Energy Sources in Horse Feeds: Facts behind Fat, Fiber and Starch

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Fats, Fiber and Soluble Carbohydrates: Not terms that horse owners use everyday. These compounds provide energy to fuel metabolic processes essential for life and well being. This paper is intended to update horse owners and industry service professionals on recent developments in nutrition research on energy containing compounds, and how application of this research is directing the formulation and feeding of horse rations. First, we will briefly overview the whole concept of energy. It is a term that is talked about, difficult to understand, and not easily identified in rations.

Energy Utilization: The Hows and Whats

Simply, energy is fuel for the body, and horses, being herbivores obtain energy from breaking down energy-containing compounds in plants. The energy obtained through digestive absorption is stored and used by the horse's body to fuel the multitude of processes essential for life and utility. Energy, not having any measurable dimensions or mass, is measured by the amount of heat that is produced when it is used as fuel. This heat is most typically measured in calories. Gross energy is the heat that is produced from complete combustion of food. Digestible energy is gross energy minus energy that is lost in feces, and metabolizable energy is gross energy minus losses in feces, urine and gases from the digestive tract. We could continue this partitioning to net energy that takes into account even more losses of energy from the body; unfortunately, the current status of recommendations for the horse stops at digestible energy.

Digestible Energy Estimates of Some Commonly Fed Feedstuffs

Feedstuff	Digestible Energy (Megacalories/lb)
Alfalfa Hay	1.0
Corn	1.5
Oats	1.3
Soybean Hulls	1.1
Wheat Mids	1.4

Energy Balance: Skinny or Obese

The horse, as with all animals, has a need for a certain amount of energy to fuel the normal, daily maintenance of its body. The bigger the horse, the more fuel for maintenance. On top of this, activity such as milk production, pregnancy, exercise or growth requires additional energy. The more production of milk, the greater the energy need. The more the growth, the greater the energy need, and so on and so on. If energy supplies are in surplus for an extended period of time, the horse's body will store part of the unneeded energy as fat. If energy supplies are deficient for an extended time, the horse will mobilize energy-containing compounds in the body, and burn stored energy for fuel.

Energy balance is measured in horse nutrition by determining the digestible intake (feed energy minus fecal energy), and comparing this to measurable items such as fat cover, body weight, weight and height gains, milk production or physiological responses to exercise. As energy balance research is beyond the capabilities and desires of horse owners, energy balance is measured in practical terms as body condition. Simply put, body condition is measured by the level of observable fat cover on a horse's body. The most recognized system for uniformly expressing these levels incorporates a scale of 1 to 9[1].

A score of 1 describes a poor or extremely emaciated animal with no observable fat. A score of 9 would be an extremely fat horse with so much cover that there are noticeably patchy areas of fat on the body with bulging fat along the neck, shoulder, hip and tailhead. For more information on body condition scoring, and how it can be used to optimize body condition for different performance traits, review OSU Facts 3920 Body Condition of Horses[2]. In general, moderation is recommended. Scores ranging from 4 to 7 are recommended; more precise recommendations depend on production and use status of the horse.

Energy-Containing Compounds in Equine Rations

Plants, through photosynthesis, capture energy from sunlight by converting carbon dioxide and water to oxygen and carbon compounds. These carbon compounds are metabolized by animals into carbon dioxide and water. This conversion back into carbon dioxide and water releases stored energy. This metabolism also produces heat. It is this breakdown that makes the energy needed for life available for use by the horse's body.

These carbon compounds in plants are carbohydrates, fats and with the addition of nitrogen, protein. All are broken down as part of normal daily metabolic processes. Different sources of feedstuffs contain different levels of these compounds as a percentage of weight, and the various compounds have different levels of energy.

Carbohydrate, Fat and Protein Estimates of Some Commonly Fed Feedstuffs[3]

	Carbohydrate			
Feedstuff	Starch, %	Fiber, %	Fat, %	Protein, %
Alfalfa Hay	3	20	2.0	18
Corn	60	2	3.6	9
Oats	12	11	5.0	12
Soybean Hulls	5	32	2.3	11
Wheat Mids	34	7	3.6	15

Gross Energy Values of Pure Substances (Dry Matter)[4]

Substance	Kilocalorie/gram
Starch	4.23
Plant oil	9.33
Alanine (amino acid)	4.35

Relating These Compounds to Feed Tags

Feed tags provide a limited amount of information that provides the horse owner an estimate of how much energy a particular feed contains. Most consumers relate the protein percent to the relative energy value, probably because it is one of the first ingredients listed on the feed tag, and historically, it is how feed has been marketed. However, the assumption that the higher the protein, the higher the energy value is not correct as it doesn't necessarily relate to the carbohydrate and fat content of the feed.

Only one type of carbohydrate is listed on feed tags, that being fiber. Consumers can use the percent fiber as an estimate of energy value. Fibrous carbohydrates are not as energy dense as nonfibrous (soluble) carbohydrates or fat, so, generally, the higher the fiber percent on a feed tag, the lower the energy content in the feed.

Crude Fiber and Digestible Energy Relation of Commonly Fed Feeds

Feedstuff	Digestible Energy (Megacalories/lb)	Crude Fiber %
Corn	1.5	2
Wheat Mids	1.4	7
Oats	1.3	12
Soybean Hulls	1.1	32
Alfalfa Hay	1.0	20

Fat contains about twice the amount of energy per weight than carbohydrates or protein, and as such, varying the amount of fat in a ration greatly alters the energy value. Historically, most of horse rations do not vary greatly in the amount of fat. As such, the inverse relationship of crude fiber to energy would be significantly correlated: As the crude fiber decreases, the digestible energy increases. Nowadays, with additions of plant oils to horse rations, the variation of fat levels are greater, and the contribution of energy from fat is more significant. As such, consumers also need to read the crude fat percent listed on the feed tag when interested in evaluating the energy value of a ration. More on how to read feed tags can be found in OSU Facts-3919 Feed Tag Information for Commercial Feeds for Horses[5].

So to sum up the previous overview of energy metabolism, all horses need energy to survive. Energy is rather a nondescript term, and is measured as heat production when a substance is metabolized. Carbohydrates, fats and protein contain energetic compounds. Protein content of rations is regulated for supplying amino acids and nitrogen for growth, and production of compounds such as milk and hormones. As such, protein has many prioritized functions above its use as an energy source. Carbohydrates and fats are the main compounds manipulated to supply energy to horses. Now that a brief overview on energy metabolism has been given, a more specific review of carbohydrates and fat utilization in horse nutrition will be provided.

Carbohydrates: All are not Alike

Carbohydrates are made up of carbon, hydrogen and oxygen arranged as groups of simple sugars. Glucose, fructose, galactose, and lactose are examples of simple sugars (monosaccharides). These sugars are assimilated into larger groups, i.e. sucrose (table sugar), is a disaccharide containing glucose and fructose joined together. Plants will assimilate monosaccharides into larger compounds called polysaccharides. It is these polysaccharides, starch and fiber, that are in largest amounts in feedstuffs. The ability to digest carbohydrates is dependant on the structural make up of these polysaccharides.

Several different partitioning schemes have been used to chemically separate different carbohydrates into those readily digested by enzymes secreted from the small intestine of digestive tract from those only digested by microbes housed in the large intestine and cecum from those not digested by either means. For the purposes of this paper, soluble carbohydrates refer to those readily digested from enzymes secreted in the small intestine. These are mainly the simple sugars, small chain carbohydrates such as sucrose and non-structural polysaccharides (starch). Soluble carbohydrates are found in large amounts within the kernel of grains. The insoluble carbohydrates function to provide structure to plants; hence they are termed structural carbohydrates. These include compounds such as cellulose and hemicellulose that are broken down into usable compounds by microbes in the cecum and large intestine of the horse, and lignin, which is indigestible. Collectively, non-structural carbohydrates are also referred to as fiber, and are found in the cell walls of grains and plant stems.

Soluble Carbohydrates: Friends or Foes?

The horse is efficient in digesting starch, as several trials have shown near complete digestion of starch over the total tract[6,7]. Ideally, the majority of soluble carbohydrates should be digested and absorbed in the small intestine of the horse. This absorption not only is energetically efficient compared to microbial digestion in the cecum and large intestine, it also guards against digestive disorders resultant of soluble carbohydrate digestion from microbes[8,9]. The degree of starch removal pre-cecally depends on a variety of factors such as the source of starch, processing, intake level in the diet, amount of non-structural carbohydrate fed in the ration and individual differences in horses[10]. Pre-cecal digestion of starch has been reported to range from 50 to 85 percent, the smaller the intake the higher the percent digestibility[6,11]. There is little difference in the pre-cecal availability of low starch intakes from corn, oats, barley or sorghum[6]. With more moderate intakes, starch in oats may be more available pre-cecally than starch from sorghum[11]. Also, pre-cecal digestibility of starch from ground oats has been shown to be nearly 100%, as compared to 60 to 80% for ground corn when both are fed at moderately low starch intakes[12].

Processing method can increase digestion of starch pre-cecally, as micronized sorghum has been shown to be more available pre-cecally than crimped sorghum[13], and heat processed barley more available than rolled barley[8]. The same trend is true for micronized oats compared with crimping, although the difference is not as significant[13]. Most probably, the lower the solubility of starch in the grain, the more impact processing will have on digestion[10, 13, 14]. Popping corn significantly increases the pre-ileal availability of starch as compared with grinding, cracking or feeding it unprocessed. One trial reported pre-ileal starch digestion for popped, ground, cracked and whole corn to be 90, 46, 30 and 29%, respectively[10]. Steam flaking corn appears to increase pre-cecal digestion of starch as compared with cracking or grinding corn[15]. Rolling oats or barley doesn't appear to increase starch digestion of these grains in the small intestine[10]. Pelleting a grain mix seems to increase the starch digestion as compared to feeding similar starch levels in a textured form[16].

Decreasing rate of flow of nutrients through the digestive tract by feeding less indigestible dry matter with high starch feedstuffs may also enhance pre-cecal digestion[17]. Also, altering the time grain is fed in relation to forage also may increase pre-cecal digestion, as one trial noted a depression of pre-ileal starch digestion of corn when hay was added to the diet[10]. One recommendation resultant of this trial is to not feed forage for an hour or more before and for three or more hours after feeding grain[9], although the practical significance of this is questionable.

As mentioned earlier, total tract digestion of starch is near 100%. Bacteria and protozoa in the hindgut will digest what is not digested in the small intestine. In a practical sense, the level of starch intake has more day-to-day significance for horse owners than starch source. Most horses that are fed grain are meal-fed once, twice or three-times daily. Pre-cecal digestion of starch is at best a constant percent of ration as intake of starch is increased[18]. So, the more starch fed, the more presented to the microbes of the cecum and colon, and the more digested by these microbes. Significant amounts of starch microbially digested may decrease intestinal pH, disrupt normal gut motility, cause shifts in water absorption, result in a build-up of toxins, and consequentially increase the incidence of founder and colic[8, 9, 19]. Significant appearance of starch presented to the cecum and large intestine changes the microbial populations of the cecum and large colon of horses, short and long term[20].

With all the noted ill consequences of over-feeding starch, it is advantageous to determine what levels can be fed safely in a meal-feeding system. Trials done with different sizes of horses receiving different levels of starch intake suggest that single meal starch intakes over 0.35 to 0.40 % of body weight greatly increase the amount of starch presented to the cecum and large intestine[9, 10, 13]. At most, grain mixes usually contain between 30 and 50% starch, so confining single meal intakes of grain rations to 0.5 to 0.6% of body weight per day should keep the concentration of starch in the ration at safe levels.

Dietary Fiber: Parts Aren't Parts

Horses are unique in their digestive arrangement in that they have both enzymatic digestion and absorption characteristic of monogastrics followed by a significant amount of fermentative digestion characteristic of ruminants. These two systems working together allow for efficiency of digestion of carbohydrates. Carbohydrates that aren't digested in the stomach and small intestine will be digested, to some extent, by microbes in the cecum and colon. How effective the process of hindgut digestion depends on factors such as the intake level, the type of fiber, rate of flow through the digestive tract and individual horse variation.

Components of crude fiber (CF) can be readily digestible at fast rates, moderately digestible at slower rates or not digestible at all. Partitioning systems divide fiber from NDS, into neutral detergent soluble, NDF, neutral detergent fiber, and ADF, Acid detergent fiber. The NDS portion is the cell contents: starches, soluble carbohydrates, and the like. NSC, nonstructural carbohydrates, is also representative of these sources of carbohydrates. The NDF fraction contains fiber: hemicellulose, cellulose and lignin. Partitioning NDF with acid detergent results in ADF, which is mainly cellulose and lignin. Cellulose and lignin are less digestible than hemicellulose, so ADF is representative of less digestible fiber fractions. As with crude fiber estimates, NDF and ADF values of feedstuffs will vary. CF, NDF and ADF increases as plants mature. Variability of fiber concentrations is also evident in rations formulated at similar Digestible Energy and crude fiber levels.

Carbohydrate (NSC, CF, NDF and ADF) Concentrations (%) in Selected Feedstuffs

Feedstuff	NSC	CF	NDF	ADF	Lignin	NDF:ADF
Alfalfa Hay	15	20	44	34	9	1.2
Corn	70	2	11	3	1	3.6
Oat	50	11	29	14	3	2.0
Soybean Hull	15	32	66	49	4	1.3
Wheat Mids	41	7	35	11	4	3.2

Fiber Values for Alfalfa Hay Harvested at Different Maturities

	DE Mcal/lb	CF %	NDF %	ADF %	Lignin %	NDF:ADF
Early Bloom	1.13	23	42	31	8	1.3
Mid Bloom	1.03	26	46	35	9	1.3
Late Bloom	1.0	29	50	37	10	1.3

Fiber Values for Two Rations with the Same Digestible Energy Estimates

	DE Mcal/lb	CF %	NDF %	ADF %	Lignin %	NDF:ADF
50:50 Corn/Oat	1.6	8.1	20	9.5	2	2.1
Wheat Mids	1.6	8.4	36	11.1	4	3.2

Bacterial digestion of fiber produces volatile fatty acids. These compounds, depending on composition of ration, supply 30 to 70% of the energy needs of the horse[21]. Horses are not near as efficient in fiber digestion as true ruminants, unless the forage source is extremely immature and low in cellulose[21, 22]. Unfortunately, research on fiber digestion in the horse lags far behind that done in the diary and beef cattle area. Research in those areas reinforce the broad range, hence their nutritive value, of compounds grouped together as fiber. Some of these substances, the soluble fibers, are digested rapidly by microbes, whereas others are more slowly or less digestible.

Fiber: How Much of What?

Horse feeds vary in fiber content. Traditionally prepared grain mixes formulated to feed with a source of forage contain 7 to 10% crude fiber. Hays may contain between 20 and 30% crude fiber. So, with typical ranges in ratios of concentrates to hay of 50:50 to 30:70, crude fiber content of total mixed rations ranges around 15 to 20%. The question of how much fiber a horse actually needs is not easily answered. Horses have been safely fed rations with as little as 12.7% ADF with no gastric disturbances[17]. Horses consuming all pasture diets may consume diets three times higher in fiber.

On one hand, starch digestion in the small intestine is much more energetically efficient than VFA production from fiber digestion in the hindgut[8, 9]. High fiber feeds are not as efficiently digested. Addition of large particle, high ADF feedstuffs like oat straw, increases rate of passage[17]. However, fiber, especially long stem forage, adds bulk to rations, and the digestion of fiber is slower than soluble carbohydrates[9, 24]. This bulk slows intake time[25]; something that may be desirable for reduction of stress[9, 26], and partitioning the energy source away from soluble carbohydrates.

While readily digestible fiber enhances the energetic value of rations, there also appears to be a need for larger particle, slower digested fiber sources to maintain gut homeostasis of cattle fed concentrate-forage rations[23]. One might expect the same for the homeostasis of the horse's cecum and colon. The complexity of the animal's physiological and nutritional factors combined with the wide variation of substances that are collectively called fiber, has created several different partitioning measures used to quantify the feeding value of fiber. Terms such as NDS, NDF, ADF, eNDF (effective neutral detergent fiber) are used extensively in the cattle area where research is more advanced than that with horses.

So, a common recommendation is to supply forage (long stem forage source) at 1% of body weight per day[28]. Whether or not this supply of long stem forage is absolutely necessary is questionable, as several complete rations containing high levels of fiber as part of a processed, pelleted mix have successfully been marketed and used by horse owners. Nevertheless, most veterinarians and nutritionists recommend forage (long-stem, chopped or cubed) be supplied to all classes of horses.

While pelleting fiber sources may not be desirable because of less intake time, and increased potential for vices such as wood chewing[9], hay cubes may be an acceptable alternative. Even though digestion efficiency may not improve with cubing, hay cubes have been fed as an alternative to long stem hay without increasing the incident of wood chewing[29].

Fiber: Some Final Thoughts

No one fiber partitioning scheme has been agreed upon to best indicate the energetic value of forages for livestock, and information on the feed tag is almost useless when relating fiber to its potential energetic contribution to the diet. How much fiber do horses need? In a practical sense, this is answered by the routine guideline of 1% of body weight of long-stem forage daily. However, fiber sources come from a variety of sources and physical forms. With the feeding of more by-product rations, there is more variation in fiber source, physical form and nutritive value than with rations containing a small number of traditionally fed grains.

Mixed hay and grain diets can result in depressed digestibilities in ruminants. The associative effects of feeding grain with long stem forage are not as apparent in horses as in cattle[30, 31]. Young horses can be fed a range of hay to grain ratios and have similar growth characteristics as long as the capacity of dry matter intake doesn't limit the supply of energy[32]. So the main disadvantage to grain and forage rations would be less energetic efficiency of fiber digestion as compared with soluble carbohydrates. However, the complete replacement of energy from fiber with that from starch is not a practical alternative, as high starch diets lead to colic and founder.

The need to partition the energy source away from starch is even apparent in spring pastures. These pastures contain high levels of hydrolysable carbohydrates. These levels, even when fed without supplemental grain, may cause ill effects because of too rapid a rate of hindgut fermentation[33, 34]. To conclude, it is apparent that some minimum level of dietary fiber is needed, preferably some being fed unprocessed as pasture and hay. If for no other reason, replacing this energy source with highly digestible fiber and soluble carbohydrates will lead to increased incidence of colic and founder. Research in cattle also suggests the physical form of the fiber influences rumen homeostasis. As such, recommendations for cattle are also incorporating minimally acceptable levels of effective NDF. Effective NDF is a measurement used to guard against too high a level of small particle sized fiber in rations. The same may hold true for horses.

Comparison of Effective NDF (eNDF) of Two Grain Mixes at similar DE values

Mix	DE Mcal/lb	NDF % DM	eNDF % NDF	eNDF % DM
50:50 Corn-Oat	1.4	20	45	9
Wheat Mids	1.4	35	2.0	1

Although energetic efficiency is less with fiber, the benefits of reducing carbohydrate intake, decreasing intake rate, and supplying a more continuous supply of nutrients throughout the day make forage based rations the desired alternative for most horse owners.

The Skinny on Fat

Horses do not have a gall bladder; hence, they do not store chemicals that assist the breakdown of dietary fat. The absence of a gall bladder doesn't necessarily mean that horses can't digest fat. In fact, a large amount of research conducted in the last quarter of the 20th century has shown just the opposite. Horses can readily digest upwards of 20% added fat in rations[9, 28, 34], although palatability and practicality of mixing fat in rations keep added-fat levels below 10% of the concentrate. Also, too high a level of fat (15 to 20%) may decrease muscle glycogen stores because of too much replacement of dietary starch with fat[35]. Muscle glycogen is the storage form of glucose, the preferred energy source for many types of athletic performance.

Digestibility coefficients range from around 75% for animal fat to 95% for vegetable oils[34, 36, 37]. Palatability tends to be higher for vegetable oils, and if a difference is noted, corn oil seems to be the most palatable among plant oils[38, 39]. Commonly used plant sources are corn and soybean oil, although many sources, including rice bran and refined dry fat[37], may be incorporated into horse rations with similar effects.

There are several advantages for adding fat and oil to horse diets. Energy supplied by fat replaces that needed from starch, thus lowering the incidence of starch overload colic and founder. As fat contains more energy per weight than carbohydrate or protein, less feed is required to meet the same digestible energy requirements. Digestibility of fat is higher than most other feedstuffs, so digestibility of the total ration is increased. Further, the digestible energy in fat-added rations is used more efficiently than conventional rations. Fat has a lower heat production during digestion, thus increasing the net energy value of the ration[40]. If enough starch is fed with fat, and if horses are adapted correctly, fat supplementation will allow for more glycogen to be stored for intense athletic performance[41]. Milk fat can be raised when lactating mares are fed fat added rations, resulting in increased growth performance of nursing foals[42]. Apparently, addition of fat does not depress the digestibility of fiber[36], crude protein[43], and has little if any negative effect on calcium and phosphorus[34].

Digestible Energy Content of Vegetable Oil, Animal Fat, Corn and Oats[a]

Feedstuff	Mcal DE/lb	lbs/qt	Mcal/qt
Vegetable Oil	4.08	1.9	7.8
Animal Fat	3.61	1.8	6.5
Corn	1.54	1.5	2.3
Oats	1.30	1.0	1.3

[a]Adapted from Lewis[9]

Starch and Fat Concentrations When Adding Fat to a Conventional Ration[44]

Ration	Intake[a] lb/day	Starch %	Starch lb/day	Fat %	Fat lb/day
60:40 Oat-Corn + Hay	30	28	8.1	3.9	1.2
60:40 Oat-Corn + 4% Fat + Hay	28	26	6.5	8.0	2.2

[a]Intake to meet an energy requirement of 35 Mcal DE/day of rations fed in a 60:40 ratio of grain to grass hay.

As such, added-fat rations and fat supplements have become commonplace in the horse feed manufacturing industry. Fat added feeds are most popular in performance horse rations, broodmare rations and aged horse rations, all requiring highly digestible, safe sources of large levels of energy.

Not So Final Thoughts

Horses have, and will continue to be fed rations with combinations of soluble carbohydrates, fiber and fat to meet their dietary energy needs. Those owners with adequate pasture can, and should, take advantage of the horse's ability to consume its dietary energy needs in forage, assuming adequate intake of pastures high in NDF is available. Grain, being high in soluble carbohydrates, should be used as an energy supplement, and a source to balance protein, vitamin and mineral needs. Those owners with performing horses, producing mares, and growing horses will feed larger amounts of grain to increase the energy density of rations. There are limits to amounts of soluble carbohydrates that can be safely fed, so when feeding large amounts of grain, owners must spread the daily ration over several meals. Also, horses that need to increase body condition, those that do not maintain adequate body condition on conventional rations, and those with high energy needs will be most suited for the feeding of added fat rations.

While more needs to be known about all the sources of energy in horse rations, fiber utilization should receive increased research interest, as the information known about fiber digestion and the horse is comparatively limited. Interactions with other energy sources, fiber size, fiber source, fiber components and individual responses from different production classes of horses will influence the application of results from future research.

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