (1991) have reported little difference in intake of pellets ranging in size from 0.4-1.9 cm but that intake was greater 20 minutes post-feeding with pellets of lower density when compared with harder, more dense pellets.

Little research has been done to determine the utilization of extruded feeds by horses. Hintz *et al* (1985) compared the digestibility of pelleted, extruded or unprocessed diets fed to horses. The concentrate diets consisted of 36% oats, 34% corn, 20% soybean meal, 6% molasses, and 4% vitamin-mineral premix. Rate of intake of the three forms of the ration was significantly different with rate of intake being significantly ($P<0.01$) slower for the extruded diet for both ponies and horses (Table 3). Digestibility of energy, protein and dry matter for the three diets is shown in table 4.

Table 3. RATE OF INTAKE OF THREE FORMS OF A GRAIN MIXTURE DURING THE FIRST 20 MINUTES POST-FEEDING

		(g/min)	
	Control	*Pelleted*	*Extruded*
Horses	97[a]	109[a]	67[b]
Ponies	60[a]	68[a]	45[b]

Each value is a mean of 6 animals
[a,b]Values in the same row bearing unlike superscripts are significantly different ($P<0.01$). Hintz *et al* (1985)

The increase in digestibility for extruded feed seen in this experiment suggests that extruded feeds are efficiently utilized by the horse, but cost is still a major obstacle in the way of wide-spread acceptance of extruded feeds by consumers.

Table 4. DIGESTIBILITY (%) OF DIETS FED IN PELLETED, TEXTURED OR EXTRUDED FORM TO HORSES

	Control	*Pelleted*	*Extruded*
Energy (%)	73.5[ab]	72.0[a]	75.5[b]
Dry Matter (%)	73.3[ab]	72.1[a]	75.3[b]
Protein (%)	84.7[a]	86.0[a,b]	87.7[b]

[a,b]Values in the same row with unlike superscripts are significantly different ($P<0.05$)

Effect of diets on the digestive tract

The end effect that consumption of a diet has on the gastro-intestinal tract is a function of physical form of the diet, percent concentrate vs percent forage in the diet, chemical composition of the diet and feeding rate. These factors govern both the utilization of feeds as well as chemical and microbiological changes which occur in the tract in response to feeding. Obviously, the closer a feeding program is to the natural manner in which the horse evolved to eat, the smaller the effect on gut homeostasis. Radical departures from small continuous meals consisting of predominantly forage result in the largest effects on gut function and stability.

Willard *et al* (1977) compared cecal pH and volatile fatty acid production in cecal fistulated horses fed either an all hay or all concentrate diet. Horses fed a diet of 8 kg of mixed hay showed smaller changes in cecal pH than seen in horses consuming 6 kg of a "sweet feed" (Table 5). In addition to the noted difference in cecal pH, the molar percentages of volatile fatty acids were different between the two diets. Horses consuming the all hay diet had higher molar percentages of acetic and lower molar percentages of propionic acid in the cecal fluid when compared with horses on an all concentrate diet. Willard *et al* (1977) further reported that the horses consuming all concentrate diets spent more time chewing wood and practicing coprophagy (eating of manure) than did horses on the all hay diet. Interestingly, both wood chewing behavior and coprophagy were reduced when 62.5 ml of 20% Na_2CO_3 was infused hourly into the cecum of the all concentrate fed horses.

Table 5. MEAN CECAL pH FOLLOWING THE FEEDING OF AN ALL HAY OR ALL CONCENTRATE DIET TO CECAL FISTULATED HORSES.

Hours Post Feeding	*Hay*	*Concentrate*
0	7.14	7.22
2	7.04	7.14
4	6.92[a]	6.43[b]
6	6.87[c]	6.12[d]

[a,b,c,d]Values in the same row with unlike superscripts are significantly different ($P<0.05$). (Willard *et al*, 1977)

TABLE 6. EFFECT OF FORAGE:GRAIN RATIO ON MOLAR PERCENTAGE OF VOLATILE FATTY ACIDS IN THE CECUM.

Forage: Grain Ratio	*Acetate*	*Propionate*	*Butyrate*
1:0	76.2	14.8	8.0
3:2	70.4	21.2	7.2
1:4	61.2	26.0	10.2

Hintz *et al*, 1971

Hintz *et al* (1971) compared digestion coefficients, blood glucose levels and volatile fatty acid production in ponies fed varying forage:grain ratios. They reported that as concentrate intake increased from 0 (1:0 forage:grain ratio) to a 1:4 forage:grain ratio, molar percentages of acetate decreased and propionate increased (Table 6). However, they failed to see any associative effects on the digestibility of fiber as forage:grain ratio changed. Digestibility of dry matter, crude protein, neutral detergent fiber and available carbohydrate was greater for higher concentrate diets than for the all forage diet.

Radicke *et al* (1991) reported the response of cecal pH to the feeding of graded levels of starch from oats and corn. Figure 2 shows cecal pH response to either oat or corn starch at graded levels of intake. Radicke *et al* (1991) reported that a cecal pH of 6.0 represented sub-clinical cecal acidosis and that cecal pH below 6.0 represented significant risk to the stability of cecal fermentation and to precipitation of clinical problems such as colic or laminitis. Chronic exposure to low pH in the cecum also predisposes the horse to anorexia and other metabolic disturbances. pH response typical of concentrate feeding is not similar to that seen with the feeding of a more fibrous diet. Data from Radicke *et al* (1991) characterizing cecal pH response to meals of hay, corn, or oats are shown in figure 3.

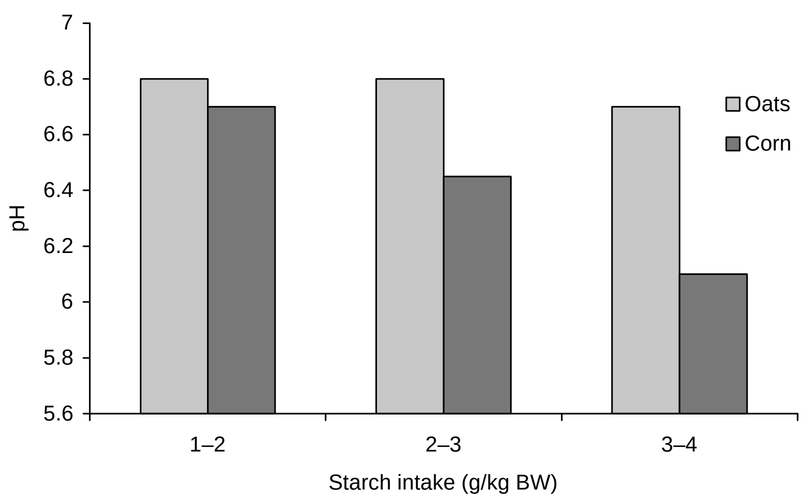

Figure 2 Minimum cecal pH as a function of starch intake g/kg bw/meal (Radicke *et al*., 1991)

The above described physiologic responses to dietary constituents are of critical importance when viewed in the context of normal feeding management practices. Due to space, employment and labor constraints, many horses are confined to stalls and fed relatively high concentrate, low forage diets which varies dramatically from the normal manner in which horses eat. Gastro-intestinal tract disturbances such as colic, rapid cecal fermentation, radical changes in the cecal micro-flora and pH, and endocrine anomalies result from episodic rather than continuous ingestion of nutrients.

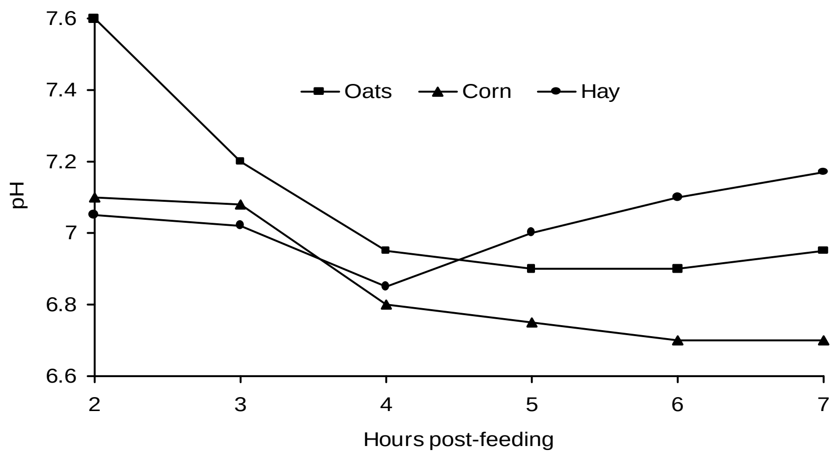

Figure 3. Postprandial cecal pH change after feeding oats, corn or hay

Plasma volume has been shown to decrease as much as 24% in response to large meals and was accompanied by hyperproteinemia or an increase in plasma protein (Clarke *et al.*, 1990). Large, infrequently fed meals also increase rate of passage of ingesta through the gastro intestinal tract, which may lead to a greater amount of very fermentable carbohydrate entering the large bowel. The physiologic consequences of soluble carbohydrate in the large intestine are increased microbial fermentation, which leads to decreased cecal and colonic pH, and increased production of gases derived from fermentation. Decreased cecal pH may initiate a serious and detrimental chain of events including alteration of the microbial flora, lysis of bacteria allowing the release of endotoxins, damage to the mucosa of the cecum and colon allowing for absorption of endotoxin and various gastro-intestinal tract pathologies including acute colitis, flatulence, colic and laminitis.

As such, the producer must be aware of the physiologic consequences of meal feeding rather than continuous feeding.

Management to prevent gut pathology

FEEDING MANAGEMENT

A crucial question is the relationship between feed and pathology involving the gastro-intestinal tract. Besides cases involving accidental inclusion of ionophores (rumensin & lasalocid) and antimicrobials (esp. linkomycin) far more problems associated with gut dysfunction and pathology are the result of poor feeding management than of the feed *per se*. The following are important:

1. Horsemen (educated by feed producers, nutritionists and veterinarians) must realize that horses were not designed to eat large meals of readily fermentable carbohydrate and must ensure adequate fiber intake which more closely mimics the horse's evolutionary adaption to alimentation. More frequent, smaller meals always decrease feeding related problems.
2. Regularity of feeding is crucial. Many times horses appear to do well on a feeding program that should be risky until the normal feeding routine is upset, at which time problems begin to occur.
3. Ingredients-Are there optimum inclusion rates? The cited work of Meyer and Radicke suggests that there is a practical maximum inclusion rate for corn. At KER we rarely would use corn at greater than 23% of the concentrate mix. Certainly there are practical maximums for other ingredients as well.
4. Feed to maintain hindgut function, maximize the contribution of forage, reduce carbohydrate overload of the cecum, manage the feeding program to promote gut homeostasis.
5. Eliminate the possibility of bad feed. Storage and procurement of feed is crucial to the prevention of mold, rancidity and loss of feed quality.
6. Maintain ingredient quality (especially critical is fusarium in corn, i.e., leukoencephalomalacia or moldy corn disease).
7. Feed by weight not volume. The bulk densities of feeds vary significantly and feeding by the "coffee can" is not appropriate.
8. Encourage adequate exercise and manage to prevent all classes of horses from becoming too fat.
9. Maintain functional dentition and routinely deworm. Immunization for botulism may be considered. Starting with a healthy, parasite "free" horse aids in allowing maximum feed utilization and decreased feed usage.

On the horizon

There are nutritional tools being developed, or that are already here, that may have real advantages.

1. Yeast Cultures - Already well accepted as a valid ingredient, yeast culture has a role in designing horse feeds. Pagan (1989), Glade (1991), Krusic (1991), Corujeira and Scipioni (1992) have reported increases in the

digestibility of horse rations as a result of the addition of live yeast culture (Yea-Sacc[1026]). More recently Newman (1993) has shown that yeast may have a stabilizing effect on in vitro cecal fermentation. Cultures of cecal microbes were challenged with amounts of starch that might be equivalent to a starch overload. Lactic acid production and pH decrease in the cultures containing yeast were less than for those cultures without added yeast culture (Yea- Sacc[1026]). Pagan's (1990) work showed an increase in the digestibility of fiber and phosphorus indicating a positive effect on cecal fermentation. The exact role of yeast in reducing lactate production in the cecum and on stabilizing the cecal environment is not clear but it is likely that similar modes of action to those in the rumen of the cow are present in the hindgut of the horse.

2. Enzymes - The use of enzymes such as cellulase, beta-gluconase, amylase and lipase is becoming more wide spread in the feed industry and more accepted by the scientific community. It is thought that some of the mode of action of yeast culture is due to enhanced activity of phytase, and Meyer (1993) has reported enhanced preileal digestion of starch when exogenous amylase is added to the diet. Meyer's work as well as the work of Radicke (1991) suggests that for starches of intermediate small intestinal digestibility, amylase is a limiting factor in digestibility. Recently Simon (1992) reported that the addition of phytase to pig diets resulted in a 20-30% increase in the digestibility of total phosphorus as well as an increase in the digestibility of dry matter and some amino acids. Pointillart (1987) has reported that there was an increase in the density of the tibia, fibula and third metatarsal in pigs receiving phytase supplementation when compared to controls. At this time there is a significant body of evidence to suggest that the utilization of barley based diets by broilers is significantly greater in betagluconase supplemented diets than in control diets (Raudati, 1991). As we explore new methods of enhancing the utilization of feed for growth, reproduction and performance, enzymes will play an increasingly greater role.

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